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Report No. CDAP-TR-78-036

for U.S. Nuclear Regulatory Commission

CODE DEVELOPMENT AND ANALYSIS PROGRAM

RELAP4/MOD7
(VERSION 2)
USER'S MANUAL

August 1978

EG&G Idaho, Inc.

IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

IDAHO OPERATIONS OFFICE UNDER CONTRACT EY-76-C-07-1570

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ERRATA TO RELAP4/MOD6 USERS MANUAL

Please make corrections shown below in the document entitled, "RELAP4/
MOD6 . . . User's Manual" - CDAP-TR-003 - dated January 1978.

1. Page 90

Change K (Thermal Conductivity) units from W/m-K to BTU/HR-FT-F.

2. Page 94

(a) In Equation (62) change 1st term on right hand side from
 $0.6 P$ to $C P$.

(b) In Equation (63) change 2nd term on right hand side from
 $0.6 \sqrt{P - 1000}$ to $C \sqrt{P - 1000}$

(c) After word "WHERE" following Equation (64), insert

C = Function of cladding material,

h_{gap} is in BTU/HR-FT²-F and,

3. Page 96

(a) Correct Equation (68) by:

Add left hand parenthesis before first term on right hand
side.

Add right hand parenthesis before β .

Delete Term $(1 - 0.94)$.

(b) Correct β definition following Equation (68) by:

Add Term $(1 - \rho)$ to numerator before 100.

4. Page 97

(a) Correct Equation (69) by:

Add left hand parenthesis before 1st term on right hand side.

Add right hand parenthesis before β .

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4. Page 97 (Cont.)

Delete term $(1 - 0.94)$.

(b) Correct Equation (70) by:

Add left hand parenthesis before 1st term on right hand side.

Add right hand parenthesis before β .

Delete term $(1 - 0.9124)$.

(c) In Equation (71) change numerator in last term on right hand side from 4 to ρ .

CODE DEVELOPMENT AND ANALYSIS PROGRAM REPORT

Report No. CDAP-TR-78-036

Date August 1978

Contract Program or Project Title: Loss-of-Coolant Accident Analysis

Subject of this Document: RELAP4/MOD7 Blowdown Code, Version 2

Type of Document: User's Manual

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Date of Document: August 1978

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Operated by
EG&G Idaho, Inc.
for the
U.S. Department of Energy

Prepared for
U.S. Nuclear Regulatory Commission
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CODE DEVELOPMENT AND ANALYSIS PROGRAM REPORT

RELAP4/MOD7
(VERSION 2)
USER'S MANUAL

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ACKNOWLEDGEMENTS

RELAP4/MOD7 (Version 2) is the latest version of the RELAP4 computer program for transient thermal-hydraulic analysis of nuclear reactors and related systems. The following people are primarily responsible for this code development effort.

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ABSTRACT

This manual describes RELAP4/MOD7 (Version 2), which is the latest version of the RELAP4-LPWR blowdown code. Version 2 is a precursor to the final version of RELAP4/MOD7, which will address LPWR LOCA analysis in integral fashion (i.e., blowdown, refill, and reflood in continuous fashion). This manual describes the new code models and provides application information required to utilize the code. It must be used in conjunction with the RELAP4/MOD5 User's Manual (ANCR-NUREG-1335, dated September 1976), and the RELAP4/MOD6 User's Manual (CDAP-TR-003, dated January 1978).

CONTENTS

ACKNOWLEDGEMENTS.	iii
ABSTRACT.	iv
I. INTRODUCTION	1
II. MODEL DESCRIPTIONS	2
1. PWR STEADY STATE INITIALIZATION MODEL	3
1.1 Energy Balancing Model	3
1.1.1 Core Region Heat Balance.	5
1.1.2 Steam Generator Heat Balance.	7
1.2 Pressure Balancing Model	13
1.2.1 Loop Pressure Balance	13
1.2.2 Secondary Flow Channel Pressure Balance	16
1.2.3 Dead End Flow Path Pressure Balance	20
1.3 Input Instructions	21
1.4 User Guidelines.	23
1.5 Subroutine Descriptions.	24
2. HEAT TRANSFER TIME STEP CONTROL	28
2.1 Temperature Derivative Approach.	29
2.2 Heat Flux Derivative Approach.	30
2.3 Stability Approach	31
2.4 Application.	32
3. WATER PROPERTY COMPUTATION IMPROVEMENT.	36
3.1 Previous Computation Method.	36
3.2 Revised Interpolation Method	43
3.3 Accuracy Comparison.	47

4.	IMPROVED METAL WATER REACTION MODEL	54
4.1	Parabolic Rate Law	55
4.2	RELAP4 Method.	58
5.	IMPROVED REACTOR KINETICS MODEL	66
5.1	Decay Heat Model	66
5.2	Reactor Kinetics Model	74
5.3	User Guidelines.	80
5.3.1	Tabular Power Data.	80
5.3.2	Power Data Retrieval.	82
6.	TWO PHASE FORM LOSS MODEL	83
6.1	Model Description.	85
6.2	Model Implementation	85
7.	BEST ESTIMATE BLOWDOWN FUEL MODEL	87
7.1	FRAP-S Link Implementation	88
7.2	RELAP4/FRAP-T Link Implementation.	89
7.3	Mechanics of the RELAP4/FRAP-T Link.	92
7.3.1	Gap Conductance	99
7.3.2	Fuel Rod Diameter Calculation	99
7.3.3	Pin Pressure.	100
7.3.4	Clad Rupture and Flow Blockage.	100
7.3.5	Fuel and Clad Thermal Properties.	100
7.4	Fuel Rod Input	101
8.	VOLUME AVERAGE MASS FLOW RATE AND MOMENTUM FLUX	103
8.1	Alternate Calculation of Volume Average Mass Flow Rate	103
8.2	Generalized Junction Orientation for Flow Rate Calculation.	103
8.3	Alternate Calculation of Momentum Flux	104

9.	SPECIAL FEATURES.	105
9.1	Fill and Heat Exchanger Data from Tape	105
9.2	Non-Uniform Fuel Pellet Power Distribution	107
9.3	Peak Temperature Edit.	108
9.4	CHF Correlation.	108
III.	PROGRAMMING IMPROVEMENTS	111
1.	CONVERSION TO LARGE CORE MEMORY	112
1.1	Purpose.	112
1.2	Method	113
2.	CONVERSION TO THE CDC UPDATE PROGRAM.	114
2.1	Purpose.	114
2.2	Method	115
3.	RESTRUCTURING OF RELAP4	117
3.1	Purpose.	117
3.2	Method	117
IV.	INPUT INSTRUCTIONS	119
1.	PROGRAM DESCRIPTION	120
2.	INPUT DATA.	121
2.1	Data Deck Organization	121
2.1.1	Title Card.	121
2.1.2	Comment Cards	121
2.1.3	Data Cards.	122
2.1.4	Terminator Cards.	123
2.2	Data Card Summary	124
(1)	Title Card.	124
(2)	Problem Dimensions Data Card 010001	124
(3)	Problem Constants Data Card 010002 - RST.	127
(4)	Program Options Card 010003	128
(5)	Preload Restart Card 010004	130
(6)	Minor Edit Variable Data Card 020000 - RST.	130
(7)	Time Step Data Cards 03XXX0 - RST	135

(8)	Detailed Edit Card 030002 - RST	136
(9)	Water Packing, Choking, Smoothing, and Enthalpy Transport Card 030003 - RST	137
(10)	Mixture Level Smoothing Card 030004 - RST	137
(11)	Miscellaneous Floating Point Data Card 030006 - RST	137
(12)	Miscellaneous Integer Data Card 030007 - RST.	138
(13)	Trip Control Data Cards 04XXX0 - RST.	139
(14)	Volume Data Cards 05XXXY.	143
(15)	Liquid Level Volume Calculation Card 060000	146
(16)	Slip Velocity Card 060001	147
(17)	Wallis Flooding Correlation Card 0600X2	148
(18)	Wallis-Crowley Flooding Correlation Card 060003.	148
(19)	Downcomer Penetration - Lower Plenum Entrain- ment Card 060004.	149
(20)	Downcomer Penetration Correlation Coefficient Card 060005	150
(21)	Accumulator Polytropic Air Expansion Model Data Card 060006	151
(22)	Volume Flow Calculation Card 060009	152
(23)	Bubble Data Cards 06XXX1.	152
(24)	Time-Dependent Volume Data Cards 07XXYY - RST	153
(25)	Flow Smoothing Data Cards 080001 through 080009.	154
(26)	Junction Data Cards 08XXXY - RST.	155
(27)	Stagnation Properties Card 082000	162
(28)	Modified Burnell/Homogeneous Equilibrium Critical Flow Model Dials Card 082001	163
(29)	HEM Critical Flow Model Dials Card 082002	163
(30)	Henry-Fauske/HEM Critical Flow Model Dials Card 082003.	163
(31)	Moody Critical Flow Model Dials Card 082004	164
(32)	Henry-Fauske Critical Flow Model Dial Card 082005.	164
(33)	Subcooled Henry-Fauske Critical Flow Model Dial Card 082006	164
(34)	Downcomer Penetration Model Dial Card 082011	164
(35)	Lower Plenum Entrainment Model Dial Card 082012.	165
(36)	Friction Factor Dial Card 082020.	165
(37)	Metal Water Reaction Dial Card 082021	165
(38)	Critical Heat Flux Dial Card 082030	165
(39)	Heat Transfer Coefficient Dial Card 082031.	165
(40)	Pool Boiling Correlation Choice Dial Card 082032.	167
(41)	Henry-Fauske/HEM Lower Limit Transition Quality Dial Card 082033.	168
(42)	Variable Dials For Henry-Fauske/HEM Critical Flow Model With Linear Weighting Transition Cards 0888XX.	168
(43)	Pump Description Data Cards 090XXY.	168

(44)	Pump Head Multiplier Data Cards 0910YY - RST.	170
(45)	Pump Torque Multiplier Data Cards 0920YY - RST.	171
(46)	Pump Stop Data Card 095XX1.	172
(47)	Pump Motor Torque Data Cards 0970XY - RST.	173
(48)	Pump Speed vs. Time Data Cards 098ZZY.	173
(49)	Pump Curve Input Indicator Data Card 100000.	174
(50)	Pump Head and Torque Data Cards 10XYYZ - RST.	175
(51)	Variable Pump Moment of Inertia Card 105500.	176
(52)	Valve Data Cards 11XXX0 - RST.	177
(53)	Leak Table Data Cards 12XXYY - RST.	178
(54)	Fill Table Data Cards 13XXYY - RST.	179
(55)	Kinetics Constants Data Card 140000.	183
(56)	Reactivity Coefficients Data Cards 140XX0.	184
(57)	Scram Table Data Cards 14YYXX - RST.	185
(58)	Density Reactivity Table Data Cards 1420XX - RST.	186
(59)	Doppler Table Data Cards 1430XX - RST.	186
(60)	Reactor Power Histogram Data Cards 1440XX.	187
(61)	Gamma Heating Power Table Data Cards 144YXX.	189
(62)	Critical Temperature Core Power Trip Card 149900.	190
(63)	Reactivity Coefficients Data Card 140XX0.	191
(64)	Heat Transfer Surface Card 150000.	191
(65)	Extra Heat Transfer Printout Card 150001 - RST.	192
(66)	Reflood Heat Transfer Options Card 150002 - RST.	193
(67)	Heat Slab Data Cards 15XXXY.	195
(68)	Wall Temperature Reset Cards 15XXX3.	200
(69)	Steam Generator Natural Convection Data Cards 15XXX4.	200
(70)	Gamma-Heated Slab Data Cards 1560XX.	201
(71)	Core Slab Data Cards 16XXXY.	201
(72)	Core Slab Data Cards for BE and Evaluation Models 16XXXY.	202
(73)	Slab Geometry Data Cards 17XXXY.	207
(74)	Core Heat Slab Power Distribution Cards 174XXY.	208
(75)	Heat Slab Node Temperature Reset Cards 175XXY.	210
(76)	Moving Mesh Refinements Data Cards 1790X0.	211
(77)	Moving Mesh Refinements Data Card 179099.	212
(78)	Thermal Conductivity Data Cards 18XXYY -RST.	212
(79)	Volumetric Heat Capacity Data Cards 19XXYY - RST.	213
(80)	Linear Expansion Coefficient Data Cards 20XXYY - RST.	214
(81)	Heat Exchanger Data Cards 21XXYY - RST.	215
(82)	Self-Initialization Core Inlet/Outlet Volume Description Card 220200.	217
(83)	Self-Initialization Steam Generator Descrip- tion Cards 2201XY.	217
(84)	Self-Initialization Core Flow Path Description Cards 2202XY.	218

(85)	Self-Initialization Steam Generator to Core Description Cards 22026X.	218
(86)	Self-Initialization Core to Steam Generator Description Cards 22028Y.	219
(87)	Self-Initialization Pump to Steam Generator Description Cards 22030X.	219
(88)	Self-Initialization Parallel Path Description Cards 22031X.	220
(89)	Self-Initialization Dead End Path Description Cards 22032X.	220
(90)	Self-Initialization Downstream Main Flow Loop Description Card 220400.	221
(91)	Self-Initialization Upstream Main Flow Loop Description Card 220401.	222
(92)	Self-Initialization Non-Main Flow Loop Descrip- tion Cards 22040Y.	222
(93)	Self-Initialization Negative Residual Turnoff Card 220408.	223
(94)	Self-Initialization Reference Temperature Volume Description Cards 22041Y.	223
(95)	Blockage, Swelling, Gap Reduction Data Card 250001.	224
(96)	ECC Bypass Input Data Card 260001 - EM.	225
(97)	Multiple Pin Clad Rupture Data Cards 270001- 270099.	226
(98)	Multiple Pin Flow Blockage Data After Rupture Cards 280001-280099.	226
(99)	Single Pin Clad Rupture Data Cards 290001- 290099.	227
(100)	Single Pin Flow Blockage Data After Rupture Cards 300001-300099.	227
(101)	Entrainment Correlation Option Card 400001 - FLOOD.	228
(102)	FLECHT Heat Transfer Correlation Data Card 400002 - FLOOD.	229
(103)	Aerojet A Entrainment Correlation Data Card 400003 - FLOOD.	229
(104)	Core Outlet Enthalpy Data Card 400004 - FLOOD.	229
(105)	Junction and Volume Numbers Data Card 400005 - FLOOD.	230
(106)	Entrainment Correlation Card 400011.	230
(107)	Entrainment Correlation Data Input Card 400012.	231
(108)	Entrainment Correlation Data Input Card 400013 - RST.	231
(109)	Core Outlet Enthalpy Card 400014.	232
(110)	Junction and Volume Numbers Card 400015.	232
(111)	PWR Upper Plenum Deentrainment and Fallback Card 400016.	232
(112)	Core Superheat Model Card 400017.	234
(113)	Core Model Numerical Coupling Card 400018.	234

(114)	Initial Clad Surface Temperature Data Cards 4001YY FLOOD	235
(115)	Steam Generator Volume Data Cards 4002YY - FLOOD	235
(116)	Ice Condenser Data Cards 51XXX0 - CONT.	236
2.3	Input for Tape Editing	237
(1)	Title Card.	237
(2)	Problem Dimensions Data Card 010001	237
(3)	Edit Variable Data Card 020000.	238
(4)	Edit Frequency Control Data Cards 03XXX0.	238
2.4	Input for Restarting	238
(1)	Title Card.	238
(2)	Problem Dimensions Data Card 010001	238
(3)	Edit Variable Data Card 020000.	239
(4)	Time Step Data Cards 03XXX0	239
(5)	Trip Control Data Cards 04XXX0.	240
(6)	Optional Restart Cards.	240
(7)	Additional Restart Considerations	242
2.5	PLOTR4M Plotting Program	242
(1)	Data Input.	243
(a)	Request Card Format and Options	243
(b)	Input Control Cards	246
(c)	Special Options	251
(d)	Input Tape.	252
(2)	Data Output	252
(3)	Plot Job Processing	252
(a)	IBM Job Control Cards	252
(b)	CDC Job Control Cards	255
(4)	Problem Limits.	255
(5)	Computer Requirements	256
(6)	Installation Notes.	256
V.	REFERENCES	259
	APPENDIX A. RELAP4 - FRAP-T LINK INFORMATION	262
	APPENDIX B. FRAP-T FUEL MODEL INPUT DATA REQUIREMENTS.	266

FIGURES

1.	Enthalpy relationships within a PWR heated core.	6
2.	Typical RELAP4 model representation of a double-pass tube type steam generator.	8
3.	Steam generator with plenum heat transfer.	10
4.	Illustration of pressure relaxation procedure.	17
5.	Self-initialization flow chart	27
6.	Heat flux averaging and extrapolation.	33
7.	Summary flow chart for heat transfer timestep control.	35
8.	One percent accuracy map for STH204 using existing interpola- tion methods	39
9.	Ten percent accuracy map for STH204 using existing interpola- tion methods	41
10.	One percent accuracy map for STH204 using revised interpola- tion techniques.	48
11.	Five percent accuracy map for STH204 using revised interpola- tion techniques.	50
12.	Ten percent accuracy map for STH204 using revised interpola- tion techniques.	52
13.	Reactor operating history illustration	72
14.	Reactor kinetics model summary flow chart.	81
15.	RELAP4/FRAP-T diagram of subroutines	91
16.	RELAP4/FRAP-T segment A.	93
17.	RELAP4/FRAP-T segment B.	94
18.	RELAP4/FRAP-T transient segment C.	95
19.	Example of output with new maximum temperature edit.	109

TABLES

I.	Temperatures and pressures in the STH20T water property table	.38
II.	Percent error associated with using the plane vs. cylindrical expression for oxide depth	.59
III.	Percent deviation from expected values.	.64
IV.	Parameters for U235 thermal fission functions	.68
V.	Parameters for Pu239 thermal fission functions.	.69
VI.	Parameters for U238 fast fission functions.	.70
VII.	Delayed neutron constants	.76
VIII.	Modifications and additions to RELAP4/FRAP-T segment A. . .	.96
IX.	Modifications and additions to RELAP4/FRAP-T segment B. . .	.97
X.	Modifications to RELAP4/FRAP-T transient segment C. . . .	.98
XI.	Format for plot request cards and control cards	244
XII.	Format for multiple data set processing card.	248
XIII.	Format for overlay plot request card.	249
XIV.	Overlay structure cards (IBM FORMAT) for PLOTR4M.	257

I. INTRODUCTION

The principal objectives of the RELAP4/MOD7 development effort are to provide a fast-running, user-convenient code package including an integral LOCA analysis capability and offering enhanced modeling capability over previous code versions where this is consistent with the preceding objectives. The interim version of the code, RELAP4/MOD7 Version 2, being released with this document embodies those code additions and revisions generally pertinent to the calculation of an LPWR blowdown. Future development effort will be directed to a re-flood model and finally to an integrated code.

This document presents descriptions of the new models associated with the interim version of the code. It includes instructions for using the code presuming the availability of both the RELAP4/MOD5 User's Manual⁽¹⁾ and the RELAP4/MOD6 User's Manual⁽²⁾.

II. MODEL DESCRIPTIONS

This section describes the new analytical models and features which have been incorporated into the RELAP4/MOD7 (Version 2) computer program.

In the sections that follow, the discussion of each model/feature will include the rationale for incorporation, description of the model/feature and method of implementation.

1. PWR STEADY STATE INITIALIZATION MODEL

An "automatic" thermal and pressure balancing feature has been implemented in the RELAP4 code to simplify the task of initializing PWR (or similar) models. In all previous code versions it was necessary for the user to:

- (1) Compute and input all control volume temperatures based on power input and water flowrate.
- (2) Compute and input all control volume pressures based on junction form loss, control volume geometry, water flowrate, and control volume elevation.

In practice, this procedure involves several computer runs as well as the necessary hand-calculations. This process is now virtually eliminated by the self-initialization feature. Advantages realized by the incorporation of this option include:

- (1) saving of time in initializing a new model,
- (2) saving of time in performing parametric runs, in which revised power, flowrate, etc., requires a rebalance of the model,
- (3) an assurance of steady-state, self consistent thermodynamic and hydrodynamic input data.

The self-initialization model is essentially composed of two parts, energy and pressure balancing.

1.1 Energy Balancing Model

To achieve a stable initial operating condition for a RELAP system model, the thermal-hydraulic input data must imply an energy balance. This must hold true both on a system basis and a control volume basis. This requirement is summarized by two basic criteria:

- (1) The total system NET heat transfer rate is zero. That is, the rate of heat transfer into the system from all sources equals the rate of transfer out at all sinks.
- (2) At each control volume, the rate of energy removal must equal the rate of energy addition. This is expressed as,

$$\sum (W_j h_j)_{IN} + Q = \sum (W_j h_j)_{OUT} \quad (1)$$

(neglecting kinetic and potential energies), where Q is defined as positive for heat transfer into the volume and W_j and h_j are the junction mass flow rate and enthalpy, respectively.

A typical RELAP4 model of a PWR includes representations of the heated core region and one or more steam generators. The procedure for performing a thermal balance on such a system is summarized by the following steps:

- (1) With the core inlet temperature established, compute the intermediate and outlet volume temperatures based on the total core power, individual volume heat transfer rates and system flowrate.
- (2) Determine the desired heat removal rate at each of the steam generators so that the total equals the sum of the core and pump energy contributions. The pump thermal energy input is assumed to be the difference between pump power input and output.
- (3) Find the temperature distribution through the steam generator primaries which satisfies the total heat removal requirement and the individual volume heat transfer rates. The temperature in the secondary side volume is simultaneously determined.

The following subsections describe the models and program methodology used to complete the steps outlined above.

1.1.1 Core Region Heat Balance. The heated core region in a RELAP4 PWR model typically consists of a single or double channel, each divided into several fluid control volumes. Each volume contains one or more heat slabs to represent an axial section of the fuel rods, and the slab heat transfer rate at initialization is determined by the power fractions specified by the user. With the inlet temperature (T_I), slab power (Q_s), gamma heating (Q_γ), and core flow rate (W) input, the average volume enthalpy for each volume (h_i) assuming the use of enthalpy transport is computed as:

$$\overline{h}_i = h_{iIN} + \frac{\sum Q_{si} + Q_{\gamma i}}{2W} \quad (2)$$

where h_{iIN} is the inlet enthalpy to volume i as determined from the outlet condition of the upstream volume. If volume j is upstream of volume i then:

$$h_{iIN} = h_{jOUT} = \overline{h}_j + \frac{\sum Q_{sj} + Q_{\gamma j}}{2W} \quad (3)$$

These relationships are shown graphically in Figure 1 for the case without gamma heating. With the enthalpies determined and the volume pressures known, the temperatures are computed from the steam tables. Following this procedure up the core channel results in determination of the core outlet temperature. It is assumed there are no two-sided slabs (i.e., capable of exchanging heat at steady-state) between the core outlet and steam generator, so the control volume temperatures along this path remain unchanged. The same holds true between the steam generator outlet and core inlet except for the contribution made by the pump. The rate of energy addition due to the pump is used to determine the steam generator outlet temperature. This is accomplished by subtracting the associated enthalpy rise

FIGURE 1. ENTHALPY RELATIONSHIPS WITHIN A PWR HEATED CORE

through the pump from the enthalpies of the control volumes between the steam generator outlet and pump inlet. Thus the steam generator inlet and outlet temperatures are determined.

1.1.2 Steam Generator Heat Balance. The typical and most generalized RELAP4 representation of a steam generator is shown in Figure 2, in which a series of primary side volumes are separated from a secondary side volume by heat slabs. With the scheme shown in Figure 2, obtaining a satisfactory energy balance involves the simultaneous determination of primary side temperatures and secondary side temperature.

Considering the generalized case where N-1 primary side control volumes are employed, the average volume temperatures for the volumes may be written:

$$T(1) = T_I - \frac{K(1) [T(1) - T(N)]}{2W(1) C_p(1)} \quad (4)$$

$$T(i) = T(i-1) - \left\{ \frac{K(i-1) [T(i-1) - T(N)]}{2W(i) C_p(i-1)} + \frac{K(i) [T(i) - T(N)]}{2W(i) C_p(i)} \right\} \quad (5)$$

for $i = 2, 3, \dots, N-1$, and,

$$T_{\emptyset} = T(N-1) - \frac{K(N-1) [T(N-1) - T(N)]}{2W(N-1) C_p(N-1)} \quad (6)$$

where

T_I = steam generator primary side inlet temperature

$T_{\emptyset}$ = steam generator primary side outlet temperature

$T(i)$ = temperature of the i th volume

FIGURE 2. TYPICAL RELAP4 MODEL REPRESENTATION OF A DOUBLE-PASS TUBE TYPE STEAM GENERATOR

$i = 1, 2, \dots, N-1$ (primary volume indices)

$i = N$ (secondary volume index)

$K =$ effective primary to secondary heat conductance

$C_p =$ specific heat capacity

$W =$ flow through the primary volumes of the steam generator

Therefore there are N linearly independent equations in N unknowns ($T_i, i = 1, \dots, N$). These equations are solved for the primary and secondary temperatures. As K and C_p are functions of temperature, it is necessary to iterate to obtain a correct set of temperatures.

The model can also take into account heat transfer between the inlet and outlet of the steam generator primary at the inlet/outlet plenum. In this case T_I as determined from the core energy contribution is modified in accordance with the following equation (See Figure 3)

$$T_I' = T_I - \frac{Q_p}{WC_{pI}} \quad (7)$$

where

$T_I' =$ fluid temperature at the outlet of the primary side inlet plenum

$Q_p =$ heat transfer across plenum boundary

FIGURE 3. STEAM GENERATOR WITH PLENUM HEAT TRANSFER

W = primary side flowrate

C_p = specific heat at constant pressure

subscript I = inlet plenum

The plenum outlet temperature remains the same, regardless of plenum heat transfer.

The mass flowrate through the steam generator secondary is dictated by the total heat transfer rate and inlet and outlet enthalpies:

$$W_s = \frac{Q_T}{h_{s\phi} - h_{si}} \quad (8)$$

where

$$Q_T = W_p(h_{p\phi} - h_{pi})$$

W_s = mass flow rate through the secondary

W_p = mass flow rate through the primary

$h_{s\phi}$ = outlet enthalpy of the secondary (assumed to be h_g , saturated steam)

h_{si} = inlet enthalpy of the secondary (given by user)

h_{pi} = inlet enthalpy of the primary side of the steam generator

$h_{p\phi}$ = outlet enthalpy of the primary side of the steam generator

A remaining criterion for steady-state conditions within the steam generator secondary is that the bubble-rise model parameters are consistent with the specified mixture quality. The bubble rise model imposes a steam bubble velocity and gradient for the two-phase mixture (See RELAP4/MOD5 User's Manual, Vol. I⁽¹⁾). Since the steam bubble mass flow at the interface of the mixture and steam dome must equal the mass flow through the steam generator, a boundary condition is imposed on the bubble rise model to meet steady state conditions. When this constraint is imposed on the expressions relating mixture quality, bubble velocity and mixture density gradient the following equations for bubble velocity are found:

$$V_b = \frac{W [v_f/X + v_{fg}]}{[A (1 + C_o)]}, \quad 0 < \alpha < 0.5 \quad (9)$$

$$V_b = \frac{W}{A \left[\frac{C_o}{v_g} + \frac{(1 - C_o)}{(v_f/X + v_{fg})} \right]}, \quad 0.5 \leq \alpha < 1.0 \quad (10)$$

where

V_b = bubble rise model bubble velocity (V_{bub} , card 06XXX1)

C_o = bubble rise model bubble density slope parameter (ALPH, card 06XXX1)

A = volume cross sectional flow area

W = mass flow rate

v_f = saturated liquid specific volume

v_g = saturated steam specific volume

$$V_{fg} = V_f - V_g$$

α = void fraction within mixture

X = mixture quality

When the self-initialization option is invoked, the bubble rise velocity is computed from Equation (9) or (10) as applicable. The velocity so computed replaces the value input for the bubble rise model set applied in the steam generator secondary control volume.

1.2 Pressure Balancing Model

This model computes control volume pressures compatible with remaining input. Three general areas are considered: pressure balancing within loops, in parallel flow channels, and along dead-ended flow paths.

1.2.1 Loop Pressure Balance. The normal RELAP4 input, consisting in part of control volume pressures, junction mass flowrates, control volume geometry, and junction form loss coefficients, represents an overspecification of the steady-state condition of the reactor system. By furnishing a thermodynamic pressure for each control volume, the user implies the pressure loss distribution within the system. Specifically, the specification of thermodynamic pressures in two adjoining volumes is interpreted as the net static pressure change between the geometric centers of the volumes resulting from the algebraic addition of the pressure change terms that make up the appropriate fluid flow equation. Given that loss coefficients and geometry are independent variables, only one of the remaining two (mass flow or ΔP) can be independent. The code resolves this incompatibility by introducing a "residual" pressure loss at each junction which represents the difference between the implied pressure change and that calculated on the basis of the mass flowrate, geome-

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- (1) the pump inlet and outlet junction pressure residuals be minimized,
- (2) the pump head match the pressure rise required to satisfy the inlet and outlet volume pressures, and,
- (3) the average pump volume pressure be set at a value midway between the inlet and outlet pressures (subject to the losses at the inlet and outlet junctions).

Corrected pressure losses at the inlet and outlet pump volume junctions are computed:

$$\Delta P'_{J_{IN}} = \Delta P_{J_{IN}} - \Delta P_{J_{IN_R}} - \Delta P_H / 2 \quad (12)$$

$$\Delta P'_{J_{OUT}} = \Delta P_{J_{OUT}} - \Delta P_{J_{OUT_R}} - \Delta P_H / 2 \quad (13)$$

where

$$\Delta P_{J_{IN}} = \text{total pressure difference between the pump volume and upstream volume } (P_{PUMP} - P_{UP})$$

$$\Delta P_{J_{OUT}} = \text{total pressure difference between the pump volume and downstream volume } (P_{DOWN} - P_{PUMP})$$

$$\Delta P_H / 2 = \text{one-half the pump head implied by the input pump speed ratio}$$

Pseudo-pressures at the pump volume inlet and outlet are then calculated as:

$$P_{p_i} = P_{UP} - \Delta P'_{J_{IN}} \quad (14)$$

$$P_{p_o} = P_{DOWN} + \Delta p_{J_{OUT}} \quad (15)$$

where P_{DOWN} and P_{UP} are the recalculated downstream and upstream volume pressures.

The required pump head (pressure rise) and pump volume pressure are then found from:

$$\Delta P_H = P_{p_i} - P_{p_o} \quad (16)$$

$$P_p = (P_{p_i} + P_{p_o})/2 \quad (17)$$

To obtain the revised pump head the speed ratio must be revised. This is accomplished by means of successive calls to subroutine PUMPS in iterative fashion until a converged solution for head, speed and flow is obtained. It should be noted that if the pump speed shows a large change in the recalculation the flow, friction and form losses could be in error and should be rechecked.

The foregoing procedure is illustrated for a simple one loop system in Figure 4.

1.2.2 Secondary Flow Channel Pressure Balance. Occasionally, it is desirable to model a secondary flow channel or parallel flow path, such as a core hot channel or core bypass. In general, the mass flow rate in a secondary flow channel will be smaller than in the primary channel. When parallel flow paths exist in a hydraulic circuit, there is only one unique flow division that will be consistent with the path "resistances" implied by the input data. If the user imposes a different flow split, a net pressure loss residual will exist in the primary or secondary channel. The self-initialization option assumes the input flow split as a boundary condition. It then balances the

FIGURE 4. ILLUSTRATION OF PRESSURE RELAXATION PROCEDURE

"R" = Reference Pressure Control Volume

$$P_8' = P_8 + \Delta P_{9r}$$

$$P_7' = P_7 + \Delta P_{9r} + \Delta P_{8r}$$

$$P_6' = P_6 + \Delta P_{9r} + \Delta P_{8r} + \Delta P_{7r}$$

$$P_1' = P_1 - \Delta P_{1r}$$

$$P_2' = P_2 - \Delta P_{1r} - \Delta P_{2r}$$

$$P_3' = P_3 - \Delta P_{1r} - \Delta P_{2r} - \Delta P_{3r}$$

$$P_4' = P_4 - \Delta P_{1r} - \Delta P_{2r} - \Delta P_{3r} - \Delta P_{4r}$$

$$\Delta P_{j6} = P_5 - P_6 - \Delta P_{6r} - \Delta P_{H/2}$$

$$\Delta P_{j5} = P_4 - P_5 - \Delta P_{5r} - \Delta P_{H/2}$$

$$P_{5i} = P_6' - \Delta P_{j6}$$

$$P_{5o} = P_4' + \Delta P_{j5}$$

$$\Delta P_H = P_{5o} - P_{5i}$$

$$P_5' = (P_{5o} + P_{5i})/2$$

pressures along the primary channel in accordance with the procedures outlined in the previous section. For the secondary channel(s) the junction form loss coefficients along the path are adjusted to yield a balance with the primary channel. If the user wishes to correct a pressure imbalance in a secondary flow channel without the junction form loss coefficients revised (i.e. by changing the flow and/or volume equivalent diameter), it must be done separately from the self-initialization routines and the flow channel should not be specified on the self-initialization input cards.

The pressure loss at junction i, ΔP_i , due to form loss is given by the equation:

$$\Delta P_i = C \frac{K_i W_i^2}{\rho_i A_i^2} \quad (18)$$

where

C = a constant (will cancel in later equations)

K_i = input loss coefficient for junction i

W_i = mass flow rate at junction i

ρ_i = density at junction i

A_i = flow area for junction i

Similarly, the residual pressure difference at junction i, ΔP_{Ri} is given by:

$$\Delta P_{Ri} = C \frac{K_{Ri} W_i^2}{\rho_i A_i^2} \quad (19)$$

where

K_{Ri} = equivalent loss coefficient from pressure imbalance at junction i

When the secondary flow channel is unbalanced, some or all of the residual pressure differences will be nonzero. Thus, the loss coefficients are adjusted such that;

$$\sum_{i=1}^N \Delta P_{Ri} = 0 \quad (20)$$

where N = number of junctions in the secondary flow channel.

The adjustment at junction i is found by multiplying the total residual pressure loss for the channel by a fraction, f_i , determined from the equation:

$$f_i = \frac{(K_i W_i^2 / \rho_i A_i^2)}{K_{TOTAL}} \quad (21)$$

where,

$$K_{TOTAL} = \sum_{i=1}^N \frac{K_i W_i^2}{\rho_i A_i^2} \quad (22)$$

The amount the junction loss coefficient has to be adjusted at junction i , K_{ADJ_i} , is given by the equation:

$$K_{ADJ_i} = \frac{\rho_i A_i^2}{W_i^2} f_i R_T \quad (23)$$

where R_T = total effective loss from residuals

$$R_T = \sum_{i=1}^N \frac{(K_R)_i W_i^2}{\rho_i A_i^2} \quad (R_T \text{ may be negative}) \quad (24)$$

The f_i weighting factor ensures that the loss coefficients are adjusted in proportion to their respective original magnitudes. The resultant equation for the new loss coefficient at junction i , $(K_{NEW})_i$, is therefore:

$$(K_{NEW})_i = K_i \left(1 + \frac{R_T}{K_{TOTAL}} \right) . \quad (25)$$

The volume pressures are then recalculated using the new form loss coefficients to achieve the pressure balance.

The secondary flow channel pressure balancing is implemented through the 22031X input cards. Up to 10 secondary flow channels can be input with a maximum of 20 junctions in any one channel. The user input is checked to ensure that a valid flow path is input, no junctions have zero area (i.e. a closed valve), and the total input form loss coefficients (forward and reverse) for a channel is greater than zero.

1.2.3 Dead End Flow Path Pressure Balance. Dead end flow paths may be used in many different areas of a RELAP4 model. A dead end flow path is defined as a volume or group of volumes with zero flow initially connected to any other volume (including other dead end volumes). An example of a dead end flow path in a typical PWR model is the pressurizer and pressurizer surge line. Balancing dead end flow paths is necessary because any pressure imbalance, artificially held in check at initialization as an acceleration pressure drop, will cause an erroneous flow at the beginning of the transient calculation.

The dead end flow paths are balanced after the primary loop pressures have been adjusted, by adding (or subtracting depending on junction orientation) the junction acceleration pressure drop to the volume upstream (away from the dead end flow path connection point). A cumulative total of acceleration pressure drops is kept to progressively adjust the volume pressures along the dead end flow path.

The dead end flow path pressure balancing is implemented through the 22032X input cards. Up to 10 dead end flow paths may be input with a maximum of 20 volumes in any one dead end flow path.

The user input is checked to ensure a valid flow path and to ensure there are no closed valves along the dead end path.

1.3 Input Instructions

The input data card descriptions for implementation of the self-initialization option are shown in Section IV. The basic steps for input are summarized below along with the identification of the appropriate data card(s).

- (1) The thermal self-initialization option is initiated by data card 220200 which also specifies the control volumes just upstream and down-stream of the core.
- (2) The control volumes for each steam generator are specified by data cards 2201XY (thermal self-initialization).
- (3) The control volumes for each core flow path are specified on data cards 2202XY (thermal self-initialization).
- (4) All control volumes lying along paths between the steam generator outlet and core inlet are specified on data cards 22026Y (thermal self-initialization).
- (5) All control volumes lying along paths between the core outlet and steam generator inlet are specified on data cards 22028Y (thermal self-initialization).

- (6) The pump volume number and associated loop volume numbers lying on the path between the pump and steam generator outlet (proceeding upstream) are specified on data cards 22030X (thermal self-initialization).
- (7) If the model contains parallel flow paths, the secondary flow paths are specified by inputting the sequential junction numbers for each path on data cards 22031X (pressure self-initialization).
- (8) All dead end flow paths are specified by inputting the sequential junction numbers along each path on data cards 22032X (pressure self-initialization).
- (9) The main flow loop (that which contains the reference pressure volume) is specified by inputting the reference pressure volume number and remaining volume numbers on data cards 220400 and 220401. Card 220400 also initiates the pressure self-initialization option.
- (10) All other flow loops (designated non-main) are specified by inputting the volume numbers not common to the main flow loop on data cards 22040Y (pressure self-initialization).
- (11) A flag is set on data card 220408 to turn off the existing code feature which terminates a calculation if a new negative junction residual exists. Since some junctions may have an input from loss of zero, even after the relaxation procedure a very small negative residual may remain, which would otherwise terminate the calculation if this flag is not set (pressure self-initialization).
- (12) Dead end path volumes do not come under revision during the thermal balance process but may be affected by the result (e.g., pressurizer). Temperatures of such volumes may be

reset to the value obtained for any other loop volume by inputting the reference volume and dead end volumes whose temperatures are to be reset on data cards 22041Y (pressure self-initialization).

1.4 User Guidelines

Although various RELAP4 input models can be initialized using the self-initialization procedures described in the previous sections, there are several important limitations and assumptions used that the user must bear in mind. The primary assumption is that the input model describes a PWR-TYPE system (i.e., single phase subcooled) and contains at least one pump in a continuous loop.

The pressure balancing procedure assumes the user input flows and loss coefficients (except in secondary flow channels) are constant and the volume pressures and the pump speed will be adjusted to eliminate any pressure imbalance. If the pump speed varies it indicates the user's flows and loss coefficients are not consistent for the geometry and they should be checked. The self-initialization procedure does not have the capability of balancing cross flow junctions that are occasionally used to connect different core channels or circumferentially split downcomers. The user must balance cross flow junctions independently from the self-initialization procedure.

The energy balance procedure is based on the assumption that the enthalpy transport model is used at core and steam generator junctions. However, the enthalpy transport model occasionally produces erroneous enthalpy distributions during transient calculations especially if the noding in the core is coarse. Therefore, it is recommended that the enthalpy transport model be turned off after initialization by using the 030003 input card.

An input model is considered to be balanced when there are no perturbations caused by inconsistent input which would impose some non-steady behavior. A method of checking the consistency of a model is by performing a "steady-state" calculation. This is accomplished by making a transient run for several seconds in which no trips are activated (i.e., breaks, scram, pump, etc.). The user should be aware that the enthalpy transport model during the transient is different from that at initialization. Consequently, even when a system model is perfectly balanced thermally, some perturbation in system temperatures (and consequently other system variables) will occur when the "steady-state" calculation is made. This perturbation is usually minor but will depend on the "coarseness" of the nodalization in the core and steam generator primary. The smaller the number of control volumes (i.e. a coarse nodalization) used to model the core (or steam generator primary) the larger the enthalpy gradient is through each volume and the greater the change will be in volume temperature during a steady-state checkout calculation.

1.5 Subroutine Descriptions

Implementation of the self-initialization option within the RELAP4 code required the development of many new subroutines and revisions to existing routines. Below is a list of new routines, as well as existing ones that were modified (indicated by an asterisk), along with a brief description of the function of each routine.

ININCR: This routine reads core inlet, core outlet, and flow path volume numbers.

PUMIST: This routine reads the numbers of the volumes between each pump and steam generator outlet.

ININIT: This routine reads steam generator volume and junction information. It also checks for two-sided heat slabs between the inlet and outlet plena of the steam generator.

- IRESEI: This routine reads the numbers of volumes between the core inlet and steam generator outlets and between the core outlet and steam generator inlets. It also reads the volume numbers of equal temperature groups.
- PSET: This routine reads the volume flow loop numbers.
- RESID: This routine calculates residuals and, from these, the volume pressures which will reduce these residuals in the flow loops.
- PUCH: This routine calculates the new pump speeds and pump volume pressures necessary to reduce residuals in the flow loops.
- INHTR: This routine calculates the enthalpies and temperatures of core volumes and enthalpies of core junctions.
- IRESET: This routine sets the temperatures of the volumes between the steam generators and the core.
- HTSET: This routine sets volume thermodynamic conditions based on the new volume temperatures which have been calculated.
- PUMRST: This routine adjusts the temperatures of the volumes between the pump and steam generator outlet to compensate for pump produced heat.
- INITSG: This routine calculates the temperatures of the primary and secondary volumes of the steam generators and the flow rate of the secondaries. It also calculates the bubble rise velocity from the input mixture quality.

- MAIND: This routine is a matrix inversion routine used by INITSG.
- PSPATH: This routine reads parallel path junction numbers.
- PDEAD: This routine reads dead end path junction numbers.
- REPATH: This routine recalculates junction loss coefficients in paths parallel to the main flow path so as to minimize residuals in these junctions.
- REDEAD: This routine recalculates volume pressures in dead end paths so as to minimize flow accelerations in these paths.
- *ENTHBL: This routine was changed to allow it to be called repeatedly during initialization.
- *INJUN2: This routine was changed to allow it to be called repeatedly during initialization. It also serves as a driver, calling the residual minimization routines.
- *INTLB: This routine was changed to allow it to be called repeatedly during initialization. It also serves as a driver for all the self-initialization routines.
- *KINITL: This routine was changed to allow it to be called repeatedly during initialization.
- *SINITL: This routine was changed to allow it to be called repeatedly during initialization.

A summary flow chart of the self-initialization logic is shown in Figure 5.

1. Iterated from once to twice the number of flow loops times.
2. Iterated twice the number of flow loops plus two times.
3. Iterated three times.

FIGURE 5. SELF-INITIALIZATION FLOW CHART

2. HEAT TRANSFER TIME STEP CONTROL

The heat transfer time step model has been developed to reduce running time for those problems in which heat transfer represents a significant portion of the calculation. The user can decouple the heat transfer and hydraulic solutions through user input. The concept is based on the idea that the frequency at which the hydrodynamic and heat transfer solutions need to be advanced is inversely proportional to the time constants associated with the behavior. Since the time constant for heat transfer is generally larger than that for fluid flow, the heat transfer time step control may be decoupled from the hydrodynamic solution to save computer time. The heat transfer calculations are then performed once at every N hydraulic time steps, where N is defined by the relation,

$$\sum_{n=1}^{N-1} \Delta t_h^n \leq \Delta t_{HT} \leq \sum_{n=1}^N \Delta t_h^n \quad (26)$$

where: Δt_h^n = the hydraulic time step for the n^{th} advancement

Δt_{HT} = the heat transfer time step

The objective of this model is to reduce computing time without sacrificing appreciable accuracy in the calculation. Differences in results are to be anticipated when the heat transfer solution is advanced at a different time step than the hydrodynamics. However, if the differences are negligible (i.e., a few degrees in temperature) the savings in computer time are worthwhile.

Three methods are considered to compute an independent time step size for the heat transfer/conduction advancement solution:

(a) Temperature time derivative

(b) Heat flux time derivative

(c) Stability (heat conduction solution)

Each of these methods is discussed in the following subsections.

2.1 Temperature Derivative Approach

In the computation of the transient analysis, the temperature gradient with respect to time, $\frac{\partial T}{\partial t}$, is calculated at each heat slab nodal point in accordance, with the relationship⁽³⁾:

$$\begin{array}{rcccl} \text{Rise in} & & \text{Heat Transfer} & & \text{Heat} \\ \text{Internal} & = & \text{from} & + & \text{Generation} \\ \text{Energy} & & \text{One Side} & & & - & \text{Heat Transfer} \\ & & & & & & \text{from} \\ & & & & & & \text{Other Side} \end{array}$$
$$\rho c v \frac{\partial T}{\partial t} = q_i A_i + u' v + q A_o \quad (27)$$

where

ρc = volumetric heat capacity

u' = volumetric heat generation rate

v = nodal volume

t = time

T = nodal temperature

A = surface area for heat transfer

q = heat transfer rate

Subscripts,

i, o = respective boundaries.

The temperature derivative $\frac{\partial T}{\partial t}$ is used to calculate the heat transfer time step with the use of the following empirical relationship:

$$\Delta t = c \frac{T}{\left| \frac{\partial T}{\partial t} \right|} \quad (28)$$

where

c = arbitrary constant

Δt = heat transfer time step

Equation (28) is used to calculate Δt at all nodal points in a slab, and the calculation is performed over all slabs. The minimum Δt to evolve is used as the heat transfer time step.

2.2 Heat Flux Derivative Approach

Another empirical approach for computing the heat transfer time step involves the use of heat slab surface flux⁽³⁾ and is expressed as:

$$\Delta t = \sqrt{\frac{2\epsilon |q_{\max}|}{\left| \frac{\partial q}{\partial t^2} \right|}} \quad (29)$$

where

$q_{\max}$ = the maximum surface heat flux (all slabs)

$\frac{\partial^2 q}{\partial t^2}$ = numerical second time derivative of the surface heat flux

ϵ = arbitrary constant

This approach offers the potential for leading to better accuracy than the temperature derivative in that flux will change more rapidly than temperature. However, to compute the second time derivative of flux at each slab surface requires additional core storage. Another difficulty with this method arises when the moving mesh model is used (i.e., reflood). The moving mesh option results in a non-constant division of heat slabs in time, whereas the flux derivative approach requires flux and flux time derivatives at a fixed location.

2.3 Stability Approach

Based on the Crank-Nicolson numerical solution technique for the conduction equation, a maximum time step size is implied for the advancement to be accurate. Such a criteria is expressed as^(4,5):

$$\frac{C_p (\Delta X)^2}{K \Delta t} = \frac{(\Delta X)^2}{\Delta t} \leq 1 \quad (30)$$

from which,

$$\Delta t \leq \frac{(\Delta X)^2}{\alpha} \quad (31)$$

Thus this last approach to the time step calculation places an upper limit on time step size.

2.4 Application

RELAP4/MOD6 already permits an independent heat transfer time step advancement, with the heat transfer time step remaining a constant value as specified by the code user. In this scheme the heat flux/conduction solution yields a stepwise change in heat flux at each new solution time. This is illustrated in Figure 6 (top). Depending on the direction in which the flux is changing this scheme may overpredict or underpredict the heat transferred during the heat transfer time step interval.

To overcome this problem a linearization and extrapolation/interpolation technique is now employed to compute the heat flux at intermediate hydrodynamic intervals. In this method, the heat flux for all hydrodynamic advancements (except the last one) occurring between the old and new heat transfer solution times is found by extrapolating the flux from the previous two heat flux solutions. For the last hydrodynamic advancement (which would otherwise advance the transient time beyond the point where the next heat transfer solution is to be made) the heat transfer solution is forced to occur coincident with the new hydrodynamic time. Consequently, the flux utilized for the last hydrodynamic interval is found by interpolation of the old and new fluxes. This technique is illustrated in Figure 6 (bottom).

A subroutine, designated TSTHT was developed to compute the heat transfer time step in accordance with the three criteria outlined. To permit evaluation of the temperature derivative criteria versus the flux derivative approach the coding and input are structured to permit usage of either test, together with the stability test as an upper limit on time step size. In addition, the user may also specify a maximum heat transfer time step size to be used if the chosen test and stability criteria yield a larger time step size. The user input is shown in Section IV. Three options are now available as follows:

FIGURE 6. HEAT FLUX AVERAGING AND EXTRAPOLATION

OLD TECHNIQUE

NEW TECHNIQUE

- (1) equal hydraulic and heat transfer advancement time step size (default option),
- (2) constant heat transfer advancement time step size (input by user),
- (3) heat transfer advancement time step size is computed (T test or q test) and limited by stability criteria and user-input maximum.

As indicated in subsection 2.2 the heat flux derivative criterion is basically incompatible with the moving mesh option, since a time-invariant slab surface definition is required. Consequently, when the reflood moving mesh option is invoked the heat flux derivative test is applied only to the coarse (user-input) slabs. This problem does not arise for the temperature derivative test and so this criteria is applied to each of the moving mesh slabs.

A summary flow chart indicating the calculational procedure within RELAP4 is shown in Figure 7.

FIGURE 7. SUMMARY FLOW CHART FOR HEAT TRANSFER TIME STEP CONTROL

3. WATER PROPERTY COMPUTATION IMPROVEMENT

Water property calculation in the RELAP4 program is accomplished by the use of a set of interpolation subroutines and a fixed table of water properties. These routines and table were drawn from the STH2Ø water properties computation package⁽⁶⁾ which is a part of the INEL Environmental Computer Library. In response to inaccuracies discovered in the water properties computed by the STH2Ø package, a complete review of the interpolation subroutines and property table was undertaken. This review showed substantial variance between STH2Ø computed values and those obtained from the ASTM equations⁽⁷⁾. In particular, errors in excess of ten percent were noted in the subcooled, low-temperature region and along the saturation line. To facilitate an understanding of the new computation methods, it is necessary to review the present STH2Ø package briefly.

3.1 Previous Computation Method

The STH2Ø code package includes subroutines STH2Ø1, STH2Ø2, STH2Ø3, STH2Ø4, and STH2Ø5 which all access a fixed table of water properties referred to as STH2ØT. The series of five subroutines differ in the quantities specified as input. Water properties are calculated given the input values of temperature and quality (STH2Ø1), pressure and quality (STH2Ø2), temperature and pressure (STH2Ø3), temperature and specific volume (STH2Ø4), or pressure and enthalpy (STH2Ø5). The properties returned by the subroutines include temperature (T), pressure (p), specific volume (v), specific internal energy (u), specific enthalpy (h), thermal expansion (β), compressibility (κ), and specific heat capacity (C_p).

All of the subroutines use similar table search and interpolation procedures. In the existing package, linear interpolation is used for all liquid properties. Linear or reciprocal interpolation is used for

vapor properties based on the perfect gas relationships, $pv = RT$, $u = C_v T$, $h = C_p T$, $\beta \approx T^{-1}$ and $\kappa \approx p^{-1}$. For example, since $v = RTp^{-1}$, linear interpolation is used for the temperature dependence and reciprocal interpolation is used for the pressure dependence.

The linear interpolation is,

$$Y = Y_1 + (Y_2 - Y_1) \frac{(Z - Z_1)}{(Z_2 - Z_1)} \quad (32)$$

and the reciprocal interpolation is

$$Y = Y_1 + (Y_2 - Y_1) \frac{(Z - Z_1)}{(Z_2 - Z_1)} \frac{Z_2}{Z} \quad (33)$$

The fixed set of water properties (STH2ØT) consists of single phase properties for each of 1363 pressure-temperature points. The 47 temperatures and 29 pressures used to generate these points are shown in Table I. Also included in STH2ØT are the saturated properties for each pressure and each temperature below the critical point.

Specific volume and temperature are the input properties in subroutine STH2Ø4 to calculate all other water properties by interpolation. This subroutine is the pivotal one used in RELAP4 to solve the thermodynamic state and associated water property derivatives. The error analysis conducted on the STH2Ø package keyed on this subroutine.

Using the existing interpolation procedures outlined above and the STH2ØT water property table, two accuracy maps were prepared that show the deviation of water properties above 1% and 10% of those calculated by the ASTM equations. These maps are shown as Figures 8 and 9. Each map was generated by considering 183 temperatures and 121 pressures. For each pressure-temperature point the specific volume

TABLE I
TEMPERATURES AND PRESSURES IN
THE STH2ØT WATER PROPERTY TABLE

47		29	
Temperatures	(°K)	Pressures	(Pa x 10 ³)
273.16	500.	2.0	2500.
280.	510.	5.0	3000.
290.	520.	10.	3500.
300.	530.	20.	4000.
310.	540.	50.	5000.
320.	550.	100.	7500.
330.	560.	150.	10,000.
340.	570.	200.	12,500.
350.	580.	300.	15,000.
360.	590.	400.	17,500.
370.	600.	600.	20,000.
380.	610.	800.	22,000.
390.	620.	1000.	23,000.
400.	630.	1500.	25,000.
410.	640.	2000.	
420.	645.		
430.	647.3		
440.	648.		
450.	650.		
460.	653.		
470.	656.		
480.	660.		
490.	675.		
	700.		

FIGURE 8. ONE PERCENT ACCURACY MAP FO

204 USING EXISTING INTERPOLATION METHODS

ERROR ANALYSIS OF SUBROUTINE - STH204

FIGURE 8. CONTINUED

HOT LEG

COLD LEG

HOT LEG

ОБЩЕЕ ПОЛОЖЕНИЕ ОБЪЕДИНЕНИЯ

三

FIGURE 9. CONTINUED

HOT LEG

COLD LEG

HOT LEG

(and remaining properties) were obtained from the ASTM equations. With specific volume and temperature, subroutine STH2Ø4 was called to solve for the properties by interpolation. The properties thus computed were compared back to the ASTM values, and percentage deviations determined. For purposes of classification, the properties T, p, u, and h were grouped separately from the derivatives β , κ and C_p . The symbols "P", "D", "*" and "T" shown in the maps are indicative of the deviations as shown in the following chart:

<u>Symbol</u>	<u>Definition</u>
blank	No deviations greater than 1% (10% in Figure 9)
P	One or more properties deviate by more than 1% (10% in Figure 9)
D	One or more derivatives deviate by more than 1% (10% in Figure 9)
*	One or more properties and one or more derivatives deviate by more than 1% (10% in Figure 9)
T	The input quantities are out of range (subroutine failure)

Overlaid on these maps are the thermodynamic state "paths" predicted for the cold and hot leg volumes of the BE/EM best-estimate analysis⁽⁸⁾. These paths show that the typical LPWR analysis requires the calculation of water properties in regions of the pressure-temperature map where demonstrated inaccuracy occurs. The inaccuracy is shown to be most pronounced in the sub-cooled region, along the saturation line and in the vicinity of the critical point.

3.2 Revised Interpolation Method

To improve the accuracy of the Environmental Water-Property Library, a new cubic-fit interpolation procedure was implemented which is outlined below.

In the subcooled region, specific volume is a very weak function of pressure and a nonlinear function of temperature. Thus, the existing interpolation technique was not adequate. In the vicinity of the critical point and along the saturation line, nonlinear behavior also exists for the p-v-T relationships. Consequently, the merits of a cubic fit relationship were investigated. A cubic relationship was established between specific volume and temperature (at constant pressure) and specific volume and pressure (at constant temperature) with the aid of the associated partial derivatives. The relationship is constructed using two reference steam table data points where all the water properties are known. With knowledge of the properties (i. e., p, v, T) at two points and the gradients $(\frac{\partial v}{\partial T})_p = v\beta$ and $(\frac{\partial v}{\partial p})_T = v\kappa$ at both points, four boundary conditions are established for the cubic fit. Then a cubic relationship is constructed. The derivation is shown below.

Assume that specific volume (v) and temperature (T) are related at constant pressure as follows:

$$v = C_0 + C_1T + C_2T^2 + C_3T^3 \quad (p = \text{constant}) \quad (34)$$

then,

$$(\frac{\partial v}{\partial T})_p = C_1 + 2C_2T + 3C_3T^2 \quad (35)$$

but,

$$(\frac{\partial v}{\partial T})_p = \beta v \quad (36)$$

thus,

$$\beta v = C_1 + 2C_2T + 3C_3T^2 \quad (37)$$

Applying boundary conditions at reference temperatures T_1 and T_2 gives,

$$v_1 = C_0 + C_1 T_1 + C_2 T_1^2 + C_3 T_1^3 \quad (38)$$

$$v_2 = C_0 + C_1 T_2 + C_2 T_2^2 + C_3 T_2^3 \quad (39)$$

$$\beta_1 v_1 = C_1 + 2C_2 T_1 + 3C_3 T_1^2 \quad (40)$$

$$\beta_2 v_2 = C_1 + 2C_2 T_2 + 3C_3 T_2^2 \quad (41)$$

This set of four equations in four unknowns is solved for the coefficients C_n to produce the cubic relationship between T_1 and T_2 .

An analogous technique is used to obtain the (p,v) relationship. At constant temperature, v is in inverse proportion to p . Thus, a cubic fit is constructed in terms of pressure and density (p,ρ) instead of pressure and specific volume (p,v) . The expression $(\frac{\partial v}{\partial p})_T = -v\kappa$ changes to $(\frac{\partial \rho}{\partial p})_T = \rho\kappa$ with the use of $\rho = \frac{1}{v}$. These deriva-

tives are known at the reference points. This technique was extended (for the subcooled liquid region) to calculate β from the quadratic relationship established in Equations (35) and (36).

Implementation of the cubic fit interpolation was first applied in subroutine STH204 for the subcooled region, along the saturation line, and for the high pressure, high temperature region above the critical point.

Along the saturation line for constant quality, temperature and pressure both vary. Therefore, the above expressions were not applicable. The expression here is given by,

$$\left(\frac{\partial v}{\partial T}\right)_X = f(X, 1-X) = X \left[\left(\frac{\partial v_g}{\partial T}\right)_p + \left(\frac{\partial v_g}{\partial p}\right)_T \frac{dp}{dT} \right] + (1-X) \left[\left(\frac{\partial v_f}{\partial T}\right)_p + \left(\frac{\partial v_f}{\partial p}\right)_T \frac{dp}{dT} \right] \quad (42)$$

where the equation

$$\frac{dp}{dT} = \frac{h_{fg}}{T(v_g - v_f)} \quad (43)$$

is the Clausius-Clapeyron relationship.

Substitution for the partial derivatives gives,

$$\left(\frac{\partial v}{\partial T}\right)_X = X \left[v_g \beta_g - v_g \kappa_g \frac{dp}{dT} \right] + (1-X) \left[v_f \beta_f - v_f \kappa_f \frac{dp}{dT} \right] \quad (44)$$

The derivative $\left(\frac{\partial v}{\partial T}\right)_X$ can then be calculated at the two reference points

from the properties and derivatives provided in the water properties table.

With the same fundamentals of the cubic fit discussed above, the following cubic relationship was derived using the knowledge of v and $\left(\frac{\partial v}{\partial T}\right)_X$ at both reference points:

$$v = C_0 + C_1 T + C_2 T^2 + C_3 T^3 \quad (45)$$

Two sets of the above cubic fit equations are used, one for $X = 0$ and another for $X = 1$.

Analogous interpolation procedures were adopted in the other subroutines of the STH2Ø package. In addition, the inverse interpolation procedure outlined earlier was applied to calculate the coefficient of thermal expansion, β , in the region above critical temperature and below the steam-table pressure.

3.3 Accuracy Comparison

Checkout of the new interpolation routines was carried out to determine the improvement in accuracy. The accuracy assessment was made by repeating the accuracy map calculations with the revised subroutines. Figures 10, 11, and 12 show the maps prepared for subroutine STH204 at accuracy levels of 1 percent, 5 percent, and 10 percent respectively. A marked improvement in accuracy is noted in the subcooled region and along the saturation line, and some improvement occurred near the critical point. Of particular significance is the elimination of all property deviations greater than 1 percent along the LPWR blowdown operating paths; at 5 percent all property and derivative (β , κ , C_p) deviations along these paths have been eliminated. Accuracy problems are still evident in the low temperature subcooled region, the very high pressure region, and near the critical point. To a major extent these problems result from the steep change in properties and derivatives in conjunction with an insufficient water property table point "density" in these regions. In particular, the inaccuracy shown above pressures of 0.3×10^8 Pa results because the properties and derivatives are unsuccessfully extrapolated above the highest table pressure (0.25×10^8 Pa). The property calculation failures (signified by the symbol "T") in the sub-cooled region near the triple point are the consequence of a "lockout" region wherein the liquid properties cannot be extrapolated below the minimum table pressure ($2000 \text{ Pa} \approx 0.29 \text{ psia}$). For typical RELAP4 applications these inadequacies obviously represent no particular hardship.

FIGURE 10. ONE PERCENT ACCURACY MAP FOR STH204 USING REVISED INTERPOLATION TECHNIQUES

FIGURE 10. CONTINUED

HOT LEG

COLD LEG

HOT LEG

FIGURE 11. FIVE PERCENT ACCURACY MAP FOR STH204 USING REVISED INTERPOLATION TECHNIQUES

ERROR ANALYSIS OF SUBROUTINE - STH234

FIGURE 11. CONTINUED

HOT LEG

COLD LEG

HOT LEG

FIGURE 12. TEN PERCENT ACCURACY MAP FOR STH204 USING REVISED INTERPOLATION TECHNIQUES

FIGURE 12. CONTINUED

HOT LEG

COLD LEG

HOT LEG

4. IMPROVED METAL WATER REACTION MODEL

Oxidation of the cladding during a hypothetical loss-of-coolant accident transient has an important influence on both the mechanical strength and peak cladding temperature. This is because:

- (1) the oxide formation is an exothermic reaction which contributes to the energy addition of the cladding,
- (2) oxide growth reduces the ductile material, and
- (3) oxygen changes the plastic behavior of the ductile material.

Therefore, it is important to be able to calculate the amount of oxidation and related heat release expected to occur in an LPWR accident transient. This has been recognized by the NRC and limits have been placed on the predicted amount of fuel rod cladding oxidation that is allowed in a licensing calculation as specified in 10 CFR Appendix K⁽⁹⁾. Also required by Appendix K is the use of a conservative parabolic reaction rate model formulated by an ANL study⁽¹⁰⁾ performed by Baker and Just. Recent work performed by Cathcart, Pawel, et al (ORNL) on the oxidation of Zircaloy⁽¹¹⁾ has produced a best estimate correlation for the parabolic rate model.

The RELAP4/MOD6 program provides for the calculation of metal-water reaction on the outside of the cladding (inside also if clad rupture has been predicted) using a model derived from the ANL study. Also available is an option to substitute for the constants in the Baker-Just model those derived from the ORNL work.

Upgrading of this model in RELAP4 included two objectives:

- (1) Evaluate the present RELAP4 parabolic rate model from the standpoint of the accuracy of the assumptions made in formulating it and in light of final publication of the ORNL work (the constants originally inserted in RELAP4/MOD6 for the Cathcart-Pawel model were preliminary).
- (2) Enable the user to invoke one of four versions of the metal-water reaction model:
 - (a) Baker-Just
 - (b) Cathcart-Pawel (C-P)
 - (c) C-P using upper limit constants reflecting the 90 percent statistical confidence level
 - (d) C-P using lower limit constants reflecting the 90 percent statistical confidence level.

The latter objective is intended to facilitate statistical analysis using the RELAP4 code.

4.1 Parabolic Rate Law

There are two methods available to calculate the oxide thickness such that the energy deposited in the cladding can be determined. The methods differ in the assumption made relative to the geometry of the surface being oxidized: plane or cylindrical. All pressurized water reactors have cylindrical fuel elements, but the complex solution of the cylindrical case makes using the plane geometry solution attractive. The error associated with the simplification of using a plane geometry solution is considered.

Examination of the rate of growth of the oxide layer thickness over a temperature range above approximately 1000°C (1832°F) revealed that the growth followed a parabolic rate law⁽¹²⁾. This law can be simply stated as the time rate of change of a kinetic parameter is inversely proportional to the instantaneous magnitude of that parameter. The constant proportionality is itself an Arrhenius function of temperature, and the law can be written as:

$$\frac{dK}{dt} = \frac{1}{K} \frac{\delta_K^2(T)}{2} \quad (46)$$

where K is a kinetic parameter and $\frac{\delta_K^2(T)}{2}$ is defined as the isothermal parabolic rate constant. The kinetic parameter can be defined alternatively as the oxide layer thickness ϕ ; alpha layer thickness α ; the oxide plus alpha layer thickness ϵ ; or the total oxygen consumed τ . To calculate the amount of equivalent thickness of Zirconium converted to ZrO_2 and heat generated as a function of time, the total oxygen consumed rate-constant is used. Thus the parabolic rate equation becomes:

$$\frac{dK}{dt} = \frac{1}{K_\tau} \frac{\delta_\tau^2(T)}{2} \quad (47)$$

where K_τ represents the oxide film thickness per unit of surface area since $\frac{\delta_K^2(T)}{2}$ has the units of $(g/cm^2)^2/sec$.

The parabolic rate law in differential form is rigorously correct only for a solid-state diffusion process occurring at the surface of a plane. Diffusion through a barrier film on a cylindrical surface depends on the ratio of the inner radius to the outer radius of the film. Thus the parabolic rate law for a plane and cylindrical case becomes:

Plane

$$A \frac{d(x_0 - x)}{dt} = \frac{1}{\frac{x_0 - x}{A}} \frac{\delta_\tau^2(T)}{2} \quad (48)$$

where,

x_0 = the original thickness of the unreacted metal

x = the thickness of unreacted metal

A = the area normal to the oxidation depth

$\frac{\delta_\tau^2(T)}{2}$ = the isothermal parabolic rate constant for total oxygen consumed.

Cylindrical

$$2 \pi L r \frac{d(r_0 - r)}{dt} = \frac{1}{\frac{\ln(r_0/r)}{2 \pi L}} \frac{\delta_\tau^2(T)}{2} \quad (49)$$

where

r_0 = the original thickness of the unreacted metal

r = the thickness of unreacted metal

L = the length of the cylinder.

The integration of the parabolic rate law can be performed assuming the temperature is held constant over the integration time step and is given by:

Plane

$$(x_0 - x)^2 = t \frac{\delta_{\tau}^2(T)}{2} \quad (50)$$

Cylindrical

$$r^2 \ln \frac{r}{r_0} + \frac{r_0^2 - r^2}{2} = t \frac{\delta_{\tau}^2(T)}{2} \quad (51)$$

Comparison of the two equations shows that the plane or slab geometry equation can be used for a cylindrical fuel rod as long as the reaction depths are not a significant fraction of the radius. Table II demonstrates the percent error associated with this assumption, which has been made in RELAP4 for computational ease. As indicated, the error introduced by using the plane assumption is less than one percent for oxide depths up to twenty percent of typical cladding thickness.

4.2 RELAP4 Method

Using the above assumption for a plane geometry derivation of the parabolic rate law (Equation 48) the depth of oxide can be determined as a function of time. The parabolic rate equation in differential form for the plane geometry case is

$$\frac{d(r_0 - r)}{dt} = \frac{1}{r_0 - r} \frac{\delta_{\tau}^2(T)}{2} \quad (52)$$

where

r_0 = the initial radius of the cladding

r = the radius the reaction has penetrated

TABLE II

PERCENT ERROR ASSOCIATED WITH USING THE PLANE
VS. CYLINDRICAL EXPRESSION FOR OXIDE DEPTH

DEPTH OF REACTION x or r (in.)	PLANE EQUATION $(x_o - x)^2$ (in ²)	CYLINDRICAL EQUATION $r^2 [\ln (\frac{r}{r_o})] + \frac{r_o^2 - r^2}{2}$ (in ²)	% ERROR
0.0001	1.0×10^{-8}	1.000248×10^{-8}	0.025
0.0005	2.5×10^{-7}	2.4980920×10^{-7}	- 0.076
0.001	1.0×10^{-6}	9.984209×10^{-7}	- 0.158
0.004*	1.7065×10^{-5}	$1.69832474 \times 10^{-5}$	- 0.6595
0.005	2.5×10^{-5}	2.4801346×10^{-5}	- 0.801

Assume $x_o = r_o = 0.211$ in. (radius of a PWR fuel rod)

*Typical maximum value allowed by Appendix K.

Integrating the above equation over a RELAP time step t_1 to t_2 yields

$$- \int_{r_1}^{r_2} (r_0 - r) dr = \int_{t_1}^{t_2} \frac{\delta_T^2(T)}{2} dt \quad (53)$$

where

r_1 = the radius the reaction has penetrated at the start of the time step,

r_2 = the radius the reaction has penetrated at the end of the time step, and

t_1 and t_2 are the time at the start and end of the time step.

Using the assumption that the temperature is constant during the integration step and introducing the variable $r' = r_0 - r$, and its differential, $dr' = -dr$ the above equation becomes,

$$\frac{r'^2}{2} \bigg|_{(r_0 - r_1)}^{(r_0 - r_2)} = \frac{\delta_T^2(T)}{2} t \bigg|_{t_1}^{t_2} \quad (54)$$

which yields,

$$\frac{DRP_1^2 - DRP^2}{2} = \frac{\delta_T^2(T)}{2} \Delta t \quad (55)$$

where

$DRP1 = r_0 - r_2 =$ the depth the reaction has penetrated the cladding at the end of the time step,

$DRP = r_0 - r_1 =$ the depth the reaction has penetrated the cladding at start of the time step, and,

$\Delta t = t_2 - t_1 =$ time step size.

If a new variable AP is defined as $(DRP1^2 - DRP^2)$, the unknown DRP1 is expressed in terms of DRP and AP as,

$$DRP1 = \sqrt{DRP^2 + AP} \quad (56)$$

The above equation allows the depth of the oxide thickness at the end of a time step to be calculated. This is then used to calculate the heat generated by the reactions which form ZrO_2 .

The linear power generated by the oxidation of zircaloy is calculated by determining the mass reacted per time step. The mass of zirconium reacted per unit length during the time step is obtained from the product of the density and the difference between the old and new oxide cross-sectional areas as,

$$MZR = \rho_{Zr} \left[\pi(r_0 - DRP)^2 - \pi(r_0 - DRP1)^2 \right] \quad (57)$$

where

$\rho_{Zr} =$ the density of zirconium.

The above equation can be expanded and expressed in terms of the parameter AP and it becomes

$$MZR = \pi \rho_{Zr} \left[2 r_0 (DRP1 - DRP) - AP \right] \quad (58)$$

If the heat of reaction is defined as Q_R the total heating rate per unit length of rod is given by

$$Q_{MWR} = \frac{Q_R MZR}{\Delta t} \quad (59)$$

To determine the exothermic heat of reaction Q_R the method of conversion of Zr to ZrO_2 must be examined. The oxidation of Zr may be written as:

with $Q_1 = 6.45 \times 10^6$ joules per kg of zircaloy reacted⁽¹²⁾.

Using this equation to produce the heat release may underpredict the oxidation heat release because it fully accounts for the energy required for the dissociation of water. In the zircaloy oxidation equation without the dissociation of water,

where $Q_2 = 1.204 \times 10^7$ joules per kg of zircaloy reacted⁽¹³⁾.

Q_1 and Q_2 differ by approximately a factor of two. This difference is due to the endothermic dissociation of water reaction,

where Q_3 is the energy necessary for the dissociation of water molecules.

The dissociation of water described by the above equation must take place either at the oxide-coolant interface, on an adjacent rod or in the coolant itself. The basic assumption is made that Q_1 should be used because the process of dissociation should average out over the rod and the heat of reaction from Equation (60) is a satisfactory approximation.

The parabolic rate constant used to define the oxide depth penetration in Equation (55) can be defined for several cases. First, a best estimate equation for the parabolic rate constant for total oxygen consumed is given by the ORNL zirconium metal-water oxidation study⁽¹¹⁾ as

$$\frac{\delta_T^2(T)}{2} = 0.1811 \text{ EXP } (-39940/RT) \quad (63)$$

where

$$\frac{\delta_T^2(T)}{2} = \text{parabolic rate constant for the total oxygen consumed (g/cm}^2\text{)}^2\text{/sec}$$

$$R = \text{gas constant, 1.987 cal/g-mole}^\circ\text{K}$$

$$T = \text{temperature } ^\circ\text{K}$$

Also reported by ORNL are the 90% confidence limit deviations for the total oxygen consumed. These are shown as a function of temperature in Table III. These data show the confidence range of the total oxygen consumed to be very narrow over the range of temperature from 1050°C to 1500°C.

It should be noted that the parabolic growth kinetics apply to both the oxide and alpha phases at temperatures above 1000°C (1832°F) but only to the alpha phase below this temperature. For this reason parabolic rate constants were not reported by ORNL⁽¹¹⁾ for total oxygen consumed at temperatures below 1000°C (1832°F).

TABLE III

PERCENT DEVIATION FROM EXPECTED VALUES

<u>Rate Constant</u>	<u>Above 1500°C (2732°F)</u>	<u>1500°C (2732°F)</u>	<u>1250°C (2282°F)</u>	<u>1050°C (1922°F)</u>	<u>Below 1050°C (1922°F)</u>
2	*	+ 3.0	+ 3.0	+ 3.4	+ 3.4
$\frac{\delta}{\tau}$	*	- 2.9	- 1.7	- 3.3	- 3.3
2					

* Extrapolated using values at 1250°C and 1500°C.

The Argonne National Laboratory (ANL) study of metal-water reactions at high temperature, performed by Baker and Just⁽¹⁰⁾, produced the rate constant used for evaluation model calculations as required in Appendix K. The Baker-Just equation is given as,

$$\frac{\delta x^2}{2} = 66.6 \times 10^6 \text{ EXP } (-45500/RT) \quad (64)$$

$$\frac{\delta x^2}{2} = \text{parabolic rate constant (milligrams of zirconium reacted/cm}^2\text{)}^2/\text{sec} \quad (65)$$

where,

R is gas constant 1.987 cal/g-mole⁰K

T is temperature ⁰K.

This equation for the rate constant has been shown to be conservative (overpredict the oxide depth) at high temperatures and is therefore required by Appendix K.

The four options enumerated above have been implemented in the RELAP4 code. Selection of the appropriate metal-water reaction rate calculation is accomplished via input of data card 010003 as indicated in section IV.

5. IMPROVED REACTOR KINETICS MODEL

Since reactor power has a direct bearing on the prediction of cladding surface temperature during a LOCA it is important that an accurate, best estimate model for decay heat and reactor shutdown kinetics be employed. RELAP4/MOD6 utilizes a decay heat model based on the 1971 ANS Standard⁽¹⁴⁾ coupled with a point reactor kinetics model from the IREKIN computer program⁽¹⁵⁾. The ANS has recently published a new decay heat standard which yields lower power levels and which also accounts for reactor power history and the fissioning of ^{239}Pu and ^{238}U (the old standard considers ^{235}U only). The following subsections discuss incorporation of the new ANS standard and some additional modifications to the kinetics model.

5.1 Decay Heat Model

The decay heat calculation based on the ANS 5.1 standard proposed in 1971 assumes that the reactor operating period is infinite and that the power is generated solely from fissioning of ^{235}U . The new standard incorporates several improvements over the earlier model:

- (1) Fission products may be produced from thermal fission of ^{235}U , ^{239}Pu (formed from the absorption of thermal and resonance neutrons by ^{238}U) and fast fission of ^{238}U .
- (2) The previous reactor operating time may be finite.
- (3) The effect of neutron capture is considered by using a small correction factor.
- (4) A statistical basis is established and uncertainty is expressed in terms of a standard deviation for a normal distribution.

The decay heat power from fission products and ^{239}U and ^{239}Np following shutdown is considered in the Revised ANS Standard. Contributions to the fission product decay heat may be distributed among the fission products from fissioning of three major fissile nuclides present, i.e., ^{235}U , ^{239}Pu thermal and ^{238}U fast, in accordance with the reactor power history. The neutron capture in fission products is treated by using a correction factor.

The decay heat power $f_i(t)$ (in MeV/sec/fission) t seconds after a fission pulse from nuclide i is expressed in exponential form as,

$$f_i(t) = \sum_{j=1}^{23} \alpha_{ji} \exp(-\lambda_{ji} t) \quad (66)$$

where $i = 1, 2, 3$ represent ^{235}U thermal, ^{239}Pu thermal, and ^{238}U fast. The parameters α and λ for the three nuclides are listed in Tables IV through VI. The uncorrected decay heat power contributed by fissioning of nuclide i is calculated from,

$$P'_{di}(t, T) = \int_0^T (P_i(T')/Q_i) f_i(t + T - T') dT' \quad (67)$$

where

T' = time measured from initial reactor startup, seconds,

T = total operating period, seconds,

t = time after shutdown; cooling time, seconds,

Q_i = total recoverable energy associated with one fission of nuclide i , MeV,

TABLE IV

PARAMETERS FOR
 ^{235}U THERMAL FISSION FUNCTIONS $f(t)$

α	λ
6.5057E-01	2.2138E+01
5.1264E-01	5.1587E-01
2.4384E-01	1.9594E-01
1.3850E-01	1.0314E-01
5.5440E-02	3.3656E-02
2.2225E-02	1.1681E-02
3.3088E-03	3.5870E-03
9.3015E-04	1.3930E-03
8.0943E-04	6.2630E-04
1.9567E-04	1.8906E-04
3.2535E-05	5.4988E-05
7.5595E-06	2.0958E-05
2.5232E-06	1.0010E-05
4.9948E-07	2.5438E-06
1.8531E-07	6.6461E-07
2.6608E-08	1.2290E-07
2.2398E-09	2.7213E-08
8.1641E-12	4.3714E-09
8.7797E-11	7.5780E-10
2.5131E-14	2.4786E-10
3.2176E-16	2.2384E-13
4.5038E-17	2.4600E-14
7.4791E-17	1.5699E-14

TABLE V
PARAMETERS FOR
 ^{239}Pu THERMAL FISSION FUNCTIONS $f(t)$

α	λ
2.083E-01	1.002E+01
3.853E-01	6.433E-01
2.213E-01	2.186E-01
9.460E-02	1.004E-01
3.531E-02	3.728E-02
2.292E-02	1.435E-02
3.946E-03	4.549E-03
1.317E-03	1.328E-03
7.052E-04	5.356E-04
1.432E-04	1.730E-04
1.765E-05	4.881E-05
7.347E-06	2.006E-05
1.747E-06	8.319E-06
5.481E-07	2.358E-06
1.671E-07	6.450E-07
2.112E-08	1.278E-07
2.996E-09	2.466E-08
5.107E-11	9.378E-09
5.730E-11	7.450E-10
4.138E-14	2.426E-10
1.088E-15	2.210E-13
2.454E-17	2.640E-14
7.557E-17	1.380E-14

TABLE VI

PARAMETERS FOR
 ^{238}U FAST FISSION FUNCTIONS $f(t)$

α	λ
1.2311E+0	3.2881E+0
1.1486E+0	9.3805E-1
7.0701E-1	3.7073E-1
2.5209E-1	1.1118E-1
7.1870E-2	3.6143E-2
2.8291E-2	1.3272E-2
6.8382E-3	5.0133E-3
1.2322E-3	1.3655E-3
6.8409E-4	5.5158E-4
1.6975E-4	1.7873E-4
2.4182E-5	4.9032E-5
6.6356E-6	1.7058E-5
1.0075E-6	7.0465E-6
4.9894E-7	2.3190E-6
1.6352E-7	6.4480E-7
2.3355E-8	1.2649E-7
2.8094E-9	2.5548E-8
3.6236E-11	8.4782E-9
6.4577E-11	7.5130E-10
4.4963E-14	2.4188E-10
3.6654E-16	2.2739E-13
5.6293E-17	9.0536E-14
7.1602E-17	5.6098E-15

$P_i(T') =$ the power generated by the i^{th} fissile nuclide at T' , MeV/sec, and

$P'_{di}(t, T) =$ fission product decay heat contributed by the i^{th} fissionable nuclide, uncorrected for neutron capture in fission products, MeV/sec.

The total fission product decay heat power $P_d(t, T)$ is given by

$$P_d(t, T) = P'_d(t, T) G(t, T, \psi) \quad , \quad (68)$$

where

$$P'_d(t, T) = \sum_{i=1}^3 P'_{di}(t, T) \quad (69)$$

and the correction factor G for neutron capture is

$$G(t, T, \psi) = 1.0 + (3.24 \times 10^{-6} + 5.23 \times 10^{-10} t) T^{0.4} \psi \quad . \quad (70)$$

Here, ψ is fissions per initial fissile atom (dimensionless). The user is required to supply the initial fissile concentration (in units of 10^{20} atoms/cm³).

The reactor operating history is represented by a histogram of N time intervals with constant power, P_{ij} , from fissionable nuclide i at the time interval $(T_j - T_{j-1})$. An example is illustrated in Figure 13.

Substitution of Eq. (66) into Eq. (67) produces

$$P'_{di}(t, T) = \sum_{j=1}^{23} A_{ji}(T) \exp(-\lambda_{ji} t) \quad , \quad (71)$$

FIGURE 13. REACTOR OPERATING HISTORY ILLUSTRATION

where

$$A_{ji}(T) = (\alpha_i / \Omega_i \lambda_i) \sum_{j=1}^N P_{ij} \exp[-\lambda_{ji} (T - T_J)] \times \left\{ 1 - \exp[-\lambda_{ji} (T_J - T_{J-1})] \right\}. \quad (72)$$

The data set $\{T_J, (P_{ij})\}$ is input by the user as Reactor Power Histogram Data. The reactor power $P = \sum_i P_{iN}$ (in units of MW) at T is entered as POWER on the Problem Constants Data Card. The Q_i is set equal to 200 MeV for all i .

The heavy element decay heat power, P_{dHE} , is given as

$$P_{dHE}(t, T) = (P/Q) \left[F_{U-239}(t, T) + F_{Np-239}(t, T) \right], \quad (73)$$

where P is taken as the maximum reactor power during the operating history and Q is the effective energy release per fission evaluated just prior to the time of shutdown and,

$$F_{U-239}(t, T) = E_{U-239} R \left[1 - \exp(-\lambda_1 T) \right] \exp(-\lambda_1 t), \quad (74)$$

$$F_{Np-239}(t, T) = E_{Np-239} R \left\{ \frac{\lambda_1}{\lambda_1 - \lambda_2} \left[1 - \exp(-\lambda_2 T) \right] \exp(-\lambda_2 t) - \frac{\lambda_2}{\lambda_1 - \lambda_2} \left[1 - \exp(-\lambda_1 T) \right] \exp(-\lambda_1 t) \right\} \quad (75)$$

Here,

E_{U-239} = average energy from the decay of one ^{239}U atom = 0.474 MeV

$E_{\text{Np-239}}$ = Average energy from the decay of one ^{239}Np atom = 0.419 MeV

R = atoms of ^{239}U produced per second per fission per second evaluated just prior to the time of shutdown

λ_1 = decay constant for ^{239}U ($= 4.91 \times 10^{-4} \text{ sec}^{-1}$)

λ_2 = decay constant for ^{239}Np ($= 3.41 \times 10^{-6} \text{ sec}^{-1}$)

The parameter R is entered as UDUF on the Kinetics Constant Data Card.

The total decay heat power is the sum of fission product decay heat power, $P_d(t, T)$ and the heavy element decay heat power, $P_{\text{dHE}}(t, T)$.

5.2 Reactor Kinetics Model

Neutron induced fission power, which is not included in the ANS Standard for shutdown decay heat power, is approximated by using the point reactor kinetics equations,

$$dn/dt = (\beta/\Lambda) (R-1)n + \sum_{i=1}^6 \lambda_i C_i + S, \quad (76)$$

$$dC_i/dt + \Lambda_i C_i = (\beta_i/\Lambda) n, \quad (77)$$

where

$i = 1, 2, \dots, 6$ (neutron groups)

n = neutron population

$$\beta = \sum_{i=1}^6 \beta_i, \text{ effective delayed neutron fraction}$$

Λ = neutron generation time

R = total reactivity normalized to the delayed neutron fraction

λ_i = decay constant of delayed neutron group i

C_i = concentration of delayed neutron group i

S = neutron source

β_i = effective fraction for delayed neutron group i

The term β/Λ is entered as BOVL on the Kinetic Constants Data Card. Table VII contains the delayed neutron constants⁽¹⁶⁾ from thermal and fast fission of ^{235}U . In RELAP4/MOD6 the fast fission constants are used. The model has been revised to use the thermal fission constants.

The driving function for the reactor kinetics equations is reactivity. Contributions to the reactivity include a time-dependent (scram) reactivity and individual reactivities due to feedback effects in each core region. Feedback effects include fuel temperature, water density, and water temperature. The feedback reactivity is calculated from:

$$R(t) = R_0 + R_{\text{exp}}(t) - R_{\text{exp}}(0) + \sum_i R^i(t) - \sum_i R^i(0) \quad (78)$$

where

$$R^i(t) = W_p^i R_p \left(\frac{\rho^i(t)}{\rho^i(0)} \right) + W_{FT}^i R_{FT} (T_F^i(t)) + \alpha_{FT}^i T_F^i(t) + \alpha_{WT}^i T_W(t) \quad (79)$$

TABLE VII

DELAYED NEUTRON CONSTANTS

Group, i	β_i / β		λ_i (sec ⁻¹)	
	Thermal	Fast	Thermal	Fast
1	0.033 $\pm$ 0.003	0.038 $\pm$ 0.003	0.0124 $\pm$ 0.0003	0.0127 $\pm$ 0.0002
2	0.219 $\pm$ 0.009	0.213 $\pm$ 0.005	0.0305 $\pm$ 0.0010	0.0317 $\pm$ 0.0008
3	0.196 $\pm$ 0.022	0.188 $\pm$ 0.016	0.111 $\pm$ 0.004	0.115 $\pm$ 0.003
4	0.395 $\pm$ 0.011	0.407 $\pm$ 0.007	0.301 $\pm$ 0.011	0.311 $\pm$ 0.008
5	0.115 $\pm$ 0.009	0.128 $\pm$ 0.008	1.14 $\pm$ 0.15	1.40 $\pm$ 0.081
6	0.042 $\pm$ 0.008	0.026 $\pm$ 0.003	3.01 $\pm$ 0.29	3.07 $\pm$ 0.369

and where

R = total reactivity normalized to the delayed neutron fraction

R_0 = initial reactivity (entered as RHOIN)

R_{exp} = explicit time-dependent reactivity (Scram Table Data Cards: TSCR(I), odd I, time; even I, reactivity)

R^i = feedback reactivity from core region i

W_p^i = weighting factor for water density feedback of core region i (entered as VOIDWT on the Reactivity Coefficients Data Cards)

R_p = reactivity as a function of normalized water density for entire core (Density Reactivity Table Data Cards: VOIDRO(I), odd I, density; even I, reactivity)

ρ = water density of core region i

W_{FT}^i = weighting factor for fuel temperature feedback of core region i (entered as DOPWT on the Reactivity Coefficients Data Cards)

R_{FT} = reactivity as a function of average fuel temperature in entire core (Doppler Table Data Cards: DOPRO(I), odd I, temperature; even I, reactivity)

T_F^i = average fuel temperature of core region i

α_{FT}^i = fuel temperature coefficient for core region i (entered as ALPHTM)

α_{WT}^i = water temperature coefficient for core region i
(entered as ALPHTW)

T_W = water temperature

t = time.

The first term of the right hand side of Equation (79) describes the reactivity effects due to water density changes, (VOIDRO), including those due to a change in water temperature. The water temperature coefficient (ALPHTW) used in the fourth term must be calculated with the water density constant. The usual procedure of measuring or calculating a water temperature coefficient at constant pressure cannot be used because the first and fourth terms would then include effects due to density changes. The second and third terms describe the reactivity effects of a change in fuel temperature. Description of the fuel temperature effects is recommended. This should include Doppler broadening of the capture resonances by using either the temperature reactivity curve (DOPRO) or the fuel temperature coefficients (ALPHTM). Overinsertion of reactivity due to fuel temperature will result if both are used, however.

Reactivity feedback phenomena in the moderator can include the effects of any vapor volume produced during subcooled boiling. The vapor volume fraction is estimated within the program by the equation shown below. It should be noted however, that vapor transport is neglected. The equation for the vapor volume fraction is

$$dV/dt = V/\tau = \lambda K q', \quad (80)$$

where

V = volume fraction of vapor in coolant channel

τ = bubble collapse life time

λ = fraction of surface heat flux utilized in producing vapor

q' = surface heat flux

K = conversion factor

t = time.

Integration of Equation (80) yields

$$V = V_0 \exp(-t/\tau) + \tau \lambda K q' [1 - \exp(-t/\tau)] \quad , \quad (81)$$

where V_0 is the value of V at beginning of a time step. The parameters, τ and λ are entered as TAU and LAMBDA on the Kinetics Constants Data Card. The values of τ and λ are strongly dependent on the surface characteristic; therefore, the above approximation i.e., Equation (81) should be used with extreme care.

Substituting the relationships $C_i = \beta_i C_i' / \Lambda \tau_i$, $S = \beta S' / \Lambda$ and $f_i = \beta_i / \beta$, into the reactor kinetics equations, the equations can be written as

$$dn/dt = (\beta/\Lambda) \left\{ (R-1)n + \sum_{i=1}^6 f_i C_i' + S' \right\} \quad (82)$$

$$dC_i'/dt = \lambda_i n - \lambda_i C_i' \quad (83)$$

The neutron population n can be normalized to 1 at $t = 0$ (steady state). Under such circumstances, the initial conditions can be obtained from Equations (82) and (83) as

$$C_1'(t=0) = n(t=0) = 1, R(t=0) = -S'(t=0). \quad (84)$$

Equations (82) and (83) together with the initial conditions specified by Equation (84) and the reactivity calculated from Equation (78) are solved numerically by the method of Cohen⁽¹⁷⁾ to obtain $n(t)$ for calculating reactor power. It should be noted that the equivalent neutron source S' is assumed to be time-independent and set equal to $-R(t=0)$ according to Equation (84).

Because of the presence of delayed neutrons, the shutdown of a reactor requires a finite length of time after sudden insertion of a large negative reactivity (scram) even if $R = -\infty$. During this transient period, new fission products are being generated. Contributions to the decay heat power from the new fission products can be calculated by the same equation used to calculate the power history effects. This is seen by visualizing the power history at time t as the reactor operating period plus the transient period up to t . The total power is the sum of prompt fission power and the decay heat power. The power is normalized such that the total power at $t = 0$ is 1.

5.3 Guidelines

Implementation of the new decay heat standard and modifications to the reactor kinetics model outlined above was accomplished through modification of subroutines INREAC, INRKEN, INSCRM, KINITL, REAC, RKEN, RND0, and SCRM. A flow chart indicating the relationships and sequence of calculation is shown in Figure 14.

With respect to the calculation of core power, the user has three principal options, two of which do not involve the reactor kinetics model:

5.3.1 Tabular Power Data (MODEL = 0 on Kinetics Constants Data Card 140000) The normalized power data during the transient are

FIGURE 14. REACTOR KINETICS MODEL SUMMARY FLOW CHART

entered as a set of tabular data on the Scram Table Data Cards. The zero time entry in the table is used until the conditions specified by the designated trip number are satisfied. From that point on, the power is obtained by interpolation from the table with the time axis translated so that zero time of the table corresponds to the time at which the trip conditions are satisfied.

5.3.2 Power Data Retrieval (NODEL = -1) The power data are retrieved from a previous RELAP4 calculation via tape. The data stored in the plot records of the previous run are interpolated to obtain the normalized power at each time step.

The kinetics model is invoked by appropriate input of variables NODEL and IPOWH on the Kinetics Constants Data Card. A complete description of all input data required for the model is presented in Section IV.

To use the reactor kinetics model for calculations of normalized power, the user should select an option best fit to the problem under consideration. The power is calculated according to the equations and procedures described in Sections 5.1 and 5.2. A new multiplier, DHMUL, is provided on the Kinetics Constants Data Card for the fission product decay heat power. This multiplier may be used for adjusting the total recoverable energy per fission. For example, if the total recoverable energy per fission is Q' rather than 200 MeV, the user may enter a value of $200/Q'$ for DHMUL. The multiplier may also be used in connection with the estimated average uncertainty in the $f(t)$ functions. There is no multiplier for the decay heat power from ^{239}U and ^{239}Np . However, the variable UDUF, which represents ^{239}U atoms produced per second per fission per second, may serve as a multiplier. It should be stressed that justification is required for assigning values to DHMUL and UDUF.

6. TWO PHASE FORM LOSS MODEL

Currently released versions of the RELAP4 program account for irreversible pressure loss caused by pipe wall friction (Fanning losses) as well as area change, bends, and obstructions (form-loss).

The wall friction pressure loss is given by the equation

$$\Delta p_w = 4 f \left(\frac{\ell}{2D_h} \right) \left(\frac{\rho \bar{v} |\bar{v}|}{2} \right) \phi_{2p} \quad (85)$$

where

f = Fanning friction factor

ℓ = Volume length

D_h = Hydraulic flow diameter

ρ = Fluid density

$\bar{v}$ = Fluid velocity

ϕ_{2p} = Multiplier for increased friction when flow is two-phase fluid.

The two-phase friction multiplier, ϕ_{2p} , is an optional correction factor used to increase the wall friction loss for two-phase fluid flow. The two-phase friction multiplier is calculated as a function of mass flux, pressure, and quality through use of a modification of the Baroczy⁽¹⁸⁾ correlation. The modification allows the final two-phase friction multiplier to be always greater than or equal to 1.0 which corresponds to single-phase liquid flow.

The pressure loss caused by area change, elbows, bends, and obstructions is generally accounted for through the junction form loss K. The expression for pressure drop is,

$$\Delta p_j = K \frac{\rho_j v_j |v_j|}{2} \quad (86)$$

where

ρ_j = Junction density

v_j = junction fluid velocity.

The dimensionless form loss coefficient K is input by the user based on the nature of the junction geometry. This model is applied for both single and two-phase pressure drop.

The calculation of two-phase form losses is dependent upon the geometry of the system. Calculations of two-phase form losses for expansions use different equations than for contractions, orifices or bends. Also, present correlations do not include a mass velocity effect and are based upon data for concurrent flow.

A two-phase pressure drop correlation for pipe bends only was selected for incorporation into RELAP4/MOD7. This decision was based on the following considerations:

- (a) A two-phase pressure drop model for pipe and tubing bends has greater utility in modeling LPWR and LBWR systems than geometry-dependent area-change models,
- (b) The area change models suffer from large uncertainties and are more dependent on flow regime.

6.1 Model Description

The particular model selected is that proposed by Chisholm⁽¹⁹⁾. The correlation used is,

$$\Delta P_{2\phi} = \Delta P_g + C (\Delta P_f \Delta P_g)^{1/2} + \Delta P_f \quad (87)$$

where

$\Delta P_{2\phi}$ = the two-phase pressure loss,

ΔP_g = the pressure loss for the gas flowing alone,

ΔP_f = the pressure loss for the liquid flowing alone, and for pipe bends C is a parameter given by,

$$C = \left[\lambda + (C_2 - \lambda) \left(\frac{v_f}{v_g} \right)^{1/2} \right] \left[\left(\frac{v_g}{v_f} \right)^{1/2} + \left(\frac{v_f}{v_g} \right)^{1/2} \right] \quad (88)$$

where λ was taken to be 1.0 which is the value reported for rough pipe. The recommended values for C_2 are

$C_2 = 1 + 35 D/L$ for 90° bends,

$= 1 + 20 D/L$ for 180° bends and 90° bends with upstream disturbances,

$= 1.75$ for tee's, where L/D is the equivalent length to diameter ratio of the bend.

6.2 Model Implementation

Since in the RELAP4 program, both single and two-phase pressure loss are computed in accordance with Equation (86) a multiplier,

$K_{2\phi}$, was defined such that:

$$\Delta K_{2\phi} \Delta P_j = K_{2\phi} K \frac{\rho_i v_j |v_j|}{2} \equiv \Delta P_g + C(\Delta P_f \Delta P_g)^{1/2} + \Delta P_f \quad (89)$$

Equation (89) is solved for K_2 to obtain,

$$K_{2\phi} = \rho_j \left[\frac{F_g^2}{\rho_g} + C F_g F_f \left(\frac{1}{\rho_f \rho_g} \right)^{1/2} + \frac{F_f^2}{\rho_f} \right] \quad (90)$$

where

ρ_j = junction density

ρ_f = density of saturated liquid

ρ_g = density of saturated vapor

F_g = $\frac{W_g}{W}$ = vapor fraction of total flow

F_f = $\frac{W_f}{W}$ = liquid fraction of total flow

and C is as defined by Equation (88). The constant $K_{2\phi}$ is computed in the program by subroutine PREW and is designated as junction quantity TPMJ. Since the model is valid only for concurrent flow of liquid and vapor the constant TPMJ is set equal to 1.0 if the liquid and vapor phase flow rates are opposite in sign.

The model is invoked for any normal junction by inputting a non-zero value for a new parameter, designated WTP, on the Junction Data Card (See Section IV). The value input for WTP is used as constant C_2 of Equation (88).

7. BEST ESTIMATE BLOWDOWN FUEL MODEL

Several alternatives were considered to accomplish the objective of providing an adequate fuel model analysis capability in RELAP4/MOD7. These consisted of upgrading the present best estimate fuel model (BEFRAP) available in MOD6, taking subroutines from the FRAP-T⁽²⁰⁾ code and inserting them into RELAP4, or providing a link between FRAP-S, FRAP-T, and RELAP4. The latter method was selected because it offered the following advantages:

1. No future fuel model development in RELAP4 would be required.
2. Changes to FRAP-T would be factored in by simply replacing FRAP-T in the current link with the newer version.
3. Verification of FRAP-S and FRAP-T fuel models would be shared by the linked code package.
4. FRAP-T time advancement could be decoupled from that of RELAP4 to contribute to rapid execution.

The RELAP4/FRAP-T link has been structured in modular fashion to permit independent modification to each code. RELAP4, FRAP-S and FRAP-T retain their respective identities and allow for independent verification of each code. By virtue of the linked code arrangement, several new capabilities will be available that are not present in RELAP4/MOD6. Significant among these are the ability to consider the detailed thermal and mechanical effects of burnup via the FRAP-S initialization link, accurate calculations of cladding plastic deformation with strain-rate effects, and the availability of the most current material properties data from the MATPRO⁽²¹⁾ package.

The following sub-sections discuss the steady-state initialization of the FRAP-T model using FRAP-S, the RELAP4/FRAP-T link, a brief description of the mechanism of this link, and required input.

7.1 FRAP-S Link Implementation

The FRAP-S program may be used to provide the initial condition for the RELAP4/FRAP-T transient fuel rod analysis model. Since the analysis of nuclear fuel rods representing different burnup conditions may be required, the initial conditions for all rods considered at each axial location must be determined.

The process of performing a multi-rod core LOCA analysis must consider fuel rods with varying degrees of in-core exposure. This variation can include, but is not limited to, differences in power history due to the rod's core location as well as accumulated burn up. As a result, the parameters for each of the different fuel rods must be determined prior to thermal-hydraulic analysis. The method selected to determine these parameters is to perform a FRAP-S historical burn up analysis for each of the distinct fuel rods and transfer the appropriate parameters as initial conditions to the RELAP4/FRAP-T5 fuel model.

The reasons for using the FRAP-S code to provide the fuel rod initial conditions are:

1. The FRAP-S and RELAP4/FRAP-T analytical and material property models are consistent and compatible.
2. The FRAP-S and FRAP-T initialization link is presently available.

Initialization parameters that are transferred from the FRAP-S analysis to the RELAP4/FRAP-T fuel model, as a function of axial

elevation, include: clad oxide thickness, fuel densification, cladding plastic strains, cladding historical peak temperature, fuel porosity, fuel burnup, gas content, internal gas pressure, interfacial pressure, radial temperature profile, and the gas gap thickness. The above information is transferred to the RELAP4/FRAP-T fuel model at each axial elevation of each distinct fuel rod. This gives maximum flexibility to the transient fuel analysis capability.

In addition, the capability of initializing the RELAP4/FRAP-T fuel model from card input has been retained. This option is provided in the event a FRAP-S analysis of the fuel rod is not available or the user does not desire to generate such an analysis (e.g., analysis of fresh fuel).

7.2 RELAP4/FRAP-T Link Implementation

Several alternate methods for accomplishing the link were considered:

1. Allow FRAP-T to calculate all fuel rod parameters from the centerline to the cladding surface.
2. Allow FRAP-T to calculate all the fuel rod parameters except the temperature solution which would be performed in RELAP4.
3. Use only subroutines out of FRAP-T and have the main solution logic in RELAP4.

The second option was selected as the strategy for accomplishing the link. By selecting the second option, the refill/reflood fuel model analysis (the second portion of the fuel model development task) would be facilitated and no future major modifications to the link strategy would be necessary.

The coupling of FRAP-T with RELAP4/MOD7 is accomplished by using the outer surface of the cladding as the interface for RELAP4 heat transfer and hydraulic analysis. The link, however, has been designed to permit RELAP4 to perform the heat conduction calculations in the fuel rod which in turn determines the radial temperature distribution. This was done because of the future interface requirement of using the reflood moving mesh model in conjunction with the fuel model. Consequently, coding within FRAP-T for the solution of surface heat transfer and internal conduction are bypassed when the code is linked to RELAP4.

In one call to FRAP-T the behavior of up to twelve distinctly different fuel rods (e.g., varying degrees of burnup) may be computed. The individual fuel rod response returned from FRAP-T is scaled up as appropriate to represent the actual number of rods in the RELAP4 lumped slab stack.

Modeling of fuel rods is presently restricted to 12 distinctly different rods due to the limited number of RELAP4 heat slabs available to the user. Radial and axial nodalization is restricted to those currently available in FRAP-T. This is 20 axial and 20 radial mesh points. By imposing this restriction in the RELAP4/FRAP-T link, inconsistencies between FRAP-T and RELAP4 are eliminated.

Initialization of the RELAP4/FRAP-T link requires that dimensions, plenum properties, moles of gas in the fuel rod, and gas composition be input. These can either be determined through a link with FRAP-S via magnetic tape or by card input to the RELAP4/FRAP-T fuel model. Initialization of the fuel model is accomplished by iterating on centerline temperature until convergence within 1°F is attained.

To accomplish the RELAP4/FRAP-T link, several new subroutines were created and placed in the "root" segment of the RELAP4 program. This was necessary to permit adequate storage in the CDC 7600 small core memory. Figure 15 shows a flow chart of the overall link which

FIGURE 15. RELAP4/FRAP-T DIAGRAM OF SUBROUTINES

consists of the steady-state initialization and transient subroutines. As indicated, these have been divided into segments A, B and C. Figure 16 shows segment A which reads the input and calls the subroutines that perform the temperature solution on the initialization step. Figure 17 shows segment B which performs the temperature iteration to ensure that RELAP4 and FRAP-T have consistent values for temperature and thermal/mechanical properties. The transient solution is presented in Figure 18 as segment C. Modifications and new routines added to segments A, B, and C are presented in Tables VIII through X respectively. Link information is summarized in Appendix A.

7.3 Mechanics of the RELAP4/FRAP-T Link

RELAP4 models a fuel rod or group of fuel rods as an axial stack of heat slabs which have a radial mesh with internal heat generation (core heat slabs). Several options are available to the user to represent various fuel rod geometries. The crucial calculation regardless of the fuel rod geometry is the gap conductance calculation. In the RELAP4/FRAP-T link, FRAP-T calculates the change in fuel rod diameter, fuel rod internal pressure and the gap conductance. These values are passed to RELAP4 for each axial heat slab of the fuel rod. These properties are then used to calculate the RELAP4 heat conduction solution to determine the fuel rod temperature distribution. FRAP-T has been restructured to bypass its heat conduction calculation and uses an axial and radial temperature array constructed by RELAP4. All fuel, clad, and gap properties in FRAP-T are therefore based on the RELAP4 temperature array.

The fuel model also considers fuel rod integrity and the flow blockage effects if cladding rupture is predicted to occur. The RELAP4/FRAP-T link will utilize the FRAP-T failure criteria. The extent of flow blockage on a bundle basis will be calculated by RELAP4

FIGURE 16. RELAP4/FRAP-T SEGMENT A

B

FIGURE 17. RELAP4/FRAP-T SEGMENT B

C

FIGURE 18. RELAP4/FRAP-T TRANSIENT SEGMENT C

TABLE VIII

MODIFICATIONS AND ADDITIONS TO RELAP4/FRAP-T SEGMENT A

SINI: The slab initialization routine (SINI) has been modified for the FRAP-T link. The call to INTLB and subsequent input routines load the common block arrays with problem data. Approximately half way through SINI, a test is made to determine the type of fuel model selected.

A RELAP/FRAP-T link causes values to be assigned to the link common blocks and returns to RELAP4 to call PLNTC. Calculations beyond the test in SINI are not executed at this stage of initialization.

TABLE IX

MODIFICATIONS AND ADDITIONS TO RELAP4/FRAP-T SEGMENT B

NEW ROUTINES

- PLNTC: This subroutine was constructed to determine the pin internal pressure during the first leg of initialization and to initiate the plenum calculation (PLNT). Once FRAP-T is called, RELAP4 replaces the pin pressure calculation with the FRAP-T pin pressure.
- PTPC: This subroutine tests for convergence of the centerline temperature. The temperature must converge to within 1°F in 144 iterations.
- SINIF: All heat slab calculations not performed in SINI are completed in SINIF. SINIF also adjusts the fuel rod thermal conductivity based on the last temperature profile. The slab surface heat flux is adjusted due to cladding deformation.
- FRAP-T: The call to FRAP-T is made between PLNTC and PTPC. FRAP-T returns pin pressure, cladding deformation, and gap conductance.

MODIFICATIONS

- TKANDC: TKANDC has been rewritten to work with either the Evaluation Fuel Model (EM) or the Best Estimate FRAP-T link.
-

TABLE X

MODIFICATIONS TO RELAP4/FRAP-T SEGMENT C

SLABHT: FRAP-T is currently called every heat transfer time step. Changes in fuel rod diameter due to swelling are used by SLABHT to recalculate the surface heat flux.

based on the differential pressure across the clad at the time failure is predicted. This model is the same as that used in the MOD6 flow blockage calculation.

The following sections examine the gap conductance, swelling, pin pressure, rupture, flow blockage, and fuel and clad thermal properties. More detailed information of each of these models is given in the FRAP-T4 User's Manual⁽²⁰⁾.

7.3.1 Gap Conductance. FRAP-T returns a gap conductance in units of $(\text{BTU}/\text{sec}\cdot\text{ft}^2\cdot^\circ\text{F})$ as a function of fuel rod number and axial heat slab location. RELAP4 multiplies the gap conductance by the cold state gap thickness and performs the heat conduction calculation using this effective gap conductivity.

The FRAP-T code uses two gap conduction models:

1. a modified Ross and Stoute model,
2. the MacDonald-Broughton model.

The Ross and Stoute gap conductance model is recommended for pressurized fuel rods.

The gap conductance is determined from the gas inventory, the average gap temperature (from RELAP4) and the gap thickness. All properties other than the temperatures are determined by FRAP-T.

7.3.2 Fuel Rod Diameter Calculation. Changes in the fuel and cladding diameters for each axial elevation are calculated by the FRAP-T models. RELAP4 temperatures for each radial and axial position are passed to FRAP-T from which diametric changes due to thermal expansion, cracking, and elastic and plastic deformation are calculated. Increased or decreased rod surface area due to diametric

changes computed by FRAP-T are used in the calculation of the heat transfer to the fluid in RELAP4. The heat fluxes are therefore recalculated in RELAP4 for each heat slab after the call to FRAP-T. The interface between RELAP4 and FRAP-T is therefore based on the fuel rod surface boundary conditions allowing FRAP-T to determine conditions inward from the cladding surface.

7.3.3 Pin Pressure. Fuel rod pin pressures are calculated by both RELAP4 and FRAP-T during the first iteration of initialization. This calculation is necessary to provide RELAP4 with an initial pressure estimate. Once the call to FRAP-T has been executed, the pin pressures are reset to those calculated by FRAP-T. While RELAP4 utilizes the FRAP-T model it assumes the rod pressure to be uniform and equal to the plenum pressure.

7.3.4 Clad Rupture and Flow Blockage. The FRAP-T program calculates cladding failure and returns the fuel rod number and the axial position of the rupture. The cladding integrity is based on the FRAP-T mechanical properties and failure criteria and is discussed in detail in the FRAP-T4 User's Manual. The failure flag passed into RELAP4 indicates that the flow blockage calculation should be performed by RELAP4. The extent of flow blockage is based on a user specified input table of percent flow blockage versus differential pressure across the clad at rupture. The differential pressure is based on the FRAP-T pin pressure at the axial location where failure is predicted and the pressure in the associated hydraulic volume.

7.3.5 Fuel and Clad Thermal Properties. The fuel and clad thermal properties used in the RELAP4/MOD6 best estimate fuel model are entered through the RELAP4 input data stream (Cards 18XXYY and 19XXYY). To provide a consistent set of material properties for FRAP-S, FRAP-T and RELAP4, the thermal properties are determined from the MATPRO 10 subroutines package. This package provides values for

fuel and clad thermal conductivity and heat capacity. A routine calculates the material properties given the temperature of the fuel or clad location since the properties are temperature dependent.

7.4 Fuel Rod Input

The RELAP4/FRAP-T link requires fuel model input data for both FRAP-T and RELAP4. The FRAP-T and RELAP4 inputs require fuel rod geometry and data to initialize the pin pressure. Much of this data is redundant but at present must be included in the input to each code. As a future task, effort to produce a single consistent set of input will be performed. Part of this task has been accomplished by modifying the FRAP-T input data stream to minimize the amount of information necessary to run a fuel rod problem. These modifications were made to permit a user with limited knowledge of fuel rod modeling to construct and perform a RELAP4 thermal-hydraulic analysis including a fuel pin model.

RELAP4/MOD7 continues to use the Core Slab Input Data Cards (cards 16XXXY) to provide information for the pin swelling logic, pin pressure and the clad failure calculation. The slab geometry for the core heat slabs is entered on the Slab Geometry Data Cards (card 17XXYY) and the number of radial nodes is limited to a maximum of 20 to provide consistency between RELAP4 and FRAP-T. Also a maximum of 20 axial heat slabs per fuel rod is imposed to maintain consistency. FRAP-T and RELAP4 should utilize the same radial mesh and heat slab lengths to preclude inconsistencies between FRAP-T and RELAP4 nodalization. Thermal conductivity and volumetric heat capacities for the fuel are calculated in RELAP4/FRAP-T from subroutines in MATPRO 10. The user must continue to enter values for other materials present in the RELAP4 problem. Section IV identifies the redundant fuel rod variables required by RELAP4/MOD7. RELAP4 retains the EM fuel model option and requires input as specified in the

RELAP4/MOD6 User's Manual⁽²⁾ if this option is selected. When the EM fuel is model used, the FRAP-T input data cards should not be included with the RELAP4 problem input deck.

The FRAP-T input data stream has been modified to allow a minimum amount of information to perform a fuel rod analysis. Multiple fuel rods are accounted for by entering a FRAP-T "deck" for each RELAP4 stack and must be in the same order as the rods input on the RELAP4 Core Slab Input Data Cards (cards 16XXXY). Appendix B outlines the various FRAP-T input cards required to perform a RELAP4/FRAP-T fuel rod calculation.

8. VOLUME AVERAGE MASS FLOW RATE AND MOMENTUM FLUX

Alternate calculations have been developed for volume average mass flow rate and momentum flux terms. In addition, junction input has been modified to render the calculation of average volume mass flow rate independent of junction orientation. These changes are discussed in the following subsections.

8.1 Alternate Calculation of Volume Average Mass Flow Rate

A primary use of the volume average mass flow rate $\bar{W}_V$ is in the calculation of wall friction and momentum flux terms which appear in

RELAP4 as $\frac{\bar{W}_V^2}{\rho_V A_V}$ which for homogeneous flow is equivalent to $\frac{\rho_V \bar{Q}_V^2}{A_V^2}$

where $\bar{Q}_V/A_V$ is the average volume velocity. The RELAP4 default calculation of volume average mass flow rate is described in the RELAP4/MOD5 User's Manual⁽¹⁾ and is a weighted average of inlet and outlet junction mass flow rates. When phase velocity differences or density gradients are predominant an average based upon junction velocities is preferable. Such an average is defined as

$$\bar{W}_V = \frac{\rho_V}{2} \left[\sum_{\text{INLETS}} (W_L/\rho_L + W_g/\rho_g) + \sum_{\text{OUTLETS}} (W_L/\rho_L + W_g/\rho_g) \right] \quad (91)$$

which is the arithmetic average of the inlet and outlet volumetric flow rates times the average volume density. This alternate calculation of volume average mass flow rate is selected if IDLSKE is input as a non-zero negative number on input card 060009 (See Section IV).

8.2 Generalized Junction Orientation for the Calculation of Volume Average Mass Flow Rate

RELAP4 has traditionally defined volume inlet (or outlet) as a junction which terminated (or originated) in the volume. In terms of

the RELAP4 junction input, volume IW1(J) is the inlet for junction J and volume IW2(J) is the outlet of junction J. Junction J, is then located at the inlet end of volume IW2(J) and at the outlet end of volume IW1(J). In order to provide greater flexibility to the RELAP4 user, the junction input has been revised so that a negative number input for IW1 will locate the junction at the inlet end (instead of the outlet end) of the volume. Similarly a negative input for IW2 will locate the junction at the outlet end of the volume instead of the inlet end.

8.3 Alternate Calculation of Momentum Flux

For MVMIX = 0 on the junction input data cards, RELAP4 will calculate the momentum flux terms as

$$\frac{1}{\rho_{IW1}} \left(\frac{W_{IW1}}{A_{IW1}} \right)^2 - \frac{1}{2\rho_J} \left(\frac{W_J}{A_J} \right)^2 + \frac{1}{2\rho_{J+}} \left(\frac{W_J}{A_J} \right)^2 - \frac{1}{\rho_{IW2}} \left(\frac{W_{IW2}}{A_{IW2}} \right)^2 \quad (92)$$

where volume IW1 is the inlet to the junction and IW2 is the outlet from the junction, J.

By inputting IDLSKE less than -1 on input card 060009, the momentum flux terms will be calculated as

$$\frac{1}{2\rho_{IW1}} \left(\frac{W_{IW1}}{A_{IW1}} \right)^2 - \frac{1}{2\rho_{IW2}} \left(\frac{W_{IW2}}{A_{IW2}} \right)^2 \quad (93)$$

9. SPECIAL FEATURES

This section lists several features which have been added to the code to correct deficiencies, improve capabilities and enhance user convenience.

9.1 Fill and Heat Exchanger Data From Tape.

The FORTRAN units and data files used in MOD7 are the same as those used in MOD5 (Section 5.2.2, RELAP4/MOD5 User's Manual), with the following exceptions:

- a. Data for fill tables may be read from FORTRAN Unit 23.
- b. Data for heat exchanger tables may be read from FORTRAN Unit 24.

This section explains how to use these FORTRAN Units.

Fill and heat exchanger data tables may be entered into the RELAP4 program from tape, rather than cards, to facilitate handling of data curves with large numbers of points. In order to utilize this option, the user specifies on the ordinary card input that 1000 or more points are to be included in the given table. For a heat exchanger, the first data point in the table must be supplied on the card input; for a fill, no table data points need be supplied. All other input information for heat exchangers and fills is supplied in the normal manner. A maximum of 20 fill tables and 99 heat exchanger tables from tape is allowed.

Fill table data is input from FORTRAN unit 23 (TAPE23) and heat exchanger data from FORTRAN unit 24 (TAPE24) when the tape data options are used. Fill flow mass flux data must be in lb/sec-ft^2 (the data is multiplied by the appropriate junction area to obtain mass flow rate).

The tables are read into the program 30 points at a time. The 30 points for a given table are contained in one logical record on the tape. The data in the logical record is arranged in the same way as it is in core.

For fills with $ITYPE \leq 3$, each point consists of an ordered pair (time or pressure, and mass flux), making a total of 60 words per logical record. The first 30 words of the record are the times or pressures, arranged in ascending order. The next 30 words are the corresponding flow rates. For $ITYPE > 3$, an additional 30 words, corresponding to the enthalpies, must be included to complete the record.

For heat exchangers, each point consists of an ordered pair (normalized power, and time), for a total of 60 words per logical record. They must be arranged as $P_1, T_1, P_2, T_2, P_3, T_3, \dots, P_{30}, T_{30}$, where P_n is the normalized power corresponding to time T_n . The T_n are in ascending order.

If N fill tables are to come from tape, then N logical records at a time, corresponding to each of the N fill tables, will be read from the tape. The fill numbers corresponding to the N fills must be in ascending order, but need not be consecutive. This allows use of ordinary fills along with fills that utilize tape data. Whenever a given point lies beyond the last point of a table, the next set of N fill table records are read from tape. If the point still lies beyond the table, the next set of N table records are read in, and so on until the table data for the given fill extends beyond the given point, or until an end of file on the tape is detected. If an end of file is detected, an informative message is issued, and execution continues with the last set of data to be read in. The data between logical records for a given fill may overlap.

For example, suppose a problem requires 5 fills. Fills 1, 3, and 5 use tabular data read from tape, and fills 2 and 4 use table data supplied in the normal manner from card input. The first logical record on the tape corresponds to the first 30 data points for fill 1, the second logical record on the tape contains the first 30 data points for fill 3, and the third logical tape record contains the first 30 data points for fill 5. Logical record 4 would contain 30 more points for fill 1, as would logical records 7, 10, 13, 16, etc. Similarly, logical records 5, 8, 11, 14, ..., would each contain sets of 30 data points for fill 2, and logical records 6, 9, 12, 15, ..., would each contain sets of 30 data points for fill 3. If logical record 2 has times ranging from 0. to 0.2 sec., and logical records 1 and 3 have times ranging from 0. to 0.5 sec., then as soon as transient time exceeds 0.2 sec., logical records 4, 5, and 6 will be read into the data tables for fills 1, 3, and 5 (assuming the three fills are all tripped on at time 0.), replacing the previous table data for these fills. In order to ensure continuity in the table data, records 4, 5, and 6 would begin at times prior, or equal, to 0.2 sec. As soon as transient time again exceeds the largest time in one of the tables for fills, 1, 3, or 5, the next three logical records will be read in, and so on until the end of transient or end of file on the tape. Fills 2 and 4 do not influence the tape reading. Tape data for heat exchangers is handled in the same manner as that for fills.

If less than 2000 points are specified on the card input for a given table, the tape data for that table will be printed out as it is read in. If 2000 or more points are indicated on the input, the tape data will not be printed.

9.2 Non-Uniform Fuel Pellet Power Distribution

This option allows the user to specify (cards 174XXY) radially non-uniform power distribution in the first radial region (i.e., fuel)

of core heat slabs. For each radial node, he supplies a power fraction (node power/average power in radial region 1) for the incremental slab volume associated with that node.

9.3 Peak Temperature Edit

In order to facilitate the determination of the peak cladding temperature produced by a RELAP4 run, two new temperature values are printed out with each time step summary. These temperatures may prove particularly convenient for users who are making statistical type RELAP4 runs and who are mainly interested in the peak cladding temperature.

At each time step summary both the maximum surface temperature since the last time step summary and the maximum surface temperature for the entire run are printed. The former capability allows the user to determine the time interval during which the maximum temperature occurred without the need for plot output.

The coding for the maximum temperature calculation is in subroutine "SENSE" and the printout is done in subroutine "ETSCON". An example of the printed output is shown in Figure 19.

9.4 CHF Correlation

An additional Critical Heat Flux correlation has been added as an option in RELAP4/MOD7. The correlation was developed using statistical regression analysis of a large collection of appropriate critical heat flux data.

The correlation will be used if the value of the 10's digit of IMCL on the Heat Slab Data Card 15XXXY is set equal to 4. If this correlation is chosen it is necessary to input the maximum radial power factor in the channel in field 21, of the same card.

FIGURE 19. EXAMPLE OF OUTPUT WITH NEW MAXIMUM TEMPERATURE EDIT

EXPP4/C G 10/31/77 (24) NEW EXPERIMENTAL RELAP4 TYPE PROGRAM CONFIGURATION CONTROL NO
SEMICSCALE S-03-02 MODEL 2 ENT3HTS3 C3/23/78

CPU TIME = 23.39

TIMING EDIT TOTAL TIME = 24.95 SEC

SUBROUTINE NAME	CPU TIME(SEC)	PERCENT	NO. OF CALLS
MAIN	0.000000	0.00	1
INITIAL	0.000000	0.00	1
READ	0.000000	0.00	1
WRITE	0.000000	0.00	1
END	0.000000	0.00	1
...	...	...	...

MAIN	.01	.02	1
INPUT	.42	1.68	1
TRAN	1.82	7.31	1
BAL	1.38	5.52	272
EGIT	2.01	8.07	272
FLOSRH	.14	.56	271
TSTP	.03	.12	271
PREW	.24	.96	271
PUMPS	.01	.06	273
SLABHT	18.71	75.60	272
NIFTE	.17	.69	271
HTS123	0.00	0.00	0
TEMP	C.00	0.00	0
TWFND	C.00	0.00	0

TIME STEP CONTROL SUMMARY

NUMBER OF TIMES TEST CONTROLLED TIME STEP

UPPER LIMIT	LOWER LIMIT	PRESSURE CH. /VOLUME	ZERO FLOW CROSSING	MASS CH. /VOLUME	ENERGY CH. /VOLUME	MASS VOL. FLOW	SAT. LINE CROSSINGS	OTHER--LO MASS DEPLETE, AIR CH
0	0	0	0	1	0	0	0	0

VOLUMES CONTROLLING PRESSURE CHANGE MINIMUM
(VOLUME INDEX TIMES CONTROLLING)

1 0 2 0 3 0

JUNCTIONS CONTROLLING FLOW CROSSING MINIMUM
(JUNCTION INDEX TIMES CONTROLLING)

1 0 2 0 3 C

SELECTED PROGRAM PARAMETERS

GAUSSIAN THIS EDIT	ELIMINATION CALLS	NUMBER OF THIS EDIT	TIME STEPS
0		1	

MAX HEAT SLAB TEMP THIS EDIT	MAX HEAT SLAB TEMP COMPLETE RUN
1514	1514

STAGP SONIC CHECK

C

HEAT TRANSFER MODE SUMMARY

[illegible]

The correlation is given below:

$$\begin{aligned}
 q_{CHF} (10^{-6}) &= 40.4773 * [G(10^{-6})]^{0.0595} \\
 &* (X_e + 1)^{1.0775} \text{ALOG}(X_e + 1) * (X_e + 1)^{-4.3238} \\
 &* \text{RPF}^{-0.7968} * p^{-0.5564}
 \end{aligned}
 \tag{94}$$

where:

- q_{CHF} = calculated critical heat flux (Btu/hr-ft²)
- G = mass flux (lbm/hr-ft²)
- X_e = equilibrium quality
- P = pressure (lbf/in²)
- RPF = normalized maximum radial power factor for channel being modeled.

III. PROGRAMMING IMPROVEMENTS

This section documents several programming improvements which are included in MOD7, Version 2. These changes facilitate or, indeed, make possible the insertion of the MOD7 model improvements into the code. The specific programming changes include the following:

- (1) the movement of input processing storage to large core memory (LCM),
- (2) the conversion to the CDC update program, and
- (3) a restructuring of RELAP4 to provide more storage.

The discussion of these programming changes in the following sections will include the purpose of a given change, a description, and the method of implementation.

1. CONVERSION TO LARGE CORE MEMORY

1.1 Purpose

The purpose of moving the input processing array to large core memory (LCM) in MOD7 is to eliminate one cause of increased running time as a function of problem size. A history of the development of this problem and its solution in MOD7 follows.

As RELAP4 has grown , a constant effort has been required to fit the program into available small semiconductor memory (SSM) on the CDC computer. In fact, the very first version of RELAP4 which was converted to the CDC 7600 (MOD3, Update 55) required all available SSM. Despite the fact that RELAP4 has approximately doubled in size since that time, RELAP4 still fits into available SSM. This has been accomplished in versions through MOD5, Update 2, with no appreciable increase in running time. For MOD6, Update 4, it was accomplished with no appreciable increase in running time for most problems. However, for some large problems, and particularly for problems requiring the use of the best estimate fuel rod model, it was accomplished only at the expense of increased execution time. The cause of this increased running time was due to the inefficiency of the CDC segmentation loader in bringing in segments of coding during the transient calculation.

For some problems in MOD6, the increase in running time was being caused simply because the largest input processing segment exceeded the length of the transient segment. This required that routines normally in the root segment be overlaid with each other simply to allow input processing, even though there was sufficient SSM available for the transient calculation, or at least for a more efficient overlaying of transient coding.

Since the main reason the initialization segment sometimes became larger than the transient segment was because of the amount of input data being processed, the SSM input processing array needed to be moved into LCM. In addition to the existing need to put the input data array into LCM, the anticipated increase in the amount of input data that RELAP4 will need to process for MOD7 made this reduction in SSM storage requirements essential to the continuing development of RELAP4. The main reason that the integral code will require additional input processing is that the blowdown nodding and all renodalization information for refill and reflood will be required at problem initialization. Reducing the SSM storage requirements for initialization allows additional input to be processed and reduces computer time for large problems.

1.2 Method

The first step in converting the input processing array to LCM was to create special LCM versions of the environmental subroutines INP2, INP8, INP9, INPUPK, LINK, and MODER and to move them from the environment library to the RELAP4 source. Next the calls to the dynamic storage allocation routines were changed to reserve LCM instead of SSM space for the input data.

The bulk of the work was to change variable names in RELAP4 to reference LCM rather than SSM variables and to insert additional LEVEL 2 statements for the variable references. Changes were also made to maintain the restart and tape edit capabilities.

2. CONVERSION TO THE CDC UPDATE PROGRAM

2.1 Purpose

The additional capabilities of the CDC update program facilitate massive programming changes such as required by the RELAP4/MOD7 renodalization and restructuring tasks. UPD, the INEL update program, was used throughout the RELAP4/MOD6 development in order to maintain compatibility with earlier versions of the program with respect to card numbering. Advantages of converting to the CDC update program in order to facilitate the MOD7 programming effort considerably outweighed the UPD update program's advantage of compatibility with earlier versions. Furthermore, the break between MOD6 and MOD7 during which more effort is being placed on model development and design tasks rather than on merging new models into the program, provided an opportune time for making such a change.

A list of the specific ways in which the conversion of RELAP4 to CDC update program will promote efficient use of manpower and computer resources follows.

- (1) Ease in changing common blocks by virtue of the *COMDECK feature of CDC update.
- (2) Ease in copying sections of existing programming into the new renodalization routines.
- (3) A form of dynamic dimensioning for heat slabs by a simple update and compile change prior to program execution.
- (4) The difficulty of merging updates from different contributors is reduced (the different updates may be "stacked" one on top of another).

- (5) A unique identification of update cards and those responsible for the update changes is possible using the CDC update program. This will allow rapid identification of changes for use in debugging and checkout and will provide additional documentation.
- (6) The CDC update program normally requires considerably less execution time than the UPD update program.
- (7) The CDC update program library for RELAP4 uses only 60% as much disk space as does the source file previously used.

2.2 Method

In order to understand the conversion process to the CDC update, some background information is presented.

The UPD update program places a deck name in columns 73 through 76 and a sequence number in columns 77 through 80 of each 80 character source card. FORTRAN cards which are intended only for IBM systems are labeled with the alphabetic character "A" in column 1. Those cards which are intended only for CDC systems are labeled with a "B" in column 1. In order to obtain a compilable source, these A's and B's must be converted to blanks and C's respectively, for IBM, and vice versa for CDC.

The CDC update program allows up to 18 columns of card identification, in addition to the usual 72 columns of FORTRAN data, including an alphanumeric deck or correction set name and a sequence number. This, in conjunction with an additional preprocessing routine for the input to the CDC update program, allows a more complete type of configuration control than possible before. Since the conversion to the CDC update program, each correction card to RELAP4/MOD7 has been individually identified by deck name, MOD and update number, and the initials of the individual responsible for the change.

In order to convert to the CDC update program a special program was written to insert `"*DECK"` cards before each subroutine with a deck name generated from the existing UPD deck name. This program also converted the letter "A" in column 1 to a dollar sign and the letter "B" in column 1 to a zero. These letters were converted in the above manner in order to create a unique identification of the IBM and CDC source differences which would also allow a direct compilation of the source cards. Previously, when using UPD, it was necessary to process the source file for every update using a special program which, for the CDC, converted the "A"'s to "C"'s and "B"'s to a blank character. The lack of need for conversion of the special character on the CDC source is possible since the zero character in column 1 is ignored and the dollar sign in column 1 denotes a comment card. Conversion back to a source readable by the IBM will simply require a conversion of the dollar sign to a blank and zero to a "C".

In order to make use of the CDC update common deck feature, it was necessary to replace existing common blocks with `"*CALL"` directives as well as to create a master copy of each common block in the form of a common deck (`CØMDECK`). In addition, nested common decks were formed for the volume and junction variable blocks in order to avoid the display of the entire set of comments and equivalence statements, when a subroutine required only a few of these variables. Thus each volume and junction variable has its own common deck within the larger common deck.

Note that it is important that the nested common decks precede the containing common decks on the program library. If they do not, when changes are made to the nested common decks, all subroutines containing them may not appear on the compile file output.

3. RESTRUCTURING OF RELAP4

3.1 Purpose

In order to provide sufficient core storage for the entire fuel rod model program, FRAP-T, to be inserted into RELAP4, a restructuring of parts of RELAP4 was required.

3.2 Method

Since RELAP4 without a fuel rod model can, for large problems, require virtually all of the 160 K octal words of SSM (small semiconductor memory) available on the INEL CDC computer, and since FRAP-T requires about 140 K octal words of SSM, FRAP-T cannot simply be appended onto the end of RELAP4. Any attempt to overlay FRAP-T with RELAP4 in the existing (i.e. MOD6) structure of RELAP and to call FRAP-T from the current location of the much smaller MOD6 best estimate fuel model would result in the destruction of existing RELAP4 executable instructions. Thus it was necessary to assure both that the FRAP-T fuel rod model could be called from the root of RELAP4 and that the size of this root segment be reduced to a minimum size (less than 20 K octal words). For these reasons and in order to maintain the same relative order in the calling sequence for the new fuel rod model as for the earlier fuel rod model calls, several subroutines were split into new routines and the calls to these new routines were moved into the main calling routine. Simultaneously, the modularity of RELAP4 was somewhat improved. Specifically, subroutine INPUT was divided into subroutines INAA and INAB, subroutine INMAIN into INTLA and INTLB, subroutine TRAN into TRANI, TRANA, and TRANB, and subroutine INHEAT into INHEAT and INSIKI. At the same time changes were made to the segmentation loader directives to take advantage of the restructured routines.

Similar changes were made to the transient structure to support the insertion of FRAP-T and to improve the functional modularity of

RELAP4: Subroutine FLOSRH was divided into subroutines TRANA, SLABC, FLOSRH, and NIFTC. One effect of the division of FLOSRH was to separate the heat transfer and hydraulic advancement functions from a routine of less global significance. Associated cleanup or efficiency improvement tasks were made in conjunction with the rest of the RELAP4 restructuring work. These include converting the timer coding into two subroutine calls (ZTMA and ZTMB) to save storage and to modify the current timer call locations to obtain more useful statistics. Also, changes were made to both RELAP4 and PRELOAD to allow the deletion of the horizontal slip routines for saving of about 1 K (octal) words when this option is not required.

IV. INPUT INSTRUCTIONS

This portion of the RELAP4/MOD7 User's Manual presents the details of setting up and entering the system model to be evaluated. The input card format and arrangement is presented in depth, including not only cards for data but also those for editing and restarting.

1. PROGRAM DESCRIPTION

The RELAP4/MOD7 computer program is written in FORTRAN IV and is operational on the CDC 7600 at INEL. The program uses single precision (60 bits) floating point arithmetic.

A RELAP4/MOD7 calculation consists of a series of time advancements. In each advancement the sequence of calculations is:

1. time step size
2. heat transfer
3. hydraulic effects
4. integration over time
5. thermodynamic balance
6. reactor kinetics
7. editing.

Calculated results are provided in printed form at time intervals specified by the user. In addition to the printed output, a user will normally choose to generate a combination plot-restart file. This file contains two types of information intermixed. The plot information is frequently placed on the file to allow later retrieval by the PLOTR4M program described in Section IV-2.5. The plot information may also be retrieved by a subsequent RELAP4/MOD7 calculation to supply fluid conditions, fluid flows, and reactor power. In addition, the plot information may be retrieved for the purpose of making detailed printed output at different time intervals than originally chosen. The restart information is placed infrequently on the file. Its purpose is to allow continuation of the RELAP4/MOD7 problem at a later time should the calculations be interrupted. MOD7 restarting procedures are described in Section IV-2.4.

2. INPUT DATA

This section provides complete descriptions of the data deck organization, data card summary, input for tape editing, and input for restarting. This section repeats information from the RELAP4/MOD5 User's Manual and the RELAP4/MOD6 User's Manual. The evaluation model options were not thoroughly checked for MOD7 (Version 2). The user should use MOD5 or MOD6 for evaluation model problems.

2.1 Data Deck Organization

A RELAP4 problem input consists of a title card, comment cards (optional), data cards, and a terminator card. A listing of the cards is printed at the beginning of each RELAP4 problem. The order of the title, data, and comment cards is unimportant except that only the last title card or the last data card having a duplicate data card number will be used.

When a card format error is detected, a line containing a dollar sign (\$) located under the character causing the error and a comment giving the card column of the error are printed. An error flag is set such that input processing continues, but the RELAP4 problem is aborted at the end of input processing. Usually another error comment is produced during input processing when the program attempts to process the erroneous data.

2.1.1 Title Card. A title card must be entered for each RELAP4 problem. A title card is identified by an equal sign (=) as the first nonblank character. The title (the remainder of the title card) is printed as the second line of every page. The title card is normally placed first in the problem.

2.1.2 Comment Cards. An asterisk (*) or a dollar sign (\$) appearing as the first nonblank character identifies the card as a comment card. Blank cards are treated as comment cards. The only processing of

comment cards is the printing of contents. Comment cards may be placed anywhere in the input deck.

2.1.3 Data Cards. The data cards contain a varying number of fields which may be integer, floating point, or alphanumeric. Blanks preceding and following fields are ignored.

The first field on a data card is a card number which must be an unsigned integer. If the first field has an error or is not an integer, an error flag is set. Consequently, data on the card are not used and the card will be identified by the card number in the list of unused data cards. After each card number and the accompanying data are read, the card number is compared to previously entered card numbers. If a matching card number is found, the data entered on the previous card are replaced by the data on the current card. If the card being processed contains only a card number, the card number and the data entered on the previous card are deleted. If a card causes replacement or deletion of data, a statement is printed indicating that the card is a replacement card.

Comment information may follow the data fields on any data card by initiating the comment with an asterisk or dollar sign.

A number field is started by either a digit (0 through 9), a sign (+ or -), or a decimal point (.). A comma or a blank (with one exception subsequently noted) terminates the number field. The number field has a number part and, optionally, an exponent part. A number field without a decimal point or an exponent is an integer field; a number field with either a decimal point, an exponent, or both is a floating-point field. A floating-point field without a decimal point is assumed to have a decimal point immediately in front of the first digit. The exponent denotes the power of ten to be applied to the number part of the field. The exponent part has an E or D, and a sign (+ or -) followed by a number giving the power of ten. These rules for floating-point numbers are identical to those for entering data in FORTRAN E or F format fields except that no blanks (with one exception) are allowed between characters. Floating-point data punched by FORTRAN

programs can be read. To permit reading of floating-point data, a blank following an E or D denoting an exponent is treated as a plus sign. Acceptable ways of entering floating-point numbers, all containing the quantity 12.45, are illustrated by the following six fields:

12.45,+12.45 1245+2 1.245+1,1.245E 1 1.245E+1

A field starting with a letter is alphanumeric. The field is terminated by a comma, a blank, or the end of the card. All characters except commas and blanks are allowed.

2.1.4 Terminator Cards. The input data for RELAP4 problems are separated by slash cards. The final problem is terminated by a period card instead of a slash card. The period card also serves as the separator between problem sets. The slash and period cards have a (/) and (.), respectively, as the first nonblank character. Comments may follow the slash and period on the slash and period cards.

When a slash card is used as a terminator, the list of card numbers and associated data used in a problem is passed to the next problem. Cards entered for the next problem are added to the passed list or act as replacement cards depending on the card number. The resulting input is the same as if all previous slash cards were removed from the input of the problem set. The user should use the slash card with care and carefully check the output to confirm that the option has been used correctly.

When a period card is used as a terminator, all previous input cards are erased before the input to the next problem is processed.

The ability to execute multiple problems and sets of input data is limited by magnetic tape usage. Only one of the problems can use restart capability if the restart file has multiple reels, and only one of the problems can generate a tape. Because of the limitations and the length of RELAP4 runs, the multiple problem and set capability will probably be of use only for input data checking.

2.2 Data Card Summary

In the following description of the data cards, the card number is given with a descriptive title of the data contained on the card. Next an explanation is given of any variable data (such as volume number) which are included in the card number. Then, the order of the data (W1, W2, . . .), the format (I, R, or A), the variable name, and the input data requirements are given where applicable. The format of the field (integer, real or floating, or alphanumeric) is indicated by I, R, or A, respectively. An "RST" following the card number implies that this card may be used in restart jobs in the same format to change previously set options. An "EM," "FLOOD," or "CONT" following the card number implies that the card is used only for the evaluation model (ISPROG = 1, or nonstandard-EM, IPROGM = 1), the FLOOD program (ISPROG = 2), or the containment program (ISPROG = 3), respectively. (See the RELAP4/MOD5 User's Manual, Volume I, Section 3.2, for differences between the program options.)

(1) Title Card. The last title card entered for each case must have at least one nonblank character in columns 1-72.

(2) Problem Dimensions Data Card 010001. (See Volume I, Section 3.1 of RELAP4/MOD5 Manual.)

W1-I	LDMP	=	Tape control (only one tape may be generated during a job). (-3 ≤ LDMP ≤ 999)
0		=	no tape used
-1		=	store restart information on FORTRAN Unit 4
-2		=	Store restart and plot information on FORTRAN Unit 4

-3 = edit the tape on FORTRAN Unit 3

N = restart at restart number N using
the tape on FORTRAN Unit 3

W2-I NEDI = Number of minor edit variables desired.
($0 \leq \text{NEDI} \leq 9$)

W3-I NTC = Time step card count. ($1 \leq \text{NTC} \leq 20$)

W4-I NTRP = Number of trip control cards.
($1 \leq \text{NTRP} \leq 20$)
For combination trips: ($-20 \leq \text{NTRP} \leq -1$)

W5-I NVOL = Number of control volumes. ($1 \leq \text{NVOL} \leq 99$)

W6-I NBUB = Number of bubble-parameter sets.
A set may be used in several volumes.
($0 \leq \text{NBUB} \leq 5$)

W7-I NTDV = Number of time-dependent volume descriptions
on cards. ($0 \leq \text{NTDV} \leq 5$)

W8-I NJUN = Number of junctions or flow paths.
($1 \leq \text{NJUN} \leq 100$)

W9-I NPMPC = Number of pumps. ($0 \leq \text{NPMPC} \leq 12$)

W10-I NCKV = Number of check valve types. A
parameter set may be used for several
junctions. ($0 \leq \text{NCKV} \leq 10$)

W11-I NLK = Number of normalized-leak-area-versus-
time curves. May be used many times.
($0 \leq \text{NLK} \leq 5$)

W12-I	NFLL	=	Number of fill system curves. May be used many times. ($0 \leq \text{NFLL} \leq 20$)
W13-I	NSLB	=	Number of heat slabs. ($0 \leq \text{NSLB} \leq 50$)
W14-I	NGOM	=	Number of heat slab geometries. ($M \leq \text{NGOM} \leq 20$) For $\text{NSLB} > 0$, $M = 1$; for $\text{NSLB} = 0$, $M = 0$.
W15-I	NMAT	=	Number of heat slab materials. ($M \leq \text{NMAT} \leq 7$) For $\text{NSLB} > 0$, $M = 1$; for $\text{NSLB} = 0$, $M = 0$.
W16-I	NCOR	=	Number of core sections. ($0 \leq \text{NCOR} \leq \text{NSLB}$)
W17-I	NHTX	=	Number of data sets for heat exchangers without conduction. ($0 \leq \text{NHTX} \leq 99$)
W18-I	ISPROG	=	Program option flag.
		0	= RELAP4 with minimum controls (standard RELAP4)
		1	= RELAP4-EM (does not fully comply with Appendix K of <u>10 CFR, Part 50</u>)
		2	= RELAP4-FLOOD
		3	= RELAP4-CONTAINMENT
		4	= Best estimate blowdown
		5	= Best estimate reflood

104 = Best estimate blowdown input
checking

105 = Best estimate reflood input
checking.

The use of ISPROG = 4 or 5 is the same as for ISPROG = 0 except that the program checks the best estimate criteria and fails if they are not met.

The use of ISPROG = 104 or 105 is the same as for ISPROG = 4 or 5 except that the program continues even if all criteria are not met.

When ISPROG exceeds 100, the program title will indicate that the run is a standard RELAP4 run, rather than a best estimate run.

W19-I IUNITS = Units selection flag.

1 = Input is English units and
output is English units

2 = Input is English units and
output is SI units (only
transient portion is SI,
initialization is English).

(3) Problem Constants Data Card 010002 -- RST. (See Volume II,
Section 4.2.2 (3) of the RELAP4/MOD5 Manual.)

W1-R POWER = Initial power (megawatts).

W2-R OMEGA = Implicit-explicit proportion multiplier
(dimensionless). ($0.0 \leq \text{OMEGA} \leq 1.0$)

1.0 = implicit (recommended)

0.5 = Crank-Nicolson

W3-R	PQUITL	=	Lower limit on pressure in any volume. (Default = 0.0886 psia.)
W4-R	PQUITH	=	Upper limit on pressure in any volume. (Default = 3626 psia.)
W5-R	TQUITL	=	Lower limit on temperature in any volume. (Default = 32.1°F except for contain- ment option which uses 32.0°F.)
W6-R	TQUITH	=	Upper limit on temperature in any volume. (Default = 8,540.31°F.)

(4) Program Options Card 010003. (See Volume I, Section 3.2 of the RELAP4/MOD5 Manual.) This card is optional and is ignored if ISPROG = 1 on Card 010001.

W1-I	IPROGM	=	Program type.
		0	= RELAP4 type of problem
		1	= nonstandard RELAP4-EM type of problem. (This option does not fully comply with Appendix K of <u>10 CFR, Part 50.</u>) This option bypasses EM input checking and, with ISPROG = 0, allows an EM type of calculation to be made without all EM Criteria being met.

W2-I	IEMHT	=	EM heat transfer logic flag.
		0	= do not use EM heat transfer logic
		1	= use EM heat transfer logic

W3-I IEMPS = Fuel rod model, pin swelling and flow blockage control.

0 = do not use any pin swelling or flow blockage fuel rod model

1 = include EM pin swelling and flow blockage model (a modified Ross and Stoute gap conductance model is automatically implied by choosing the EM option).

11 = use the best estimate FRAP-T fuel rod model

W4-I IEMEC = EM ECC bypass logic flag.

0 = do not include EM bypass logic

1 = include EM bypass logic

W5-I ICATHP = Metal water reaction flag.

0 = Baker-Just (EM) Zr-O_2 reaction model

1 = Cathcart-Pawel (Best estimate) Zr-O_2 reaction model.

2 = Cathcart-Pawel Zr-O_2 reaction model (lower limit of 90% confidence level on reaction rate).

3 = Cathcart-Pawel Zr-O_2 reaction model (upper limit of

90% confidence level on
reaction rate).

Part of the purpose of the input above is compliance with configuration control requirements placed on the EM option. The EM code will now check user input to ensure that all RELAP4-EM input requirements are met. The program will abort if they are not. Users who wish to make nonstandard EM type runs must set ISPROG = 0 and IPROGM = 1. The nonstandard option will definitely not meet NRC acceptance criteria and the program heading and plot titles will not identify the program as the EM. Even when all EM input checks are made, RELAP4-EM will not fully comply with the requirements within Appendix K of 10 CFR, Part 50.

(5) Preload Restart Card 010004. This card is generated by the RELAP4-PRELOAD program and should not be input by the user.

(6) Minor Edit Variable Data Card 020000 -- RST. (See Volume I, Section 3.8 and Volume II, Section 5.3.1 of the RELAP4/MOD5 Manual.) An edit variable data card is required if NEDI (on Card 010001) is greater than zero. This card specifies the variables to be printed in the minor edits. NEDI specifications must be entered. Each specification consists of an alphanumeric entry and an integer entry as follows:

W1-A	Symbol variable
------	-----------------

W2-I	Region number.
------	----------------

The symbols of available minor edit variables are as follows:

(a) Symbol Variable (with reference to volumes). (For these variables, W2 is the volume number with $1 \leq W2 \leq 99$.)

AP	Average pressure
----	------------------

TM	Total mass
----	------------

TE	Total energy
----	--------------

AT	Average temperature
AR	Average density
AH	Average enthalpy
AX	Average quality
BM	Bubble mass
ML	Mixture level
VF	Specific volume of saturated liquid
VG	Specific volume of saturated vapor
HF	Specific enthalpy of saturated liquid
HG	Specific enthalpy of saturated vapor
TS	Saturation temperature
PS	Saturation pressure
WM	Liquid mass
WQ	Power into coolant
PR	Pump speed (calculated only for pump volumes)
PT	Normalized hydraulic pump torque (calculated only for pump volumes)
WV	Average volume mass flow
AM	Air mass.

(b) Symbol Variable (with reference to junctions). (For these variables, W2 is the junction number with $1 \leq W2 \leq 100$.)

JW	Junction mass flow
JH	Junction enthalpy
JX	Junction quality
JV	Junction specific volume
TD	Total pressure differential
FD	Pressure differential due to friction
ED	Pressure differential due to elevation
PD	Pressure differential due to pump
PD	Pressure differential due to pump (calculated only for junctions connected to a pump volume)
AD	Pressure differential due to acceleration

JC	Choking index
JF	Volumetric junction flow (ft^3/sec)
DA	Inertial door angle
FV	Junction velocity
JK	Junction specific kinetic energy.

(c) Symbol Variable (with reference to heat slabs). (For these variables, W2 is the slab number with $1 \leq W2 \leq 50$.)

SL	Left surface temperature
----	--------------------------

SR	Right surface temperature
CL	Left heat transfer coefficient
CR	Right heat transfer coefficient
FL	Left heat flux
FR	Right heat flux
WL	Left heat transfer rate to coolant
WR	Right heat transfer rate to coolant
KL	Left heat transfer mode
KR	Right heat transfer mode
DL	Left critical heat flux
DR	Right critical heat flux
ST	Average slab temperature (calculated only for core slabs)
SQ	Slab fuel power (calculated only for core slabs)
DM	Depth of metal water reaction (calculated only for core slabs)
PC ^[a]	Fuel rod internal gas pressure (calculated only for core slabs)
MP	Moderator heating rate (calculated only for core slabs)
SV	Subcooled void volume (calculated only for core slabs)

[a] These edit variables are available as minor edits during the calculation and from the PLOT4M program. They are not available as minor edits from tape editing jobs.

SE Stored energy (calculated only for core slabs)

TP^[a] Fuel rod gas plenum temperature (calculated only for
core slabs).

(d) Symbol Variable (with reference to the system). (These
variables are system variables, $W2 = 0.$)

NQ Normalized power

AE Total energy added during transient

FE Total energy stored in all heat slabs

LE Total energy leaked

HE Energy removed by heat exchanger

EB Energy balance term

LM Total mass leaked

MB Mass balance

TR Total reactivity

RV Reactivity due to coolant voids

RW Reactivity due to temperature changes in coolant

RF Reactivity due to temperature changes in fuel

RC Reactivity due to control rod changes

RD Reactivity due to Doppler effect (fuel temperature)

[a] These edit variables are available as minor edits during the calculation and from the PLOT4M program. They are not available as minor edits from tape editing jobs.

P0	Power
HL	Total heat removed
RP	Reactor period
WT	Total heat transfer rate to coolant from all heat slabs.

(7) Time Step Data Cards 03XXX0 -- RST. (See Volume I, Section 3.8 of the RELAP4/MOD5 Manual.) A total of NTC (on Card 010001) cards must be entered with XXX = 001, 002, ..., NTC. Each card specifies the data for a particular calculation time interval.

W1-I	NMIN	=	Number of time steps (of size DELTM) per minor edit and number of time steps per plot tape edit (0 is interpreted as 1).
W2-I	NMAJ	=	Number of minor edits per major edit ^[a] (0 is interpreted as 50).
W3-I	NDMP	=	Number of major edits per restart tape edit (0 is interpreted as 20).
W4-I	NCHK	=	Option for time step control.

-1	=	time step control on nonlinear conditions only
0	=	time step control on linear and nonlinear conditions (recommended)
1	=	no time step control. Program uses DELTM as fixed time step size

[a] A major edit is a printing of the principal variables of interest. The user does not control which variables are printed as may be done in a minor edit.

W5-R	DELT	=	Maximum time step size (sec). (0 < DELT)
W6-R	DTMIN	=	Minimum time step size when under time step control. (0 < DTMIN < DELT) for NCHK = 1, DTMIN must be 0.0.
W7-R	TLAST	=	End of time step data interval (sec).
W8-R	ENDCPU	=	CPU time in seconds at which problem will terminate (default = 1E6). The variable is reinitialized to the default value for restart jobs. To be used only on the first time step Card 030010.

(8) Detailed Edit Card 030002 -- RST. (See Volume I, Section 3.8 of the RELAP4/MOD5 Manual.) This card is optional.

W1-I	IEVERY(1)	=	Detailed edit control as follows:
W2-I	IEVERY(2)		If = 0, there is no effect on the printed
...	...		output for the time step interval
...	...		indicated by the index, I, of IEVERY(I)
...	...		where I refers back to the XXX of Cards
...	...		03XXX0.
...	...		
...	...		If = 1, a major edit is obtained
...	...		for every actual time step for the
...	...		time step interval indicated by the
...	...		index, I.
...	...		
...	...		If = 2, a minor edit is obtained for
...	...		every actual time step for the time step
...	...		interval indicated by the index, I.
...	...		
...	...		If = 3, a minor and a major edit are obtained
...	...		for every actual time step for the time step
...	...		interval indicated by the index, I.

Note that the use of this option may result in up to DELTM/DTMIN times as much printed output as a request for a major edit every standard time step.

(9) Water Packing and Enthalpy Transport Card 030003 -- RST.

(See Volume I, Section 3.6.7 of the RELAP4/MOD5 Manual.) This card is optional

W1-I	IWPEDT	=	Maximum number of water packing edits per volume (Default = 0).
W2-R	WPTIME	=	Starting time for applying water packing fix (Default = 0).
W3-R	STCHOK	=	Set = 0 (for later use).
W4-R	TIENTH	=	Starting time for turning off the enthalpy transport model. (Default = 1E6.)

(10) Mixture Level Smoothing Card 030004 -- RST. (See Volume

I, Section 3.6.7 of the RELAP4/MOD5 Manual.) This card is optional.

W1-I	IMLCFA	=	Maximum number of mixture level crossing edits. (Default = 0.)
W2-R	XMLCFA	=	Starting time for applying smoothing for mixture level crossing. (Default = 1E6.)

(11) Miscellaneous Floating Point Data Card 030006 -- RST.

This card is optional.

W1-R	REW6	=	Output rewind option. This option allows rewinding the output unit (FORTRAN Logical Unit 6) in order to save paper when debugging. (Default = 0.)
------	------	---	---

- 0 = Do not rewind the output unit.
- 1 = Rewind the output unit after the zeroeth time step.
- >0 = Rewind the output unit at transient time REW6.

W2-R DTHMX = Heat transfer solution time step control indicator.

- 0 = The heat transfer advancement is made every hydraulic time step.
- >0 = Heat transfer time step size remains constant during the complete run. This option is not normally recommended.
- <0 = The program will calculate the size of the heat transfer time step but will always use a value less than or equal to |DTHMX|. DTHMX must be between -0.1 and 0.1.

W3-I IFLG = Heat transfer time step control type indicator.

- 0 = Temperature-time derivative.
(recommended)
- 1 = Flux time derivative.

(12) Miscellaneous Integer Data Card 030007 -- RST. This card is optional.

W1-I^[a] IDTRP = Action to be taken. ($1 \leq \text{IDTRP} \leq 20$)

1 = End of problem

IDTRP corresponds to entry on pertinent card elsewhere in input where trip action is desired. For this option a requirement is that $\text{IDTRP} = \text{IDSIG} = 1$ on the first trip card.

W1-A^[a] IDTRP = Alphanumeric identifier for this trip card. For this option a requirement is that $\text{IDSIG} = 1$ on the first trip card.

W2-I IDSIG = Signal being compared Trip Limit
($1 \leq |\text{IDSIG}| \leq 10$)
 $\text{IDSIG} = 0$ is allowed for restart jobs (See Section III.2.4(5)).

1 = Elapsed time + = HIGH,
- = HIGH

2 = Normalized reactor power + = HIGH,
- = LOW

3 = Reactor period [b]

4 = Pressure (Vol IX1) + = HIGH,
- = LOW

[a] Used only if NTRP is positive.

[b] Only a + sign is used; a check is made only on positive periods less than signal setpoint (SETPT).

5 = Mixture level + = HIGH,
 (Vol IX1) - = LOW

6 = Liquid level + = HIGH,
 (Vol IX1) - = LOW

7 = Water temperature + = HIGH,
 (Vol IX1) - = LOW

8 = Metal temperature + = HIGH,
 (Vol IX1) - = LOW

9 = Flow + = HIGH,
 (Junction IX1) - = LOW

10 = Slab surface + = HIGH,
 temperature - = LOW
 (Vol IX1)

W3-I IX1 = Volume or junction index.
 (1 ≤ IX1 ≤ NVOL for IDSIG = 8 or 10)
 (1 ≤ IX1 ≤ NVOL for IDSIG = 4, 5, 6, or 7)
 (1 ≤ IX1 ≤ NJUN for IDSIG = 9)

W4-I IX2 = Optional volume
 If IX2 > 0, a ΔP or ΔT test is used
 (for IDSIG = 4, -4, 7, -7)

W5-I SETPT = Signal setpoint

W6-R DELAY = Delay time for initiation of action after
 reaching setpoint (sec).

The following combination trip cards are to be supplied only if
 NTRP (on Card 010001) is input as a negative value. Any number of

cards (to a maximum of 19) may be input. The sequence numbers will be 04XXX0, where XXX = NTRP + 1, NTRP + 2, . . . etc.

W1-I CTRPN(1) = Action to be taken. ($1 \leq \text{CTRPN}(1) \leq 20$)

1 = End of problem

CTRPN(1) refers to entry on pertinent card elsewhere in input where trip action is desired

Note: A combination trip card of the form

1 '=' 'XXX' 'END'

will be automatically generated by the program as the last card of the input set where 'XXX' will be the alphanumeric identifier used on the first trip control data card. If a card with CTRPN(1) = 1 is input by the user it will override this generated card. This is done to make certain that a problem termination signal is supplied.

W2-A CTRPN(2) = '=' (This serves as a separator word to make the logical statement easier to read.)

W3-A CTRPN(3) = This input consists of a sequence of
W4-A CTRPN(4) identifiers (IDTRP from the trip control
... ... data cards) plus the logical expressions
WN-A CTRPN(N) 'AND' and 'OR', one set of parentheses,
... ... and the word 'END' to indicate the end
... ... of the sequence. Up to four identifiers
... ... may be used in one logic sequence.

Assuming that 'A', 'B', 'C', and 'D', are input as IDTRP values on four of the trip control data cards some examples of possible combination trip cards are:

3 '=' 'A' 'END'

6 '=' 'A' 'OR' 'B', 'OR', '(', 'C', 'AND', 'D', ')', 'END'.

(14) Volume Data Cards 05XXXY. (See Volume I, Section 3.3.2 of the RELAP4/MOD5 Manual.) A total of NVOL (on Card 010001) sets of cards must be entered with XXX = 001, 002, ..., NVOL. The following items may be entered on up to nine cards.

Y is the card sequence number for each set, starting at 1, and must be consecutive. See Volume I, Section 3.3.2, Table I of the RELAP4/MOD5 Users Manual for selecting the proper fluid state using the variables P, TEMP, HORX, ZM, and ZVOL.

W1-I IBUB = Bubble index and trip selection. The bubble rise trip is selected with the IBUB input on the volume data cards (05XXXY) and the IDTRP input on the trip control data cards (04XXX0). The user can trip the bubble velocity calculation on or off, or trip both the bubble velocity and the bubble gradient calculations on or off. The option is selected as follows: Let I equal the number of the bubble data card (06XXX1). Then IBUB is as described below where I = IDTRP on Card 04XXX0.
(0 < IBUB ≤ NBUB) = normal case, bubble data index, no trip
|IBUB| > 10 = Input for selecting a bubble rise trip where I is IDTRP on Card 04XXX0.

I = bubble data index, no trip.

I+10 = bubble rise velocity calculation
will start with trip signal
IDTRP = I.

I+20 = bubble rise velocity and gradient
calculations will start with
trip signal IDTRP = I.

-(I+10) = bubble rise velocity calculation
will stop with trip signal
IDTRP = I.

-(I+20) = bubble rise velocity and gradient
calculations will stop with
trip signal IDTRP = I.

Since IDTRP = 1 indicates an end of
problem trip, only bubble data sets 2
through 5 can be referred to by the trip
control data cards. Note that this
implies that the trip ID and the digit
for the bubble data index must be
identical.

W2-I IREAD = Volume data retrieval index.

0 = no retrieval

<0 = use the data pertaining to volume
IREAD stored on the plot-restart
tape of a previous run (input data
on FORTRAN logical unit 2)

-101 = use data pertaining to Volume 1
stored on the plot-restart tape

of a previous run, and print the data being used every time step

>0 = use set IRIN of the time-dependent volume conditions

W3-R	P	=	Pressure (psia). ($0.0 \leq P \leq 3,625.94$)
W4-R	TEMP	=	Temperature ($^{\circ}\text{F}$). ($32.018 < \text{TEMP} < 1,472$) (TEMP < 0.0 used as logic control.)
W5-R	HORX	=	Quality or relative humidity. (dimensionless)
W6-R	V	=	Volume (ft^3) ($0.0 < V$).
W7-R	ZVOL	=	Volume height, bottom to top (ft). ($0 < \text{ZVOL}$)
W8-R	ZM	=	Mixture level (from bottom) (ft). ($0 \leq \text{ZM} \leq \text{ZVOL}$)
W9-I	JTPMV	=	Two-phase friction index.

0 = use two-phase friction multiplier with Fanning friction losses. Smooth pipe walls are implied.

1 = no two-phase multiplier in Fanning type of friction losses. Smooth pipe walls are implied.

2 = Use two-phase friction multiplier with Fanning friction losses. Rough pipe walls are implied.

A multiplier for the roughness factor may be input on Card 082020.

3 = No two-phase multiplier. Rough pipe walls are implied.

W10-R FLOWA = Flow area of volume (ft²).

W11-R DIAMV = Equivalent diameter of flow area (ft).
(For Fanning friction calculation only.)

0 = program computes diameter

$$\text{from } 2 \sqrt{\frac{\text{flow area}}{\pi}}$$

W12-R ELEV = Elevation at the bottom of the volume (ft).

W13-I IAMBLO = Single mixture level calculation for stacked volumes. $1 \leq \text{IAMBLO} \leq \text{NVOL}$, the number of the volume above the volume described on this card. This option will compute a single mixture level for a series of stacked control volumes for which IBUB > 0 and vertical slip has been specified between the volumes (see Volume I, Section 3.6.6 of the RELAP4/MOD5 Manual.)

0 = there is no single mixture level calculation.

(15) Liquid Level Volume Calculation Card 060000. (See Volume I, Section 3.10.6 of the RELAP4/MOD5 Manual.) This card is optional.

W1-I ILVC(1) = Indices for the volumes over which liquid
W2-I ILVC(2) masses are to be summed to determine the

...	...		equivalent liquid level. The bottom of the
...	...		first level is used as the reference ele-
...	...		vation for the equivalent liquid level. A
WN-I	ILVC(N)		maximum of 20 volumes is allowed.

(16) Slip Velocity Card 060001. (See Volume I, Section 3.6.2 of the RELAP4/MOD5 Manual.) This card is optional.

W1-R	SLVAMX	=	Void limit slip parameter, α_l (zero defaults to 0.995).
W2-R	SLVELZ	=	Slip velocity coefficient (ft/sec) (zero defaults to 10.0).
W3-R	SLVPWR	=	Slip velocity exponent, P (zero defaults to 1.25).
W4-R	SLVSL1	=	Slip velocity coefficients, u_{s1} (ft/sec) (zero defaults to 4.0).
W5-R	SLBDPF	=	Slip velocity constant, u_c (ft/sec) (zero defaults to 0.0).
W6-R	SLVMXX	=	Multiplier for gas velocity for transition to dispersed flow cor- relations (0.0 or no entry defaults to 10^{99}).
W7-R	SLVM1	=	Multiplier for low-void-fraction, dispersed-flow slip velocity cor- relation (0.0 or no entry defaults to 1.0).

W8-R SLVMZ = Multiplier for high-void-fraction,
dispersed-flow slip velocity correlation (0.0 or no entry defaults to 1.0).

(17) Wallis Flooding Correlation Card 0600X2. (See Volume I, Section 3.6.4 of the RELAP4/MOD5 Manual and Ref. 2, II-1.5).
These cards are optional with $0 \leq X \leq 5$. The number $X+1$ refers to the correlation number used for IFLOOD on Card 08XXXV.

W1-R WLC1(X+1) = First Wallis flooding correlation parameter, W_{C1} . If $W_{C1} > 0$, use the input value. A zero value for W_{C1} will default to 0.7. $W_{C1} < 0$ will skip the use of the Wallis correlation.

W2-R WLC2(X+1) = Second Wallis flooding correlation parameter, W_{C2} . If $W_{C2} > 0$, use the input value. A zero value for W_{C2} will default to 0.47.

(18) Wallis-Crowley Flooding Correlation Card 060003. (See Volume I, Section 3.6.4 of RELAP4/MOD5 Manual.) This card is optional.

W1-R DTRDWN = Downcomer diameter (ft).

W2-R DWNGAP = Downcomer gap (ft).
The outer minus the inner downcomer radius.

W3-R WALSC3 = Downcomer flooding parameter, W_{C3} .
(zero defaults to 1.0).

W4-R WALSC4 = Downcomer flooding parameter, W_{C4} .
(zero defaults to 1.0).

W5-R	WALSC5	=	Downcomer flooding parameter, W_{C5} (zero defaults to 1.0).
W6-R	WALSC6	=	Downcomer flooding parameter, W_{C6} (zero defaults to 1.0).
W7-I	JCNDWN	=	Downcomer junction. $1 \leq JCNDWN \leq NJUN$, use Wallis- Crowley flooding correlation for junction JCNDWN.
W8-I	IDWNEM	=	Optional model for Wallis-Crowley flooding correlation option.
		0	= do not use the optional flood- ing correlation
		1	= use the optional flooding correlation.

(19) Downcomer Penetration -- Lower Plenum Entrainment

Card 060004. (See Volume I, Section 3.6.4 of the RELAP4/MOD5 Manual.)

This card is optional.

W1-I	ICL	=	Cold leg volume adjacent to the downcomer on intact loop.
W2-I	ILP	=	Lower plenum volume in communication with the downcomer and core.
W3-I	IBC	=	Core barrel volume immediately above the lower plenum.
W4-I	ID	=	Downcomer volume immediately above the lower plenum.

W5-I	JCLP	=	Junction between the core (IBC) and lower plenum (ILP). Junction cannot be a fill junction.
W6-I	JDLP	=	Junction between the downcomer (ID) and lower plenum (ILP). Junction cannot be a fill junction.
W7-I	JCLD	=	Junction between the intact cold leg (ICL) and downcomer (ID). Junction cannot be a fill junction.
W8-I	IX	=	1, use lower plenum entrainment model only
		=	2, use downcomer penetration model only
		=	3, use both models where the lower plenum entrainment model may override the downcomer penetration model
		=	0, use neither model.
W9-R	TPRES	=	Trip pressure (psia). The models are activated when the pressure in the lower plenum (ILP) is no longer greater than TPRES.
W10-R	DH	=	Hydraulic diameter of downcomer (ft) (twice the downcomer gap).
W11-R	CCF	=	Contraction coefficient (optional) (no entry defaults to 0.6). Required only for use in the lower plenum entrainment model.

(20) Downcomer Penetration Correlation Coefficient Card 060005.

(See Volume I, Section 3.6.4 of the RELAP4/MOD5 Manual.) This card is optional.

W1-R	G	=	Coefficient in Battelle downcomer penetration correlation. (No entry defaults to 0.36266.)
W2-R	B	=	Coefficient in Battelle downcomer penetration correlation. (No entry defaults to 1.134.)
W3-R	C	=	Coefficient in Battelle downcomer penetration correlation. (No entry defaults to 1.1625.)
W4-R	D	=	Coefficient in Battelle downcomer penetration correlation. (No entry defaults to 0.00387.)

(21) Accumulator Polytropic Air Expansion Model Data Card 060006.
(See Ref. 2, II-7.8). This card is optional.

W1-R	POLY	=	Polytropic exponent (n) used to compute the thermodynamic state of air in an accumulator volume according to the relationship, $pn^n = \text{constant.}$ (1.0 ≤ POLY ≤ 1.67)
W2-I		=	Indices for the volumes to which the model will apply. A maximum of five volumes is allowed.
...			
...			
...			
WN-I			Each volume specified must contain both air and water.

(22) Volume Flow Calculation Card 060009.

W1-I IDLSKE = 0 (or no card input)
 = Volume average mass flow rate
 calculated as described in
 RELAP4/MOD5 User's Manual.

 -1 = Volume average mass flow
 rate calculated as an
 average of junction volumetric
 flow rates times average
 volume density.

 -2 = Volume average mass flow rate
 calculated as for IDLSKE = -1.
 Momentum flux terms calculated
 as $1/2 \rho V^2$.

(23) Bubble Data Cards 06XXX1. (See Volume I, Section 3.6.6
of the RELAP4/MOD5 Manual.) NBUB (on Card 010001) cards must be entered
with XXX = 001, 002, . . . , NBUB.

W1-R ALPH = Bubble gradient parameter ($0 \leq \text{ALPH} \leq 1.0$).

W2-R VBUB = Bubble rise velocity (ft/sec).

 >0 = the standard bubble rise calcu-
 lation performed

 0 = always yield a mixture-full
 volume

 -1 = allow the bubble rise velocity
 to be recomputed for each time
 step using the Wilson bubble
 rise model (See Ref. 2, II.3.1)

- 2 = enables the user to simulate complete separation of phases within a control volume. [This option yields the same result as could be obtained with an infinite bubble rise velocity (see Ref. 2, II-3.2).]
- 3 = activates the implicit calculation of entrainment within a particular volume employing the entrainment correlation specified on Card 400011
- 4 = activates the deentrainment model calculation which is intended for use in the upper plenum volume of a PWR. [This option will compute the liquid level and the quality of the two phase mixture above the liquid level in the upper plenum. Card 400016 must be used in conjunction with this model (see Ref. 2, II-1.4).]

(24) Time-Dependent Volume Data Cards 07XXYY -- RST. (See Volume I, Section 3.3.2 of RELAP4/MOD5 Manual.) NTDV (from Card 010001) sets of cards must be entered with the set number XX = 01, 02, . . . , NTDV. Data points may be entered on cards ordered by YY where $00 \leq YY \leq 99$. YY need not be consecutive. A data point consists of time, pressure, temperature, mixture quality, and mixture level. The first entry for a set is the number of data points (IRIN) contained in the set. Since the first data point (TIME = 0) has been read from the normal volume

data, only IRIN-1 data points are entered in a set. An IRIN value of either 0 or 1 may be used to specify that the initial conditions of the volume are used throughout the transient. For a positive mixture quality, the pressure will be used if positive and the temperature ignored. Pressure, temperature, and zero quality should be entered for subcooled liquid.

W1-I IRIN = N (Number of data points in the set.)
(0 < IRIN < 20)

W2-R TIMTBL(2) = Time (sec).

W3-R PTABL(2) = Pressure (psia).

W4-R TTABL(2) = Temperature (°F).

W5-R XTABL(2) = Quality of mixture.

W6-R ZTABL(2) = Mixture level (from bottom of volume)
 (ft).

W7-R,...TIMTBL(3), PTABL(3), TTABL(3), XTABL(3), ZTABL(3),

W12-R . . .

(25) Flow Smoothing Data Cards 080001 through 080009. (See Volume I, Section 3.10.7 of the RELAP4/MOD5 Manual.) These cards are optional. This card is used with flow smoothing option.

This option is not operational on RELAP4/MOD7 (Version 2).

$$W1-R \quad TAU(1) = TAU(sec), \text{ where } TAU(1) < 0.$$

W2-R WFUN(1) = Weighting function.

W3-R TAU(2)

W4-R WFUN(2)

...

...

...

Up to 20 points.

(26) Junction Data Cards 08XXXY -- RST. (See Volume I, Sections 3.3.2 and 3.6.8 of the RELAP4/MOD5 Manual and Ref. 2, II-1.5.) NJUN (on Card 010001) sets of cards must be entered with XXX = 001, 002, . . ., NJUN. The items listed below may be entered on up to nine cards. Y is a card sequence number for each set, starting at 1, and must be consecutive. Normal junctions, leak junctions, and fill junctions may be entered in any order. The requirement for ordering normal junctions ahead of leak and fill junctions needed in earlier versions is no longer necessary. The sign of IW1 and IW2 determines the relative flow direction for the volume flow calculation. See Section II-8 for direction definitions.

W1-I IW1 = Volume index at junction inlet.
($0 \leq |IW1| \leq NVOL$)

0 = a null volume

W2-I IW2 = Volume index at junction exit.
($0 \leq |IW2| \leq NVOL$)

0 = a null volume

W3-I IPUMP = Pump, leak, or fill index.

(a) If $|IW1| > 0$, $|IW2| > 0$, and $IPUMP = 0$, then this is a normal junction not connected to a pump.

(b) If $|IW1| > 0$, $|IW2| > 0$, and $1 \leq |IPUMP| \leq NPMPC$,

then this junction uses the pump data on Card 090XXY. XX here corresponds to IPUMP.

For the junctions connecting to the pump volume, the suction side junction should have a negative pump number and the discharge junction should have a positive pump index number, IPUMP. Flow in these junctions must be positive initially.

(c) If $|IW1| > 0$ and $IW2 = 0$, IPUMP is the leak index, XX, on the 12XXY card.

(d) If $IW1 = 0$ and $|IW2| > 0$, IPUMP is the fill index, XX, on Card 13XXYY.

W4-I IVALVE

= Valve index.

$(0 \leq IVALVE \leq NCKV)$

(a) $IVALVE = 0$, no valve at junction.

(b) $1 \leq IVALVE \leq NCKV$, check valve.

(c) $IVALVE < 0$, the negative of the old junction number used in smoothing.

W5-R WP

= Flow (lb/sec).

W6-R AJUN = Junction flow area in square feet and must be greater than zero. For a leak, AJUN is the full leak area.

W7-R ZJUN = Junction elevation (ft).

(a) $|IW1| > 0$, $|IW2| > 0$, the ZJUN must lie between the bottom and top of both volumes, IW1 and IW2.

(b) $|IW1| > 0$, $IW2 = 0$, the ZJUN must lie between the bottom and top of volume IW1.

(c) $IW1 = 0$, $|IW2| > 0$, the ZJUN must lie between the bottom and top of volume IW2.

W8-R INERTA = Junction effective inertia L/A (ft^{-1}).

INERTA is calculated by the program if $|JCALCI| \geq 2$. The calculated value is one-half the length of each adjacent volume divided by the volume flow area, where length is V/FLOWA .

W9-R FJUNF = Forward flow form loss coefficient.

This is either a dimensionless positive number dependent on geometric changes occurring within the flow control volume, or zero. It is the standard energy loss coefficient, as normally used in textbooks. The energy loss is

$$K \frac{v^2}{2}$$

where FJUNF is K, and the velocity v is based on the junction area.

W10-R FJUNR = Reverse flow 'form loss coefficient.' If FJUNR is entered as zero, FJUNF is nonzero, and JCALCI = ± 2 , the FJUNR is set equal to FJUNF.

W11-I JVERTL = Vertical junction index.

0 = junction flow area not distributed vertically and junction enthalpy is 'smoothed' when the two-phase mixture interface is near the junction elevation

1 = junction flow area assumed to be a circular area centered and distributed vertically about ZJUN (the flow cross section plane is perpendicular to the horizontal)

2 = no bubble smoothing, junction flow area not distributed vertically

W12-I JCHOKE = Junction choking index. (See Volume I-3.6.8, Table V of the RELAP4/MOD5 Manual.)

W13-I JCALCI = Initial condition calculation index.

- 0 = use input for inertia and form loss coefficients as given by user
- 1 = calculate form loss coefficients (FJUNF and FJUNR) (for sharp-edge area changes)
- ±2 = calculate inertias
- ±3 = calculate both form loss coefficients and inertias
- <0 = frictionless junction except in mixed streams
- 4 = no Fanning friction used and does not use junction flow in volume flow calculation

W14-I MVMIX = Momentum equation type.

- 0 = Form 1 -- compressible single-stream flow with momentum flux
- 1 or 2 = Form 2 -- compressible two-stream flow with one-dimensional momentum mixing in the ''to'' volume
For jet pump modeling, MVMIX = 1 is the drive junction and MVMIX = 2 is the suction junction and the momentum mixing term is ''smoothed'' between design and off-design flow modes if W_{DRIVE} is positive.

If MVMIX is the same for both mixed flows, no smoothing is performed

- 3 = Form 3 -- incompressible single-stream flow without momentum flux (no Bernoulli effects)
- 4 = Form 4 -- compressible integral momentum equation, single stream (Zuber's derivation)
- 2 = special case, a fill with negative flow used to represent the outlet junction

W15-R DIAMJ = Junction diameter (ft).

If $\text{DIAMJ} \leq 0.0$, the program will calculate DIAMJ as $2 \sqrt{\text{AJUN}/\pi}$ (used for junction quality calculations).

W16-R CONCO = Contraction coefficient for leak (0 is interpreted as 1).

W17-I ICHOKE = Junction choking index. (See Volume I-3.6.8, Table V of the RELAP4/MOD5 Manual.)

W18-I IHQCOR = Enthalpy transport index.

0 = both sides off

1 = inlet side on, outlet side off
(volume 'from' heated)

2 = outlet side on, inlet side off
(volume 'to' heated)

3 = both sides on (both volumes
heated)

W19-R SRCOS = Slip velocity direction indicator and
multiplier.

<0.0 = the normal (positive) flow
direction is up. Vertical slip
will be used at this junction.
The calculated value of the slip
velocity will be multiplied
by this number. (Recommended
value = -1.0.)

0.0 = no vertical slip for this
junction. The flow is
homogeneous.

>0.0 = vertical slip will be used at
this junction. The normal
(positive) flow direction is
down. The calculated value of
the slip velocity will be
multiplied by this number.
(Recommended value = +1.0.)

W20-I IFLOOD = Wallis Flooding correlation number.

$1 \leq K \leq 6$ = use the Wallis flooding param-
eters WLC1(K) and WLC2(K)
specified on Card 0600X2 where

$K = X + 1$ should be used only when $SRCOS \neq 0.0$ except when the PWR fallback model is utilized.

0 = no flooding correlation specified for junction XXX. This implies that counter-current flow will not be limited by flooding.

W21-I IADJUN = Adjacent junction number for horizontal slip.

0 = no horizontal slip

>0 = adjacent junction number

W22-R WTP = Two-phase pressure drop constant (Chisholm Model).

0.0 = Two-phase model not used

>1.0 = Constant C_2 used in Chisholm two-phase pressure drop model.
(See Section II-6.1 for the definition of C_2).

(27) Stagnation Properties Card 082000. (See Volume I, Section 3.6.9 of the RELAP4/MOD5 Manual.) This card is optional.

W1-I ISTAGP = Stagnation properties.

0 = do not use stagnation properties

1 = use stagnation properties unless
JCHOKE = 2

The following dials are intended for statistical use by model verification and are not for general use.

(28) Modified Burnell/Homogeneous Equilibrium Critical Flow Model Dials Card 082001. (See Ref. 2, II-4 and II-10). This card is optional.

W1-R	DLHEM	=	Flow rate multiplier applied to HEM in the saturated and superheated regions. (Default = 1.0.)
W2-R	DLMBUR	=	Flow rate multiplier applied to modified Burnell model in the subcooled and transition regions ($0 < \text{Quality} < \text{DLXTMB}$). (Default = 1.0.)
W3-R	DLXTMB	=	Upper boundary of the transition region, quality. (Default = 0.02.)

(29) HEM Critical Flow Model Dials Card 082002. (See Volume I, Section 3.9 of the RELAP4/MOD5 Manual.) This card is optional.

W1-R	DLHEM	=	Dial applied to HEM flow in all regions. (Default = 1.0.)
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(30) Henry-Fauske-HEM Critical Flow Model Dials Card 082003. (See Volume I, Section 3.9 of the RELAP4/MOD5 Manual.) This card is optional.

W1-R	DLHEM	=	Flow rate multiplier for HEM. (Default = 1.0.)
W2-R	DLHRY	=	Flow rate multiplier for saturated Henry critical flow. (Default = 1.0.)

W4-R DLXTFE = Boundary of the transition region, quality, (Best estimate value and no entry value equal to 0.02.)

WI-R DLMDY = Flow rate multiplier for Moody critical flow model. (Default = 1.0.)

W1-R DLHRY = Flow rate multiplier for saturated Henry critical flow model. (Default = 1.0.)

W1-R DLEHRY = Flow rate multiplier for subcooled
(extended) Henry critical flow model.
(Default = 1.0.)

W1-R DDWNPN = Liquid flow rate multiplier to the lower plenum (XJL) for the Battelle downcomer penetration model. (Default = 1.0.)

(35) Lower Plenum Entrainment Model Dial Card 082012. (See Volume I, Section 3.9 of the RELAP4/MOD5 Manual.) This card is optional.

W1-R DPLNEN = Multiplier of the calculated value of the critical distance (HCRIT) between the bottom of the downcomer and the lower plenum liquid level for the Wallis lower plenum entrainment model. (Default = 1.0.)

(36) Friction Factor Dial Card 082020. (See Volume I, Section 3.9 of the RELAP4/MOD5 Manual and Section II-10.) This card is optional.

W1-R DLTFFM = Two-phase friction factor multiplier (best estimate value = 1.0).

W2-R DLDK = Rough wall friction factor multiplier (best estimate value = 1.0).

(37) Metal Water Reaction Dial Card 082021. (See Volume I, Section 3.9 of the RELAP4/MOD5 Manual.) This card is optional.

W1-R DLMWR = Multiplier for metal water reaction heat production (best estimate value = 1.0).

(38) Critical Heat Flux Dial Card 082030. (See Volume I, Section 3.9 of the RELAP4/MOD5 Manual and Ref. 2, II-10.2.) This card is optional.

W1-R DCHF = Multiplier for all critical heat fluxes (best estimate value = 1.0).

(39) Heat Transfer Coefficient Dial Card 082031. (See Volume I, Section 3.9 of the RELAP4/MOD5 Manual and Ref. 2, II-10.) This card is used when NSUR = -1 or 2 on Card 150000. The best estimate value for all these dials is 1.0.

Note: It is particularly risky to use heat transfer dials without understanding the heat transfer logic and the ramifications of the use of these dials. A further discussion of this is provided in Volume I, Section 3.9 of the RELAP4/MOD5 Manual and Ref. 2, II-10.2.

If NSUR = -1, then the dials are used as heat transfer coefficient multipliers where the mode number is defined in the MOD5 Manual.

W1-R	DHTC1	=	Multiplier for heat transfer coefficient in Mode 1.
W2-R	DHTC2	=	Multiplier for heat transfer coefficient in Mode 2.
W3-R	DHTC3	=	Multiplier for heat transfer coefficient in Mode 3.
W4-R	DHTC5	=	Multiplier for heat transfer coefficient in Mode 5.
W5-R	DHTC6	=	Multiplier for heat transfer coefficient in Mode 6.
W6-R	DHTC7	=	Multiplier for heat transfer coefficient in Mode 7.
W7-R	DHTC8	=	Multiplier for heat transfer coefficient in Mode 8.
W8-R	DHTC9	=	Multiplier for heat transfer coefficient in Mode 9.

If NSUR = 2, the dials are used as heat flux multipliers (see Ref. 2, II-10.2 where the mode number is further defined).

W1-R	DHTC1	=	Multiplier for heat flux in Mode 1 (Dittus-Boelter, liquid).
W2-R	DHTC2	=	Multiplier for heat flux in Mode 2 (Chen).
W3-R	DHTC3	=	Multiplier for heat flux in Mode 11 (natural convection).
W4-R	DHTC5	=	Multiplier for heat flux in Mode 5 (Groeneveld).
W5-R	DHTC6	=	Multiplier for heat flux in Mode 6 (Condie-Bengston).
W6-R	DHTC7	=	Multiplier for heat flux in Mode 7 (free convection plus radiation).
W7-R	DHTC8	=	Multiplier for heat flux in Mode 8 (Dittus-Boelter, vapor).
W8-R	DHTC9	=	Multiplier for heat flux in Mode 9 (Hsu plus Bromley-Pomeranz. DHTC9 applies only to the Bromley-Pomeranz contribution).

(40) Pool Boiling Correlation Choice Dial Card 082032. (See
Volume I, Section 3.9 of the RELAP4/MOD5 Manual and Ref. 2, II-10.2).
This card is optional.

W1-R	DPBAL	=	Void fraction used to select pool boiling heat transfer correlation (not a multiplier). (Best estimate and no entry value = 0.6.)
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(41) Henry-Fauske/HEM Lower Limit Transition Quality Dial Card
082003. (See Ref. 2, II-10.5) This card is optional and will apply only
to junctions for which JCHOKE = 5 and ICHOKE < 0.

W1-R DXTRLL = Quality at which the linear weighting transi-
tion begins for the Henry-Fauske to HEM
critical flow transition. It is required
that $0.0 \leq DXTRLL \leq DLXTFE$. (Default
= 0.0.)

(42) Variable Dials for Henry-Fauske/HEM Critical Flow Model
with Linear Weighting Transition Cards 0888XX. (See Ref. 2, II-10.5). These
cards are optional and will apply only to junctions for which JCHOKE = 5
and ICHOKE < 0. Up to 10 sets of variable dials can be entered with
XX = 00, 01, ..., 09. The first card must have XX = 00 and subsequent
cards must be sequential.

W1-I NDYL = Index of the junction for which the
following dials are to be applied

W2-R CRH1 = Dial to be applied to Henry-Fauske and
extended Henry critical flow models for
junction NDYL

W3-R CRH2 = Dial to be applied to HEM critical flow
model for junction NDYL

(43) Pump Description Data Cards 090XXY. (See Volume I, Section
3.6.10 of the RELAP4/MOD5 Manual). NPMPC (on Card 010001) sets of
cards must be entered with XX = 01, 02, ..., NPMPC. The items subsequently
listed may be entered on one or two cards. Y is a card sequence number
for each set, Y = 1 for the first card and 2 for the second card, if used.

W1-I IPC = Curve set. If any pump uses the two-phase
option, set 4 is regarded as the single-

phase minus two-phase difference curve.
($1 \leq IPC \leq 4$)

W2-I ITPUMP = Trip number IDTRP to shut off pump where
($2 \leq ITPUMP \leq 20$)

W3-I IRP = Reverse indicator.

0 = no reverse allowed

1 = reverse allowed

W4-I IPM = Index for two-phase option.

0 = no two-phase option

1 = two-phase option

W5-I IMT = Index for pump motor torque curve.

0 = no curve

1 = curve 1

2 = curve 2

W6-R POMGAR = Rated speed (rev/min).

W7-R PSRAT = Pump speed ratio of initial speed to rated speed.

W8-R PFLOWR = Rated flow (gal/min).

W9-R PHEADR = Rated head (ft).

W10-R	PTORKR	=	Rated torque (lbf-ft).
W11-R	PINRTA	=	Moment of inertia (lbm-ft ²).
W12-R	VRHOI	=	Rated density (lbm/ft ³). If VRHOI = 0, initial density is used.
W13-R	TORKF(3)	=	Coefficient in frictional term calculation.
W14-R	TORKMR	=	Rated pump motor torque (lbf-ft). If TORKMR = 0, it is set to the sum of the frictional torque and the hydraulic torque at time t = 0.
W15-R	TORKF(1)		These three numbers are coefficients in the frictional torque calculation (lbf-ft) above. All three numbers are optional (with default values = 0.0).
W16-R	TORKF(2)		
W17-R	TORKF(4)		

The frictional torque is calculated as:

$$\sum_{i=1}^4 \text{TORKF}(i) S^{i-1}$$

Note: i-1 is exponent of S.

where

S = |pump speed|/rated speed. S is the absolute value of the speed ratio term α .

(44) Pump Head Multiplier Data Cards 0910YY -- RST. (See Volume I, Section 3.6.10 of the RELAP4/MOD5 Manual.) This curve is read

if any IPM (on Cards 090XXY) equals unity. YY is a card sequence number, $0 \leq YY \leq 99$. These cards are ordered by YY, but YY need not start at 0 and need not be consecutive to facilitate additions or deletions from the table.

W1-I	NPHM	=	Number of points on curve where $1 \leq NPHM \leq 20$. Positive value indicates no extrapolation. Negative value permits extrapolation.
W2-R	PHDM(1)	=	Void fraction for first point.
W3-R	PHDM(2)	=	Head multiplier for first point for difference curves in Set 4.
W4-R	PHDM(3)	=	Void fraction for second point.
W5-R	PHDM(4),		
...	...		Until NPHM points are entered.
...	...		Void fraction must be in ascending sequence.
...	...		Normally, both void fraction and multiplier
...	...		will range from 0.0 to 1.0.

(45) Pump Torque Multiplier Data Cards 0920YY -- RST. (See Volume I, Section 3.6.10 of the RELAP4/MOD5 Manual). This curve is also read if any IPM (on Cards 090XXY) equals unity. YY is a card sequence number, the same as with Cards 0910YY.

W1-I	NPTM	=	Number of points on curve where $1 \leq NPTM \leq 20$. A negative value here also indicates that extrapolation is permitted.
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W2-R PTKM(1) = Void fraction for first point.

W3-R PTKM(2) = Torque multiplier for first point for
difference curves in Set 4.

W4-R PTKM(3) = Void fraction for second point.

W5-R PTKM(4),

... ... Until NPTM points are entered. Void fraction
... ... must be in ascending sequence.

(46) Pump Stop Data Card 095XX1. (See Volume I, Section
3.6.10 of the RELAP4/MOD5 Manual). This card must be present for
each pump to which this option applies, where XX is the pump number
between 01 and 12. Once any of the conditions below are met, the
pump speed is set to 0.

W1-R CAVCON = Elapsed time (sec).

 <0.0 = option not used

 >0.0 = option used

W2-R FPUMP = Maximum forward speed (rev/min).

 0.0 = option not used

 ≠0.0 = option used

W3-R SPUMP = Maximum reverse speed (rev/min).

 0.0 = option not used

≠0.0 = option used

(Note: Normally this number is negative.)

(47) Pump Motor Torque Data Cards 0970XY -- RST. (See Volume I, Section 3.6.10 of the RELAP4/MOD5 Manual.) X, with $1 \leq X \leq 2$, indicates the curve number. Curve 09701Y is read if any IMT (on Cards 090XXY) equals 1; curve 09702Y is read if any IMT = 2. Y is a card sequence number, with $1 \leq Y \leq 9$.

W1-I	NTMO	=	Number of points on curve where $1 \leq NTMO \leq 20$. A negative value indicates that extrapolation is permitted.
W2-R	PTMO(1)	=	Pump speed (rev/min) for first point.
W3-R	PTMO(2)	=	Motor torque, normalized for first point.
W4-R	PTMO(3)	=	Pump speed for second point.
W5-R	PTMO(4),		
...	...		Until NTMO points are entered. Speed
...	...		must be in ascending sequence.

(48) Pump Speed vs Time Data Cards 098ZZY. ZZ indicates the curve number ($00 \leq ZZ \leq 12$). The ZZ need not be in any particular order and need not be consecutive. The card sequence for a given curve is ordered by Y ($0 \leq Y \leq 9$), but Y need not start at 0 and need not be consecutive.

W1-I	ITPSP	=	Trip ID for actuation of pump speed table.
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(50) Pump Head and Torque Data Cards 10XYZ -- RST. (See Volume I, Section 3.6.10 of the RELAP4/MOD5 Manual.) X, with $1 \leq X \leq 4$, indicates the curve set number. NC (from Card 100000) total curves must be read for each set X. YY indicates the curve number, with YY = 01, 02, . . . , NC. Z, with $0 \leq Z \leq 9$, is the card sequence number for each curve. The cards are ordered by Z, but Z need not start at 0 and need not be consecutive. An arbitrary number of items may be entered on each card. At least one table pair must be entered. Any single-phase minus two-phase difference curves should be read into Set 4.

Curves for the following pumps are already built in:

Curve Set 1 -- Bingham Pump Company pump specific speed, $N_S = 4200$

Curve Set 2 -- Westinghouse Electric Corporation pump specific speed, $N_S = 5200$.

The foregoing can be accessed by entry of 1 or 2 for IPC on the pump description data cards. Entry of separate pump head and torque data cards for curve Set 1 or 2 will override the built-in curve data.

W1-I IT = Head or torque indicator.

1 = head

2 = torque

W2-I IC = Curve type where $1 \leq IC \leq 8$.
(See Table XIV, Volume I, Section 3.6.10 of the MOD5 Manual.)

W3-I N = Number of data points where
 $1 < |N| \leq 10$.

Positive value indicates no extrapolation;
negative value permits extrapolation.

W4-R PHEAD(1)
or PTORK(1) = Independent variable 1 (v/α for IC odd;
 α/v for IC even).

W5-R PHEAD(2)
or PTORK(2) = Dependent variable 1 (h/α^2 or β/α^2 for IC
odd; h/v^2 or β/v^2 for IC even).

W6-R Independent variable 2 and dependent variable 2,
W7-R . . ., until N pairs entered, where independent
... variable $j < \text{independent variable } j + 1$.
... v, h, α and β are ratios of performance
... parameters to the rated parameters, where
... $v = \text{flow ratio}$, $h = \text{head ratio}$, $\alpha = \text{speed}$
... ratio, and $\beta = \text{torque ratio}$.

(51) Variable Pump Moment-of-Inertia Card 105500. (See Ref. 2,
II-7.2). Use this card only if variable pump moment-of-inertia is
wanted.

W1-R RTRIP = Pump speed (in RPM) above which variable
moment-of-inertia is to be used. If
speed is less than RTRIP, PINRTA (from
Card 090XXY) is used. RTRIP must be
 ≥ 0.0 .

W2-R VARIN(1) = Coefficients for variable moment-of-
inertia, where moment-of-inertia
(lbm-ft^2) is calculated as:

W3-R VARIN(2) $I = \text{VARIN}(1) + \text{VARIN}(2) * S$

$$W4-R \quad \text{VARIN}(3) \quad + \text{VARIN}(3) * S^2 + \text{VARIN}(4) * S^3$$

$$W5-R \quad \text{VARIN}(4) \quad \text{where } S = \text{normalized pump speed.}$$

(52) Valve Data Cards 11XXX0 -- RST. (See Volume I, Section 3.6.12 of the RELAP4/MOD5 Manual). Cards must be entered with XXX = 001, 002, . . . , NCKV to correspond with Card 010001. The data on the card are interpreted according to the type of valve being described.

W1-I ITCV = Type of check valve.

-1 = inertial valve

0 = type 0 check valve (without hysteresis)

1 = type 0 check valve (with hysteresis)

$-20 \leq \text{ITCV} \leq -2$ = a closed valve to open
under control of the desired trip by
 $\text{IDTRP} = |\text{ITCV}|$

$2 \leq \text{ITCV} \leq 20$ = an open valve to close
under control of the desired trip by
 $\text{IDTRP} = \text{ITCV}$

21 = valve that will operate (open or shut)
based on static pressure

$22 \leq \text{ITCV} \leq 40$ = same as type 21 valve
except will close on the desired trip
by $\text{IDTRP} = \text{ITCV} - 20$.

W2-I	IACV	=	Number of area-versus-angle table in the leak table data if ITCV = -1.
		=	Number of area-versus-time table in leak table data if $ ITCV \geq 2$.
		=	0, do not use leak table data.
W3-I	LATCH	=	Gate latching option, used only if ITCV = -1.
		0	= gate will be allowed to open and close repeatedly.
		$\neq 0$	= gate will be locked full open after a rotation of 90 degrees is achieved.
W4-R	PCV	=	Back pressure for closure (psia).
W5-R	CV1	=	Forward flow friction coefficient if ITCV $\neq -1$ (dimensionless).
			Area * moment arm if ITCV = -1 (ft^3).
W6-R	CV2	=	Reverse flow friction coefficient for valve open if ITCV $\neq -1$ (dimensionless).
			Moment of inertia if ITCV = -1 (lbm-ft^2).
W7-R	CV3	=	Reverse flow friction coefficient for valve closed if ITCV $\neq 1$ (dimensionless).
			Damping constant if ITCV = -1.

(53) Leak Table Data Cards 12XXYY -- RST. (See Volume I, Sections 3.3.2 and 3.6.12 of the RELAP4/MOD5 Manual). NLK (on Card 010001) sets of cards must be entered with XX = 01, 02, . . . , NLK. YY is a card sequence number for each set, $00 \leq YY \leq 99$; the cards are ordered by YY, but YY need not start at 00 and need not be consecutive.

An arbitrary number of pairs may be entered on each card. At least one table pair must be entered.

W1-I	NAREA	=	Number of data points. ($1 \leq NAREA \leq 20$) A positive value indicates no extrapolation; a negative value permits extrapolation.
W2-I	ITLEAK	=	Trip signal number IDTRP to open leak. ($2 \leq ITLEAK \leq 20$)
W3-R	SINK	=	Sink pressure (psia).
W4-R	TAREA(1)	=	Time (sec) or angle (degrees) for first point.
W5-R	TAREA(2)	=	Leak area normalized to full open area AJUN for first point.
W6-R	TAREA(3)	=	Time or angle for second point.
W7-R	TAREA(4),		Until NAREA points are entered, where the time and degree values are in ascending order.
...	...		
...	...		

(54) Fill Table Data Cards 13XXYY -- RST. (See Volume I, Section 3.3.2 of the RELAP4/MOD5 Manual). Fill data sets are defined by the card series 13XXYY where XX is the data set number and YY is the card sequence number within each data set. The data set numbers, XX, must be between 01 and 99 but need not be consecutive. Likewise, the sequence numbers within any data set need not be consecutive. A fill data set may be used with more than one junction and is referenced by the fill index given in data field W3 on Cards 08XXYY.

For YY = 00

W1-I ITFILL = Trip signal IDTRP to start.
 (2 $\leq$ ITFILL $\leq$ 20)

W2-I ITYPE = Fill Type.

1 = flow rate a function of time,
 enthalpy constant

2 = flow rate a function of down-
 stream volume pressure
 ($P_{vol} + P_{grav}$) psia.
 enthalpy constant

3 = flow rate a function of dif-
 ferential pressure
 ($P_{fill} - P_{vol} - P_{grav}$) psia,
 enthalpy constant

4 = flow rate a function of time,
 enthalpy a function of time (for
 this case Words W4 to W7 are not
 used but Words 4 and 5 must be
 entered with one at the pre-
 scribed value to allow the pro-
 grammed checking function to
 conclude)

W3-I NPTS = Number of points in fill curve (NPTS $\geq$ 2.
 If NPTS $\geq$ 1000 fill curve will come from
 FORTRAN Unit 23. See Section II-9.1).

W4-I ICALC = Thermodynamic variable indicator.

1 = PORT = pressure (psia)
 HORX = enthalpy (Btu/lb)

		2	=	PORT = pressure (psia) HORX = quality (dimensionless)
		3	=	PORT = temperature (°F) HORX = quality (dimensionless)
		4	=	PORT = pressure (psia) HORX = temperature (°F)
W5-J	ISATFL	=		0, other values are reserved for future MOD 7 usage.
W6-A	UNITS	=		Units of flow rate 'LBS/SEC' or 'GAL/MIN'. (If ICALC = 1 or ITYPE = 4 units must be LBS/SEC.)
W7-R	PORT	=		Pressure or temperature of fill reservoir depending on ICALC operation.
W8-R	HORX	=		Enthalpy, quality, or temperature of fill reservoir depending on ICALC option.
W9-R	AFRAC	=		Fraction of air in fill mass flow. This is used only for positive flow. Defaults to 0.0 if not between zero and one.
W10-R	TAUMIX	=		0.0, other values are reserved for future MOD 7 usage.

For YY = 01, 01, . . . 99

If ITYPE = 1, 2, 3:

W1-R	FILTBL(1)	=	Time or pressure (sec or psia) for first point.
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W2-R FILTBL(2) = Flow (lbm/sec-ft^2 or gpm/ft^2) for first point. This flow is multiplied by junction area if nonzero.

W3-R FILTBL(3) = Time or pressure for second point.

W4-R FILTBL(4), = Until NPTS points are entered, where the
... ... time or pressure values are in ascending
... ... order.

If ITYPE = 4:

W1-R FILTBL(1) = Time (sec) for first point.

W2-R FILTBL(2) = Flow rate (lbs/sec-ft^2) for first point.
This flow is multiplied by junction area if nonzero.

W3-R FILTBL(3) = Enthalpy (Btu/lb) for first point.

W4-R FILTBL(4) = Time for second point.

W5-R FILTBL(5), Until NPTS points are entered

W6-R FILTBL(6), where the time values are in ascending order.

... ...

Caution: fill table should be extensive enough to cover the range of values expected. If the table values are exceeded, the nearest table value will be used and a warning message will be printed.

Note: If a fill with a negative flow is used to represent an outlet junction, set MVMIX = -2 on the corresponding junction data card, Card 08XXXY.

(55) Kinetics Constants Data Card 140000. This card is required if NCOR (on Card 010001) is greater than zero. The data required on this card are words 1 to I inclusive, where $4 \leq I \leq 9$.

W1-I NODEL = Power calculation indicator.

-1 = retrieve data from FORTRAN Unit 2.

0 = explicit power versus time.

1 = one prompt plus six delayed neutron groups.

+2 = '+2' same as 1 above plus fission product decay heat; '-2' fission product decay heat only (instantaneous shutdown).

+3 = same as +2 above plus decay heat from U-239 and Np-239.

W2-I IPOWH = Indicator for reactor power histogram.

0 = no power histogram required (fission of U-235 for 10^{13} sec assumed; uncorrected for neutron capture effect.

>0 = power histogram required; uncorrected for neutron capture effect.

<0 = power histogram required; small correction for neutron capture effect is calculated (not

recommended for operating period
greater than 4 years).

W3-R	BOVL	=	β/Λ , the effective delayed neutron fraction over mean lifetime (sec^{-1}).
W4-R	RHOIN	=	Initial reactivity (\$). (Note: equivalent neutron source = -RHOIN is set by the program.)
W5-R	UDUF	=	U-239 produced per second per fission per second (default = 1.0, but input by user is recommended; may also be considered as a multiplying factor for heavy element decay heat).
W6-R	DHMUL	=	Multiplying factor for fission product decay heat power (default = 1.0).
W7-R	PHIFCT	=	Initial fissile concentration in units of 10^{20} atom/cm ³ (default = 5.929); required only if IPOWH < 0.
W8-R	LAMBDA	=	Fraction of surface heat flux utilized in producing subcooled vapor bubbles (default = 0.0).
W9-R	TAU	=	Vapor bubble lifetime (sec) (default = 0.0).

(56) Reactivity Coefficients Data Cards 140XX0. NCOR (on Card 010001) sets of cards are required if NODEL (on Card 140000) is greater than zero with $01 \leq XX \leq \text{NCOR}$.

W1-R	VOIDWT	=	Density weighting factor.
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W2-R	DOPWT	=	Fuel temperature weighting factor.
W3-R	ALPHTM	=	Fuel temperature coefficient (\$/°F).
W4-R	ALPHTW	=	Water temperature coefficient (\$/°F).

(57) Scram Table Data Cards 14YYXX -- RST. This set of cards is required if NCOR (on Card 01001) is greater than zero and NODEL (on Card 140000) is zero or positive. A maximum of ten (10) reactivity tables may be input specifying the control reactivity as a function of time. Each table is activated by a trip signal. The total control reactivity is summed over all tables which have been tripped. The trip controls are such that once tripped, the trip stays on. Also, at any given entry, the time variable is the elapsed time since the trip, not the problem time. Note also that the reactivity tables are normalized such that the first value is zero to avoid step reactivity changes when the table is first tripped. YY, where $(10 \leq YY \leq 19)$, specifies the number of the table. XX, where $(00, \leq XX \leq 99)$, is the card sequence number for the set. The cards are ordered by XX, but XX need not start at 00 and need not be consecutive.

W1-I	NSCR	=	Number of data points where $ NSCR \leq 20$. Positive value indicates no extrapolation; negative value permits extrapolation NSCR = 1, a constant value.
W2-I	ITSCRM	=	Trip number IDTRP for scram. $(2 \leq ITSCRM \leq 20)$.
W3-R	TSCR(1)	=	Time (sec) for first point.
W4-R	TSCR(2)	=	Reactivity or normalized power (\$ or dimensionless) for first point.
W5-R	TSCR(3)	=	Time for second point.

• • • • •

(58) Density Reactivity Table Data Cards 1420XX -- RST. This set

W1-I N-DEN

W2-R VOI DRO(1)

W3-R VOI DRO(2)

W4-R VOIDRO(3)

W5-R VOIDRO(4),

(59) Doppler Table Data Cards 1430XX -- RST. This set of cards is

W1-I . NDOP

while a negative value permits extrapolation.

W2-R DOPRO(1) = Temperature (°F) for first point.

(60) Reactor Power Histogram Data Cards 1440XX. This set of cards is required if NCOR > 0 (on Card 010001), |NODEL| > 1 and IPOWH ≠ 0 (on Card 140000). XX, where 00 ≤ XX ≤ 99, is the card sequence number for the set. The cards are ordered by XX, but XX need not start at 00 and need not be consecutive. An arbitrary number of items may be entered on each card.

If NUCLI = 1:

W3-R	FA(1)	=	Operating time (days) for the first subset (time period).
W4-R	FA(2)	=	Power due to U-235 for the first subset.
W5-R	FA(3)	=	Operating time (days) for the second subset.
W6-R	FA(4)	=	Power due to U-235 for the second subset. etc., until N subsets are entered (i.e., 2N entries).

If NUCLI = 2:

W3-R	FA(1)	=	Operating time (days) for the first subset (time period).
W4-R	FA(2)	=	Power due to U-235 for the first subset.
W5-R	FA(3)	=	Power due to Pu-239 for the first subset.
W6-R	FA(4)	=	Operating time (days) for the second subset.
W7-R	FA(5)	=	Power due to U-235 for the second subset.
W8-R	FA(6)	=	Power due to Pu-239 for the second subset. etc., until N subsets are entered (i.e., 3N entries).

If NUCLI = 3:

W3-R	FA(1)	=	Operating time (days) for the first subset (time period).
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W4-R	FA(2)	=	Power due to U-235 for the first subset.
W5-R	FA(3)	=	Power due to Pu-239 for the first subset.
W6-R	FA(4)	=	Power due to U-238 for the first subset.
W7-R	FA(5)	=	Operating time (days) for the second subset.
W8-R	FA(6)	=	Power due to U-235 for the second subset.
W9-R	FA(7)	=	Power due to Pu-239 for the second subset.
W10-R	FA(8)	=	Power due to U-238 for the second subset. etc., until N subsets are entered (i.e., 4N entries), with time values in ascending order.

(61) Gamma Heating Power Table Data Cards 144YXX. (See Ref. 2, II.7.6.) These cards are required only if Card 1560XX (gamma-heated slab data card) is used. Y, where $(1 \leq Y \leq 4)$, specifies the number of the table. Y must be 1 for the first table and be sequential for subsequent tables. XX, where $(00 \leq XX \leq 99)$, is the card sequence number for the set. The cards are ordered by XX, but XX need not start at 00 and need not be consecutive.

W1-I	NGTBL	=	Number of time and normalized power data pairs where $1 \leq NGTBL \leq 20$. A positive value indicates no extrapolation. A negative value permits extrapolation. If NGTBL = 1, a constant value of normalized power is used.
------	-------	---	---

W2-I IGTRP = Trip number corresponding to IDTRP on trip data card (04XXX0) for the time for beginning the power history in table NGTBL. The initial power density is used until the trip is actuated.
($2 \leq \text{IGTRP} \leq \text{maximum value of IDTRP}$)

W3-I GTBL(1) = Time (sec) after trip for first point.

W4-R GTBL(2) = Normalized power (dimensionless) for first point.

W5-R GTBL(3) = Time for second point.

W6-R GTBL(4) = Power for second point, until NGTBL pairs
... of data are entered, where time values
... must be in ascending order.

(62) Critical Temperature Core Power Trip Card 149900. (See Ref. 2, II.7.7). This card is optional.

W1-R THI = Upper temperature limit ($^{\circ}\text{F}$).

W2-R TLO = Lower temperature limit ($^{\circ}\text{F}$).

W3-R PFHI = Upper power fraction.

W4-R PFLO = Lower power fraction.

Critical temperature is a linear interpolation between the point (THI, PFLO) and the point (TLO, PFHI) based on normalized power. $TLO \leq THI$ and $PFLO \leq PFHI$. If any core slab surface temperature exceeds TCRIT, the core power is instantly reduced to 6% of the initial power.

(63) Reactivity Coefficients Data Cards 140XX0. (See Volume I, Section 3.5 of the RELAP4/MOD5 Manual.) NCOR (on Card 010001) sets of cards are required if NODEL (on Card 140000) is greater than zero with XX = 01, 02, . . ., NCOR.

W1-R	VOIDWT	=	Density weighting factor.
W2-R	DOPWT	=	Fuel temperature weighting factor.
W3-R	ALPHTM	=	Fuel temperature coefficient ($$/^{\circ}\text{F}$).
W4-R	ALPHTW	=	Water temperature coefficient ($$/^{\circ}\text{F}$).

(64) Heat Transfer Surface Card 150000. (See Ref. 2, II-2.) This card is optional. If this card is not used, the default values of the following four integers are 2, 0, 0, and 0, respectively. If the card is used, all four values must appear. Options apply to all heat slabs.

W1-I	NSUR	=	Indicator for set of correlations (heat transfer surface).
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-1	=	Subroutine HTRC logic as in MOD5
1	=	MOD 5 correlations (subroutine HTS1)
2	=	MOD 6 blowdown correlations (subroutine HTS2)
3	=	Alternate Mod 6 blowdown correlations
4	=	MOD 6 reflood correlations (subroutine HTS4)

W2-I IMSS = Implicit or Explicit Wall Temperature Solution. Used only if NSUR > 0.

0 = implicit wall temperature solution on right side of all conductors

1 = explicit wall temperature solution on right side of all conductors

W3-I IQTB = Transition boiling correlation indicator. Used only if NSUR = 2.

0 = modified Tong-Young (recommended)

1 = modified Condie-Bengston

W4-I IQFB = Film boiling correlation indicator. Used only if NSUR = 2 or 3.

0 = greater of two film boiling correlations

1 = new Groeneveld (HTS2).
Chen (HTS3)

2 = Condie-Bengston III (HTS2)
(recommended)
Condie-Bengston IV (HTS3)

(65) Extra Heat Transfer Printout Card 150001 -- RST. (See Ref. 2, III-3.) This card is optional, and is used only for debugging. This card should only be used with caution (that is, with short time intervals),

or excessive printout will be generated. If the card is used, all 6 quantities must be present.

W1-I	IWR(1)	=	First print indicator.
	0	=	no extra printout
	1	=	extra printout
	2	=	extra printout, plus even more details if NSUR = 2
W2-R	WRTI(1)	=	Elapsed time to activate IWR(1) (sec).
W3-R	WRTI(2)	=	Elapsed time to turn off IWR(1) (sec).
W4-I	IWR(2)	=	Second print indicator. Same meaning as IWR(1).
W5-R	WRTI(3)	=	Elapsed time to activate IWR(2) (sec).
W6-R	WRTI(4)	=	Elapsed time to turn off IWR(2) (sec).

(66) Reflood Heat Transfer Options Card 150002 -- RST. (See Ref. 2, II-2 and II-10.) This card is optional and is used only if NSUR = 4. This card can be read on restart as well as in initialization.

W1-R	TKRK(8)	=	Exponential decay coefficient for the Hsu correlation. The default option, which can also be obtained by a zero for this value, is to use the number calculated by subroutine HSUAB.
W2-R	TKRK(9)	=	Energy partitioning coefficient for the core superheat model.

$0.0 \leq \text{TKRK}(9) \leq 1.0$ = this value is used

>1.0 = the value calculated by
subroutine HTS4 is used
(best estimate option)

W3-R $\text{TKRK}(10)$ = Multiplier for the Bromley heat transfer
coefficient. If this is zero, the default
value of 1.0 is used.
($0.0 \leq \text{TKRK}(10) \leq 10.0$)

W4-I $\text{IFLAG}(10)$ = Indicator for use of Bromley and Hsu
correlations. (Default = 0.)

0 = Bromley and Hsu are added

1 = maximum of Bromley and Hsu is used

W5-I $\text{IFLAG}(11)$ = Indicator for independent variable in the
dispersed flow weighting function.
(Default = 0.)

0 = void fraction

1 = quality

W6-R $\text{TKRK}(11)$ = Exponent of the independent variable in
the liquid portion of the weighting
function. (Default = 30.)

W7-R $\text{TKRK}(12)$ = Exponent of the superheated vapor portion
of the weighting function. (Default
= 1.0.)

W8-I IFLAG(12) = Indicator for mass flux value used to calculate Reynolds number for Dittus-Boelter superheated vapor calculation.
(Default = 0.)

0 = quality times total mass flux is used

1 = total mass flux is used

W9-R TKRK(6) = XCRIT (dryout quality). (Default = 1.0)
($0 < XCRIT \leq 1.0$)

W10-R TKRK(7) = ACRIT (dryout void fraction). (Default = 1.0.)

($0 < ACRIT \leq 1.0$)

(67) Heat Slab Data Cards 15XXXY. (See Volume I, Section 3.4 of the RELAP4/MOD5 Manual and Ref. 2, II-2.) NSLB (on Card 010001) cards must be entered with XXX = 001, 002, . . ., NSLB. Y is a sequence number, Y = 1, 2.

W1-I IVSL = Index number of volume at left slab surface where $-1 \leq IVSL \leq NVOL$.

W2-I IVSR = Index number of volume at right slab surface where $-1 \leq IVSR \leq NVOL$.

A zero value for either IVSL or IVSR means that the slab surface does not conduct heat. A value of -1 for either IVSL or IVSR means that the slab is being used as a heat exchanger with constant sink conditions on the left or right side, respectively. For this case, two more input quantities are needed; viz, constant heat transfer coefficient and a removal

fraction of the total power initially generated. The user can also model a heat exchanger slab using volumes on both sides of the slab. At least one of the quantities IVSL or IVSR must be greater than zero. If a heat slab is a core section, IVSL must be zero.

W3-I IGOM = Geometry index where $1 \leq IGOM \leq NGOM$.
NGOM is entered on the problem dimensions
data card.

W4-I ISB = Stack indicator. This number will not
affect answers if ISPROG on Card 010001
is 0 or 3 and IEMPS $\neq$ 1.

0 = this slab is at the bottom of
a stack

1 = this slab is stacked on top of
slab XXX-1

W5-I IXL0 = The indicator for slab quality (X)
calculation, which is based on the
bubble rise model for two-phase mixture
conditions.

0 = no slab X calculation

1 = calculation of X on left side
of slab

2 = calculation of X on right side
of slab

3 = calculation of X on both sides
of slab

The use of IMCL and IMCR with NSUR (on Card 150000) = 2 or 3 is indicated below. If NSUR > 3, IMCL and IMCR are not used. If NSUR = -1 or 1, they are used the same way as in MOD5.

W6-I	IMCL	=	The indicator for film boiling heat transfer and DNB correlations at left slab surface. This number has 2 digits, JK.
			K (unit's place) = film boiling correlation indicator, used only for NSUR = -1 or 1.
		0	= Groeneveld 5.9
		1	= Groeneveld 5.7
		2	= Dougall-Rohsenow
		J (ten's place)	= DNB correlation indicator, used for NSUR ≤ 2
		-1	= B&W-2, Barnett, modified Barnett
		0 or blank	= B&W-2, Barnett, modified Barnett for NSUR = -1 or 1. = W-3, Hsu-Beckner and modified Zuber for NSUR = 2
		1	= G. E.
		2	= Savannah River
		3	= W-3, Hsu-Beckner, and modified Zuber. Use only for NSUR = 2

4 = New MOD7 Correlation

W7-I IMCR = Indicator for film boiling heat transfer and DNB correlations at right slab surface. Same use as for IMCL above.

W8-R AHTL = Heat transfer area at left surface (ft^2).
AHTL = 0 if IVSL = 0.
AHTL < 0 if IVSL $\neq$ 0.

W9-R AHTR^[a] = Heat transfer area at right surface (ft^2).
AHTR = 0 if IVSR = 0.
AHTR > 0 if IVSR $\neq$ 0.

W10-R VOLSL = Total volume of slab (ft^3)
0 < VOLSL.

W11-R HDML = Left side hydraulic diameter (ft)
HDML $\geq$ 0. If HDML = 0 and IVSL > 0, HDML will be set equal to DIAMV (on Card 05XXXXY) for volume IVSL.

W12-R HDMS = Right side hydraulic diameter (ft)
HDMS $\geq$ 0. If HDMS = 0 and IVSR > 0, HDMS will be set equal to DIAMV (on Card 05XXXXY) for volume IVSR.

W13-R DHEL = Left side heated equivalent diameter (ft)
with DHEL $\geq$ 0. If DHEL = 0 and IVSL > 0, DHEL will be set equal to HDML.

[a] For stacked fuel rod heat slabs, geometry inputs for each slab within a stack must be consistent within 1% if fuel rod swelling is called (ISPROG = 1, Card 010001 or ISPROG = 0 and IEMPS $\neq$ 0, Card 010003). These parameters are: AHTR, ZBOT and ZTOP on Cards 15XXXXY and the sum of the XR's (outside radii) on Cards 17XXXXY.

W14-R DHER = Right side heated equivalent diameter (ft) with $DHER \geq 0$. If $DHER = 0$ and $IVSR > 0$, DHER will be set equal to HDMR.

W15-R CHNL = Channel length on left side (ft). If $CHNL = 0$ and $IVSL > 0$, CHNL will be set equal to ZVOL (on Card 05XXXY) for volume IVSL.

W16-R CHNR = Channel length on right side (ft). If $CHNR = 0$ and $IVSR > 0$, CHNR will be set equal to ZVOL (on Card 05XXXY) for volume IVSR.

W17-R ZBOT^[a] = Height of bottom of slab above bottom of volume on right side (ft) if $IVSR > 0$, on left side otherwise. $0 \leq ZBOT < ZVOL$ (volume height), and $ZBOT < ZTOP$, unless $ZTOP = 0$.

W18-R ZTOP^[a] = Height of top of slab above bottom of volume on right side (ft) if $IVSR > 0$; on left side otherwise. $0 \leq ZTOP \leq ZVOL$ (volume height). If $ZTOP = 0$, ZTOP is set equal to ZVOL as entered on the volume data card. If there is a volume on both sides of the heat slab, then the entire length of the slab must lie within the left volume, as well as within the right volume.

[a] For stacked fuel rod heat slabs, geometry inputs for each slab within a stack must be consistent within 1% if fuel rod swelling is called ($ISPROG = 1$, Card 010001 or $ISPROG = 0$ and $IEMPS \neq 0$, Card 010003). These parameters are: AHTR, ZBOT and ZTOP on Cards 15XXXY and the sum of the XR'f (outside radii) on Cards 17XXYY.

The following quantities are required only if IVSL or IVSR is -1 or if IMCL -J = 4:

W19-R	PFR	=	Fraction of total power generated which is removed by this slab, where $0 \leq \text{PFR} \leq 1$.
W20-R	HTC	=	Constant heat transfer coefficient in $\text{Btu/ft}^2\text{-hr}^\circ\text{F}$.
W21-R	RPF	=	Maximum radial peaking factor in channel being modeled.

(68) Wall Temperature Reset Cards 15XXX3. (See Volume I, Section 3.4 of the RELAP4/MOD5 Manual.) This set of cards allows the initialization of slab wall temperatures to values other than those determined by initial fluid conditions. The cards must satisfy $001 \leq \text{XXX} \leq \text{NSLB}$ as entered on the problem dimensions data card. Any or all cards may be omitted and the order is immaterial. If only one number is entered, the entire slab is initialized to that temperature.

W1-I	TP(1,XXX)	=	Temperature at the left side of the slab ($^\circ\text{F}$).
W2-R	TP(NODER, XXX)	=	Temperature at the right side of the slab ($^\circ\text{F}$). NODER is the number of nodes for slab XXX and is computed by the program using the values NR and NDX on the slab geometry data cards. Temperatures at the inner slab nodes are obtained by linear interpolation.

(69) Steam Generator Natural Convection Data Cards 15XXX4. (See Ref. 2, II-2.) These cards are optional. XXX is the heat slab number. Use of this option requires that variables IVSL and IVSR both be nonzero on the corresponding heat slab data Card 15XXX5. Variables ZBOT and

ZTOP on the same card must be input to reference the slab height relative to volume IVSR regardless of the value of ISHD.

W1-I ISHD = Indicator for steam generator secondary natural convection heat transfer model.

0 = model not used (this is the default value for any heat slab without one of these cards)

1 = use model on left slab surface

2 = use model on right slab surface

(70) Gamma-Heated Slab Data Cards 1560XX. (See Ref. 2, II.7.6)

These cards are optional. XX, where ($01 \leq XX \leq 50$), is the heat slab number for which gamma heating is to be imposed. One data card is entered for each slab.

W1-I IGTBL = Gamma heating power table index (equal to the Y in Card 144YXX) to be used for slab XX.

W2-R QV = Initial power density in Btu/hr-ft³ for slab XX.

(71) Core Slab Data Cards 16XXX0. (See Volume I, Section 3.4 of the RELAP4/MOD5 Manual.) NCOR (on Card 010001) cards must be entered with XXX = 001, 001, . . . , NCOR. The data required on cards 16XXX0 are Words 1 to I inclusive, where $6 \leq I \leq 8$. Y is a sequence number, 0 or 1.

W1-I ISLB = Slab number where
 $1 \leq ISLB \leq NSLB$.

W2-I
W3-I NODT = Node numbers at which temperatures are
W4-I to be printed on major edits.

W5-R CLTI = Initial cladding thickness (ft).
If CLTI > 0, then metal-water
reaction is calculated for this
core section. If CLTI = 0, then
metal-water reaction is not calculated
for this core slab.

W6-R QFRAC = Fraction of power generated in core slab
where $0 \leq QFRAC \leq 1.0$ and

$$\sum_{i=1}^{NCOR} QFRAC_i \text{ should} = 1.0.$$

W7-R QPMOD = Fraction of QFRAC in moderator as prompt
heat.

W8-R QDMOD = Fraction of QFRAC in moderator as delay
heat.

(72) Core Slab Data Cards for BE and Evaluation Models 16XXXY. (See Volume I, Section 3.10 of the RELAP4/MOD5 Manual.) Use if ISPROG = 1, W18 on Card 010001, or IEMPS ≥ 1 , W3 on Card 010003. NCOR cards must be entered with XXX = 001, 002, . . . , NCOR. Y is a sequence number where $5 \leq Y \leq 9$.

The information on this card is used in conjunction with the pin swelling logic in determining the conductivity in the gap in the fuel pin and to determine the internal pin pressure used in clad failure calculations. To provide for proper calculation of the internal gas pressure, the pin should be set up as a stack. (Refer to ISB, W4 on

Card 15XXX1.) IGP also must be set to 1 on the slab geometry data Cards 17XXXY for the gap region, but the expansion data from Cards 20XXYY are not used.

The user should also remember that a pin-type slab includes all the pins, not just one, and therefore to enter values for GSMOL, VPLENI, SL, and SN accordingly.

W1-I ISLBAJ = Flag to indicate what calculations to make after a rupture event.

0 = swollen radius and area will be used in generating metal-water reaction and heat transfer data and in adjusting flow friction in the adjacent junctions

1 = swollen radius and area will be used in generating metal-water reaction and heat transfer data only; junction flow will not be restricted (hot pin option)

2 = swollen radius will be used to adjust flow friction in adjacent junctions only (hot channel option)

W2-I ISWTAB = Indicates which table to use in determining percent blockage after swelling event.

0 = use data for multiple pins

1 = use data for single pin

W3-R ^[a]	GSMOL	=	Gram-moles of gas in pin gap and plenum ^[a]
W4-R	EF	=	Emissivity of fuel (for effective radiation conductivity). This input value will not be used when the BE Fuel Model option is employed.
W5-R	EC	=	Emissivity of clad (for effective radiation conductivity). This input value will not be used when the BE Fuel Model option is employed.
W6-R	FRACT	=	Fraction of theoretical density (for fuel porosity adjustments).
W7-R ^[b]	AFR(1)	=	Mole fraction of helium.
W8-R ^[b]	AFR(2)	=	Mole fraction of argon.
W9-R ^[b]	AFR(3)	=	Mole fraction of krypton.
W10-R ^[b]	AFR(4)	=	Mole fraction of xenon.
W11-R ^[b]	AFR(5)	=	Mole fraction of hydrogen.
W12-R ^[b]	AFR(6)	=	Mole fraction of nitrogen.
W13-R ^[b]	AFR(7)	=	Mole fraction of steam.

[a] Only the sum of the slab values for a stack of slabs is now used in any calculations. Thus, the user can distribute the stack totals within the stack slabs as he wishes. One way is to use 0.0 on all core slab cards except on the card for the first slab in the stack, where the stack totals would be used.

[b] The gas fractions are reset to FRAP-T values after the first call to FRAP-T.

- *W14-R HCOND = Conductance term when fuel pin gap is closed (Btu/sec-ft²-°F). The RELAP4/FRAP-T option contains a contact conductance calculation and this input value will not be used.
- W15-R^[a] VPLENI = Gas volume for fuel rod core section (ft³)^[a]. A plenum is required for the top slab of a stack. The volume for this should be entered for a 68°F temperature. See below for options on the use of this quantity. Note that VPLENI is an extra volume in addition to the normal gap region described on the slab geometry data cards.
- *W16-R RSHD = Radius of shoulder for axial expansion of fuel (ft). Not used when RELAP4/FRAP-T option is selected.
- *W17-R EPSMXR = Permanent hoop strain of cladding. Not used in RELAP4/FRAP-T option.
- *W18-R FSWELL = Fuel radial swelling (ft). This variable may be used to describe a fixed axial variation of fuel due to the thermal and neutron flux history of the rod. FSWELL is added to the fuel pellet radius after the normal calculation of thermal expansion. Not used in RELAP4/FRAP-T option.

[a] Only the sum of the slab values for a stack of slabs is now used in any calculations. Thus, the user can distribute the stack totals within the stack slabs as he wishes. One way is to use 0.0 on all core slab cards except on the card for the first slab in the stack, where the stack totals would be used.

* Designates information not necessary for BE fuel model.

W19-R FPEL = Pellet insulation factor for the rod plenum (dimensionless, $FPEL \geq 1.0$). Values ≤ 1.0 are used to select the temperature to be associated with the gas volume VPLENI (W15) for nonplenum slabs. If $FPEL > 0$, the effective temperature is a volume weighted radial average over the fuel region. This choice is appropriate for broadly dished areas on the pellet ends, or other voids with large radial extent. If $FPEL = 0$, the fuel centerline temperature is used for the gas in VPLENI, as for central voids. If $FPEL < 0$, the fuel surface temperature is used for the gas contained in VPLENI, as for voids dominated by cracks near the surface. Large void volumes should probably also be accompanied by modifications of the fuel power and geometry or material.

A plenum with heat transfer is defined by $FPEL \geq 1$ and spring parameters to give positive spring area and volume. If these parameters are omitted for the top (LAST) core section, an older model is used in which the adjacent coolant temperature is used for the plenum temperature.

W20-R^[a] SL = Length of the coiled spring in the plenum (ft).^[a]

[a] Only the sum of the slab values for a stack of slabs is now used in any calculations. Thus, the user can distribute the stack totals within the stack slabs as he wishes. One way is to use 0.0 on all core slab cards except on the card for the first slab in the stack, where the stack totals would be used.

W21-R^[a] SN = Number of coils in plenum spring for all pins.^[a]

W22-R SDC = Outside coil diameter of a spring (ft).

W23-R SDW = Spring wire diameter (ft).

W24-R GAMFPL = Gamma heat multiplier for rod plenum spring and clad.

(73) Slab Geometry Data Cards 17XXYY. (See Volume I, Section 3.4 of the RELAP4/MOD5 Manual.) NGOM (on Card 010001) sets of cards must be entered with XX = 01, 01, . . . , NGOM. One card is required for each region and YY is the region number.

For YY = 01

W1-I IG = Geometry type.

1 = rectangular

2 = cylindrical

W2-I NR = Number of regions where $1 \leq NR \leq \text{MAXREG} = 6$.

W3-I IM = Material index where $1 \leq IM \leq \text{NMAT} = 7$.

W4-I NDX = Number of space steps where $1 \leq \text{NDX}$ and

[a] Only the sum of the slab values for a stack of slabs is now used in any calculations. Thus, the user can distribute the stack totals within the stack slabs as he wishes. One way is to use 0.0 on all core slab cards except on the card for the first slab in the stack, where the stack totals would be used.

$$\sum_{j=1}^{NR} NDX_j < MAXNOD = 21.$$

(MAXNOD $\leq$ 20 for BE Fuel Model)

W5-R X0 = Radial distance to left surface (ft) X0 = 0
for a solid rod or a flat slab.

W6-R XR = Region width (ft).

W7-R PF = Fraction of slab power generated in
region.

For YY = 02, 03, . . . , NR

W1-I IGP = Gap indicator

0 = no gap

1 = gap expansion model desired

Neither two successive region cards nor the
last card in the set can have IGP = 1.

W2-I	IM	}	Same as for the first region card. (However if IGP = 1 then NDX must = 1).
W3-I	NDX		
W4-R	XR		
W5-R	PF		

(74) Core Heat Slab Power Distribution Cards 174XXY. These optional
cards allow for non-uniform fuel power distribution in the first radial region
of core heat slabs. If these cards are absent, uniform power distribution is
assumed. XX = distribution set number, 0 < XX $\leq$ 12.

A. $0 \leq Y \leq 4$

$$W1-R \quad PFN(1,XX) = P_1/\bar{P}_{R1}$$

$$W2-R \quad PFN(2,XX) = P_2/\bar{P}_{R1}$$

...

...

...

$$WN-R \quad PFN(N,XX) = P_N/\bar{P}_{R1}, \text{ where}$$

P_i = power generation rate at radial node i ,

$\bar{P}_{R1}$ = average power generation rate
for the first radial region, and

N = the last radial node in the
first radial region.

$$PFN(I,XX) \geq 0.0$$

If $F = \frac{\sum PFN_i * V_i}{\sum V_i}$ is not nearly equal to 1.0, then the PFN's are divided by F so that the fraction is equal to 1.0, and a message is printed.

B. $5 \leq Y \leq 9$

These cards are required if and only if the above A cards are present.

W1-I K1 = number of 1st core heat slab using set XX

W2-I K2 = number of 2nd core heat slab using set XX

...

...

...

WM-I KM = number of Mth core heat slab using set XX
 [XX is stored into NPD(K1), NDP(K2), ---NPD
 (KM).]

All core slabs using set XX must have the same geometry, which has N nodes in the first radial region.

(75) Heat Slab Node Temperature Reset Cards 175XXY. (See Ref. 2, II-7.4.) These cards are optional. New node temperatures for any heat slab can be input where XX is the heat slab number, Y is a sequence number (Y = 0, 1, 2, 9) beginning at 0 and must be sequential for a heat slab.

W1-R	TP(1)	=	New node temperatures beginning at node
...	...		1 (left side) and continuing until a
...	...		temperature has been entered for all nodes.
...	...		The total number of nodes, N, for a
WN-R	TP(N)		heat slab geometry is:

$$N = 1 + \sum_{n=1}^{NR} NDX_n$$

where

NR = number of regions

NDX_n = number of space steps input for region n.

See description on page 61, Vol. I of the RELAP4/MOD5 User's Manual for an example of node spacing.

(76) Moving Mesh Refinements Data Cards 1790X0. (See Ref. 2, II-1.1.) ($1 \leq X \leq 9$). One card must be entered for each stack of (coarse) core heat slabs for which moving mesh refinements are desired.

W1-I LSLAB = Slab number of the bottom slab of the core heat slab stack to which the following specifications apply.

W2-I MTRIP = Trip index to signal activation or deactivation of moving mesh refinements in stack.

0 = moving mesh refinements continually active for stack

>1 = activate moving mesh refinements in stack according to signal monitoring specified on trip control data card for which IDTRIP = MTRIP

<-1 = deactivate moving mesh refinements in stack according to signal monitoring specified on trip control data for which IDTRIP = MTRIP (maintain active otherwise)

W3-I NTEMP = Indication of radial extent of moving mesh refinements.

-1 = moving mesh refinements extend through coarse slabs (recommended).

0 = moving mesh refinements restricted to cladding or outer region only. (Not recommended - see Ref. 2, II-1.1.)

W4-R DZF = Common height of fine slabs in central group (ft).
 (DZF should be an integral divisor of DZM.)

W5-R DZM = Common nominal maximum height of the medium-
 sized slabs in the outer groups (ft). (DZM
 should be an integral divisor of the common
 height of the coarse slabs in the stack.)

W6-R SMINF = Minimum distance to be encompassed by central
 group of fine mesh slabs (ft).

W7-R SMINLO = Minimum distance to be encompassed by lower
 group of medium mesh slabs (ft).

W8-R SMINUP = Minimum distance to be encompassed by upper
 group of medium mesh slabs (ft).

(77) Moving Mesh Refinements Data Card 179099. (See Ref. 2,
 II-1.1.)

W1-I MSMAX = Upper bound for the maximum total number
 of active moving mesh heat slabs which
 the problem will involve at one time. The
 default value is 30. (Number is used for
 input-time memory allocation.)

(78) Thermal Conductivity Data Cards 18XXYY -- RST. (See Volume
 I Section 3.4 of the RELAP4/MOD5 Manual.) NMAT (on Card 010001) sets
 of data must be entered with XX indicating the material number, XX = 01,
 02, . . ., NMAT. YY is the card sequence number for each set where
 $00 \leq YY \leq 99$. The cards are ordered by YY, but YY need not start at
 00 and need not be consecutive. An arbitrary number of items may be
 entered on each card. At least one table pair must be entered. The BE
 Fuel Model will construct tables of thermal conductivity. However, the
 user must continue to enter card series 18XXYY for the fuel material.

W1-I NKP = Number of points in thermal conductivity table ($1 \leq |NKP| \leq 20$). Positive value indicates no extrapolation. Negative value indicates extrapolation. If NKP = 1, a constant value is used.

W2-R TPK(1) = Temperature ($^{\circ}$ F) for the first point.

W3-R TPK(2) = Thermal conductivity (Btu/ft-hr- $^{\circ}$ F) for the first point.

W4-R TPK(3) = Temperature for the second point.

W5-R TPK(4),

... ... Until NKP points are entered, where
 temperature values are in ascending
 order.

(79) Volumetric Heat Capacity Data Cards 19XXYY -- RST. NMAT (on Card 010001) sets of data must be entered with XX indicating the material number, XX = 01, 01, . . . , NMAT. YY is the card sequence number for each set where $00 \leq YY \leq 99$. The cards are ordered by YY, but YY need not start at 00 and need not be consecutive. An arbitrary number of items can be entered on each card. At least one table pair must be entered. The BE Fuel Model will construct tables of volumetric heat capacity. However, the user must continue to enter card series 19XXYY for the fuel material.

W1-I NCP = Number of points in heat capacity table where $1 \leq |NCP| \leq 20$.

A positive value indicates no extrapolation while a negative value permits extrapolation. If NCP = 1, a constant value is used.

W2-I TPC(1) = Temperature ($^{\circ}\text{F}$) for first point.

W3-R TCP(2) = Volumetric heat capacity ($\text{Btu}/^{\circ}\text{F}\text{-ft}^3$) for
first point.

W4-R TPC(3) = Temperature for second point.

W5-R TPC(4),

... ... Until NCP points are entered, where
... ... temperature values are in ascending order.

(80) Linear Expansion Coefficient Data Cards 20XXYY -- RST.

(See Volume I, Section 3.4 of the RELAP4/MOD5 Manual.) These cards are required for each material only if any heat slab specifies the gap expansion model, that is, if IGP on any Card 17XXYY is 1. NMAT (on Card 010001) sets are entered with XX indicating the material number, $\text{XX} = 01, \leq \text{YY} \leq 99$. The cards are ordered by YY, but YY need not start at 00 and need not be consecutive. An arbitrary number of items may be entered on each card.

W1-I NXP = Number of points in linear expansion
coefficient table where $1 \leq |\text{NXP}| \leq 20$.
A positive value indicates no extrapolation
while a negative value permits extrapolation.
If $\text{NXP} = 1$, a constant value is used.

W2-R TPX(1) = Temperature ($^{\circ}\text{F}$) for first point.

W3-R TPX(2) = Linear expansion coefficient ($^{\circ}\text{F}^{-1}$) for first
point.

W4-R TPX(3) = Temperature for second point.

W5-R TPX(4),

...
...
...

Until NXP points are entered, where
temperature values are in ascending order.

(81) Heat Exchanger Data Cards 21XXYY -- RST. (See Volume I, Section 3.6.13 of the RELAP4/MOD5 Manual.) This option provides two simplified heat exchanger models. Neither model has heat conduction.

NHTX (on Card 010001) sets of data must be entered with $xx = 01, 02, \dots$, NHTX. YY is the card sequence number for each set where $00 \leq YY \leq 99$. The cards are ordered by YY, but YY need not start at 00 and need not be consecutive. An arbitrary number of items may be entered on each card. If a table is entered, at least one table pair must be entered.

W1-I	IHTX	=	Number of data points with 0 meaning flow and temperature dependent, i.e. $IHTX = 0$ or $2 < IHTX < 20$. A positive value indicates no extrapolation while a negative value permits extrapolation. $IHTX = 1$, a constant value. $ IHTX \geq 1000$ means data points are to come from FORTRAN Unit 24. See Section II-9.1.
W2-I	ITHXQ	=	Trip number IDTRP controlling heat exchanger with $2 \leq ITHXQ \leq 20$. If $IHTX = 0$, ITHXQ may be 0, since it is neither used nor checked.
W3-I	JVOL	=	Volume number. Only one nonconduction heat exchanger may be in a given volume.

If $IHTX = 0$

For $IHTX = 0$, the trip turns off the flow.

W4-R	HTQ	=	Fraction of power removed by heat exchanger.
------	-----	---	--

W5-R TSEC = Secondary side temperature (°F).

W6-R HTXCO = Heat exchanger coefficient
 (Btu-sec/hr-°F-lbm).

If HTXCO is entered as zero, then the program calculates the steady state value as $HTXCO = \text{heat removal rate} / (\text{initial flow multiplied by the temperature difference between the primary fluid and secondary fluid})$.

If initial flow is zero, the user must put in a nonzero value for HTXCO.

The program will always use the entered value of HTXCO if it is nonzero.

If |IHTX| > 0

For |IHTX| > 0, the trip turns on the use of the table. Prior to the trip, the first table value is used.

W4-R HXTXBL(1) = Time (sec) for the first point.

W5-R HTXTBL(2) = Normalized power for the first point.

W6-R HTXTBL(3) = Time for the second point.

W7-R HTXTBL(4),

... ...
... ...

Until IHTX points are entered, where time values are in ascending order.

(82) Self-Initialization Core Inlet/Outlet Volume Description Card 220200. This card is optional. The presence of this card sets the thermal self-initialization flag to true. It is required if the user wishes to use the thermal self-initialization feature.

W1-I ICRIN = Volume number for control volume just upstream of the core.

W2-I ICROUT = Volume number for control volume just downstream of the core.

(83) Self-Initialization Steam Generator Description Cards 2201XY.
A set of these cards is required for each steam generator modeled if and only if Card 220200 (thermal self-initialization) is input.

$0 \leq X < n$ where n is the number of steam generators (≤ 10).

$0 \leq Y \leq 9$ where Y is the card sequence number in each steam generator set.

There may be up to 9 primary volumes per steam generator.

W1-I IVOL(1) = Steam generator inlet plenum volume number.

W2-I IVOL(2) = First steam generator primary volume number (next to the inlet plenum).

W3-I IVOL(3) = Next primary volume number.

...

...

...

W_{M-4}-I IVOL(M-4) = Last primary volume number before outlet plenum.

$W_{M-3}-I$ $IVOL(M-3)$ = Steam generator secondary volume number.
 $W_{M-2}-I$ $IVOL(M-2)$ = Steam generator outlet plenum volume number.
 $W_{M-1}-I$ $IVOL(M-1)$ = Secondary feedwater junction number.
 W_M-I $IVOL(M)$ = Secondary steam outlet junction number.

(84) Self-Initialization Core Flow Path Description Cards 2202XY.

This card is required for each core flow path if and only if Card 220200 (thermal self-initialization) is input.

$1 \leq X \leq n$ where n is the number of core flow paths to a maximum of 5 paths with up to 15 volumes per path.

$0 \leq Y \leq 9$ where Y is the card sequence number within set X .

$W1-I$ $IVOL(1)$ = Volume number of core volume nearest inlet end of core.
 $W2-I$ $IVOL(2)$ = Next core volume number.
 ...
 ...
 ...
 $WM-I$ $IVOL(M)$ = Volume number of core volume nearest outlet end of core.

(85) Self-Initialization Steam Generator to Core Description Card 22026Y. This card is required if and only if Card 220200 (thermal self-initialization) is input.

$0 \leq Y \leq 9$ where Y is the card sequence number.

$0 < M \leq 40.$

W1-I ICOIN(1) = Volume numbers for all volumes between the
 steam generator outlet plenum and the volume
 upstream of the core inclusive, any order,
 until all M such volumes have been entered
 for all steam generator to core paths (no
 duplicate volume numbers).
 ...
 ...
 ...
 WM-I ICOIN(M)

(86) Self-Initialization Core to Steam Generator Description Cards
 22028Y. This card is required if and only if Card 220200 (thermal self-
 initialization) is input.

$0 \leq Y \leq 9$ where Y is the card sequence number.

$0 < M < 40$.

W1-I IC00UT(1) = Volume numbers for volumes between the
 core outlet (e.g., upper plenum) and the
 steam generator inlet plenum inclusive,
 any order, until all M such volumes have
 been entered for all core-to-steam
 generator paths (no duplicate volume
 numbers).
 ...
 ...
 ...
 WM-I IC00UT(M)

(87) Self-Initialization Pump to Steam Generator Description Cards
 22030X. This card is required if and only if Card 220200 (thermal self-
 initialization) is input.

$0 \leq X < n$ where n is the number of steam generators ($n \leq 10$).

$0 < M \leq 24$.

W1-I IVV(1) = The volume number of the pump for the
 group.

W2-I IVV(2) = The volume number of a volume between the
 ... pump volume and the steam generator outlet
 ... plenum, in order from the pump, proceeding
 ... upstream until all such volumes have been
 entered.

WM-I IVV(M) = The volume number of the steam generator
 outlet plenum in that group.

(88) Self-Initialization Parallel Path Description Card 22031X.

These cards are optional and may be input only if Card 220400 (pressure self-initialization) is input. These cards allow pressure flow balancing within paths parallel to the main flow paths, i.e., primarily core flow paths.

$0 \leq X < n$ where n is the number of parallel paths being described with a maximum of 10 paths.

$0 < M \leq 20$.

W1-I IJUNSC(1) = Number of the first junction in the path,
 either end. This junction connects the
 first volume of the parallel path with a
 volume of the primary path.

W2-I IJUNSC(2) = Number of the next junction in the path.
 ...
 ...
 ...

WM-I IJUNSC(M) = Number of the last junction in the path.
 This junction connects the last volume of
 the path with a volume of the primary path.

(89) Self-Initialization Dead End Path Description Card 22032X.

These cards are optional and may be input only if Card 220400 (pressure

self-initialization) is input. These cards enable the self-initialization model to minimize accelerations on dead end paths with zero initial flow. Descriptions of dead end paths branching from other dead end paths must be entered with a higher sequence number than that of the parent dead end path.

$0 \leq X < n$ where n is the number of different dead end paths with a maximum of 10 paths.

$0 < M \leq 20$.

W1-I	IJUND(1)	=	Number of the junction connected to the flow loop.
W2-I	IJUND(2)	=	Number of the next junction in the dead end path.
...			
...			
...			
WM-I	IJUND(M)	=	Number of the last junction in the dead end path.

(90) Self-Initialization Downstream Main Flow Loop Description Card 220400. The main flow channel through the core should be included in the flow loop. This card sets the pressure self-initialization flag to true. It is required if the user wishes to use the pressure self-initialization feature. $N \leq 38$.

W1-I	IVOL(1)	=	Volume number of the pressure reference volume within the flow loop.
W2-I	IVOL(2)	=	Volume number of the next volume downstream in the loop.

...

...

...

WN-I IVOL(N) = Volume number of the pump in the flow loop.

(91) Self-Initialization Upstream Main Flow Loop Description Card 220401. This card is required if and only if Card 220400 (pressure self-initialization) is input.

$N \leq 38$.

W1-I IVOL(1) = Number of the pressure reference volume
(same as on W1-I, Card 220400).

W2-I IVOL(2) = Number of the next volume upstream.

...

...

...

WN-I IVOL(N) = Number of the pump in the flow loop (same
as WN-I, Card 220400).

(92) Self-Initialization Non-Main Flow Loop Description Cards 22040Y. These cards must be entered in even/odd consecutive pairs. They are required for all non-main flow paths if and only if Card 220400 (pressure self-initialization) is input.

$N \leq 38$.

For Y = 2, 4, 6:

W1-I IVOL(1) = Number of the last volume in common with
the main reference loop on the core outlet
end.

W2-I IVOL(2) = Number of the next volume in the loop down-
stream.

...

...

...

WN-I IVOL(N) = Volume number of the pump in the loop.

For Y = 3, 5, 7:

W1-I IVOL(1) = Number of the last volume in common with
the main reference loop on the core inlet
end.

W2-I IVOL(2) = Number of the next volume in the loop up-
stream.

...

...

WN-I IVOL(N) = Volume number of the pump in the loop.

(93) Self-Initialization Negative Residual Turnoff Card 220408.

This card is optional, but recommended for use with the self-initialization option. It may be entered only if Card 220400 (pressure self-initialization) is input.

W1-I IFLAG = Any integer. This prevents negative residuals from causing the problem to fail. However, the final set of residuals should be inspected carefully to ensure that all negative residuals are, in fact, insignificant.

(94) Self-Initialization Reference Temperature Volume Descriptions Cards 22041Y. This card is optional and may be input only if Card 220200 (thermal self-initialization) is input.

$1 \leq Y \leq n$ where n is the number of different volume groups, each with a temperature reference volume, to a maximum of 9 groups, with a maximum of M volumes per group, $M \leq 10$.

W1-I ISAME(1) = The number of the volume to be used as a temperature reference for the following volumes on the card (their temperature will be set to the temperature of the reference volume).

W2-I ISAME(2) = The number of a volume whose temperature is to be set equal to the temperature of the volume ISAME(1).

...

...

...

WM-I ISAME(M)

(95) Blockage, Swelling, Gap Reduction Data Card 25000. (See Volume I, Section 3.10 of the RELAP4/MOD5 Manual.) Use if and only if ISPROG = 1, W18 on Card 010001, or IEMPS $\geq$ 1, W3 on Card 010003.

W1-I IRGPIN = Region number of external region of fuel pellet. (Defaults to 1.)

W2-I IRGGAP = Region in heat slab where gap is present. (Defaults to 2.)

Note: When this card is used, the logic assumes a gap will be present.

W3-I IRGSW = Region in heat slab where clad swelling takes place. (Defaults to 3.)

W4-I IMSPR = Material index for rod plenum spring. (Defaults to built-in constants as follows: $C = 32.2 \text{ Btu/ft}^3\text{-}^\circ\text{F}$ for clad and 60.0 for spring; $K = 0.00253 \text{ Btu/sec-ft-}^\circ\text{F}$ for clad and 0.0027 for spring.)

W5-R PITCH = Pin pitch in lattice (ft).

(96) ECC Bypass Input Data Card 260001 -- EM. (See Volume I, Section 3.10 of the RELAP4/MOD5 Manual.) Use if and only if ISPROG = 1, W18 on Card 010001, or IEMEC = 1, W4 on Card 010003.

W1-I IACCV(1) = First accumulator volume.

W2-I IACCV(2) = Second accumulator volume.

W3-I IACCV(3) = Third accumulator volume.

W4-I IACCV(4) = Fourth accumulator volume.

W5-I ITRIP(1) = Junction number for 1st accumulator
volume outlet.

W6-I ITRIP(2) = Junction number for 2nd accumulator
volume outlet.

W7-I ITRIP(3) = Junction number for 3rd accumulator
volume outlet.

W8-I ITRIP(4) = Junction number for 4th accumulator
volume outlet.

W9-I IDNCMV = Volume monitored for end-of-bypass (EOB).

W10-I VINPUT = Velocity above which EOB occurs in
volume IDNCMV (ft/sec). Downward flow is
assumed to be the positive direction.

W11-I IREMV(1), Volumes from which injected accumulator
... ... fluid is to be subtracted at EOB. Volumes
... ... are adjusted in order of input.

W20-I IREMV(10)

(97) Multiple Pin Clad Rupture Data Cards 270001 - 270099. (See Volume I, Section 3.10 of the RELAP4/MOD5 Manual.) These cards may be used if and only if ISPROG = 1, W18 on Card 010001, or IEMPS ≥ 1 , W3 on Card 010003.

W1-I NTAB1 = Number of points in table with
 $0 < |NTAB1| \leq 25$.

A positive value indicates no extrapolation while a negative value permits extrapolation.

W2-R TAB1(1) = Average rupture temperature for first point.

W3-R TAB1(2) = Pressure differential across clad (psia for first point.

W4-R TAB1(3) = Average rupture temperature for second point.

W5-R TAB1(4),

... ... Until NTAB1 points have been entered.

(98) Multiple Pin Flow Blockage Data after Rupture Cards 280001 - 280099. (See Volume I, Section 3.10 of the RELAP4/MOD5 Manual.) These cards may be used only if ISPROG = 1, or IEMPS ≥ 1 .

W1-I NTAB2 = Number of points in table where
 $0 < |NTAB2| \leq 25$.

A positive value indicates no extrapolation while a negative value permits extrapolation.

W2-R TAB2(1) = Percent blockage of flow area for first point.

W3-R TAB2(2) = Pressure differential across clad (psia) for first point.

W4-R TAB2(3) = Percent blockage for second point.

W5-R TAB2(4),

... ... Until NTAB2 points have been entered.

(99) Single Pin Clad Rupture Data Cards 290001 - 290099.

(See Volume I, Section 3.10 of the RELAP4/MOD5 Manual.) These cards may be used only if ISPROG = 1, or IEMPS $\geq$ 1.

W1-I NTAB3 = Number of points in table where
 $0 < |NTAB3| \leq 25$.

A positive value indicates no extrapolation while a negative value permits extrapolation.

W2-R TAB3(1) = Average rupture temperature for first point.

W3-R TAB3(2) = Pressure differential across clad (psia) for first point.

W4-R TAB3(3) = Average rupture temperature for second point.

W5-R TAB3(4),

... ... Until NTAB3 points have been entered.

(100) Single Pin Flow Blockage Data after Rupture Cards 300001 - 300099. (See Volume I, Section 3.10 of the RELAP4/MOD5 Manual.)

These cards may be used only if ISPROG = 1, or IEMPS $\geq$ 1.

(102) FLECHT Heat Transfer Correlation Data Card 400002 -- FLOOD.
(See Volume I, Section 3.11 of the RELAP4/MOD5 Manual.)

W1-R	DTSUB	=	Subcooling temperature (°F) ECC Water.
W2-R	TINIT	=	Maximum initial clad temperature (°F).
W3-R	QMAXFD	=	Peak power input (kW/ft).
W4-R	BFFF	=	Fraction of channel blockage.
W5-R	HRAD	=	Radiation heat transfer coefficient (Btu/hr-ft ² -°F). If HRAD = 0.0, the code will compute a value.
W6-R	CORCHL	=	Core channel length (ft).

(103) Aerojet A Entrainment Correlation Data Card 400003 -- FLOOD.
(See Volume I, Section 3.11 of the RELAP4/MOD5 Manual.) Use only if
IENT = 2, W1 on Card 40001.

W1-R	EN2	=	Entrainment fraction at liquid level = HC2.
W2-R	HC1	=	Liquid level (ft).
W3-R	HC2	=	Liquid level (ft).

(104) Core Outlet Enthalpy Data Card 400004 -- FLOOD. (See Volume
I, Section 3.11 of the RELAP4/MOD5 Manual.) Optional, if not specified
defaults to calculated value.

W1-R	HCOU	=	Core outlet enthalpy (Btu/lbm).
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(105) Junction and Volume Numbers Data Card 400005 -- FLOOD:

(See Volume I, Section 3.11 of the RELAP4/MOD5 Manual.)

W1-I	JUNIN	=	Core inlet junction number.
W2-I	JUNOUT	=	Core outlet junction number.
W3-I	JUNWSL	=	Water slip junction number.
W4-I	JUNSSL	=	Steam slip junction number.
W5-I	NCVOL	=	Core volume number.
W6-I	NUPVOL	=	Upper plenum volume number.
W7-I	NLPVOL	=	Lower plenum volume number.
W8-I	NDCVOL	=	Downcomer volume number.

(106) Entrainment Correlation Card 400011. (See Ref. 2, II-1:3.)

Cards 400011, 400012, 400013, 400014, and 400015 can be grouped to yield both implicit and explicit entrainment calculations employing various correlations. When IENT on Card 400011 equals 21, 22, 23, 24, or 25 the specified entrainment model will be used in volumes for which VBUB on Card 06XXX1 is set equal to -3. Entrainment option 24 is recommended for reflood calculations. Use IENT > 20 when core superheat (Card 400017) is used.

W1-I	IENT	=	Entrainment correlation.
	1	=	Babcock and Wilcox correlation - explicit approach
	2	=	Aerojet A - explicit approach

- 3 = Aerojet B - explicit approach
- 4 = Steen-Wallis correlation - explicit approach
- 21 = Babcock and Wilcox correlation - implicit approach
- 22 = Aerojet A - implicit approach
- 23 = Aerojet B - implicit approach
- 24 = Steen-Wallis correlation - implicit approach
- 25 = Griffith-Kirchner REFLUX model - implicit approach

(107) Entrainment Correlation Data Input Card 400012. (See Ref. 2, II-1.3.) This card required for IENT = 1, 2, 3, 4, 21, and 23.

- W1-R DTSUB = Subcooling of water entering bottom of core (°F).
- W2-R TINIT = Maximum initial clad temperature (°F).
- W3-R QMAXF = Peak power input (kW/ft).
- W4-R CORCHL = Core channel length (ft).

(108) Entrainment Correlation Data Input Card 400013 -- RST. (See Ref. 2, II-1.3.) This card is required for IENT = 2, 4, 22, and 24.

- W1-R EN2 = Maximum entrainment fraction.

W2-R HC1 = Constant used in Aerojet A and Steen-Wallis model. Entrainment fraction exponential factor parameter (IENT = 4 or 24).

W3-R HC2 = Constant used in Aerojet A and Steen-Wallis model. Entrainment fraction exponential factor parameter (IENT = 4 or 24).

(109) Core Outlet Enthalpy Card 400014. (See Ref. 2, II-1.3.) Optional; if not specified defaults to the calculated value. Can only be used with IENT = 1, 2, 3, or 4.

W1-R HCOU = Core outlet enthalpy (Btu/lbm).

(110) Junction and Volume Numbers Card 400015. (See Ref. 2, II-1.3.) This card is required for IENT = 1, 2, 3, 4, 21, and 23.

W1-I JUNIN = Core inlet junction number. The positive flow direction must be from lower plenum to core.

W2-I JUNOUT = Core outlet junction number. The positive flow direction must be from core to upper plenum.

W3-I NCVOL = Core volume number.

W4-I NUPVOL = Upper plenum volume number.

W5-I NLPVOL = Lower plenum volume number.

(111) PWR Upper Plenum Deentrainment and Fallback Card 400016. (See Section II-1.4 and II-1.5.) The deentrainment model will be used in the volume for which VBUB on Card 06XXX1 equals -4. In a similar fashion, fallback will be calculated at all junctions specified by NSGVOL

(7), (8), (9), (10), (11), and (12) providing $SRCOS > 0$ and $IFLOOD > 0$ in Cards 08XXXY for core/upper plenum junctions XXX.

W1-R	TSKRK(1)	=	Critical velocity for entrainment (V_{crit}). The recommended values are 3.0-7.0 ft/sec.
W2-R	TSKRK(2)	=	Exponential entrainment coefficient (B). The recommended value is 0.05.
W3-R	TSKRK(3)	=	Minimum deentrainment efficiency (ϵ_0). The recommended value is 0.0.
W4-R	TSKRK(4)	=	Maximum deentrainment efficiency (ϵ_1). The recommended value is 1.0.
W5-R	TSKRK(5)	=	Critical pool depth in upper plenum (z_{crit}). The recommended input is 0.2 ft.
W6-R	TSKRK(6)	=	Bradie-Dickson multiplier C_1 . The recommended value is 0.01.
W7-R	TSKRK(7)	=	Bradie-Dickson velocity power C_2 . The recommended value is 3.0.
W8-I	NSGVOL(1)	=	Volume number in which model is to be applied (upper plenum).
W9-I	NSGVOL(2)	=	0 for PWR -- upper plenum outlet junction number.
W10-I	NSGVOL(3)	=	0 for PWR -- core spray junction number.
W11-I	NSGVOL(7)	=	0 (variable not presently used).

W12-I	NSGVOL(8)	=	Junction numbers of junctions entering the
W13-I	NSGVOL(9)		upper plenum which contribute steam flow for
W14-I	NSGVOL(10)		entrainment. If fewer than six junctions are
W15-I	NSGVOL(11)		used, set the remaining values to zero.
W16-I	NSGVOL(12)	= 1	To activate fallback model.
W17-I	NSGVOL(4)	≠ 1	The deentrainment model is used
			but no fallback is calculated.

Note: The fallback or deentrainment models cannot be used concurrently with the steam generator data cards.

(112) Core Superheat Model Card 400017. (See Ref. 2, II-1.6.)

The model will be used to calculate local fluid properties for heat slabs and volume outlet enthalpy for volumes specified on this card. This model should be used with VBUB on Card 06XXX1 set to -3 and IENT > 20 on Card 400011 for the volumes specified.

W1-I	ISHVOL(2)	=	Core volume number within which the
W2-I	ISHVOL(3)		core superheat model is to be used.
W3-I	ISHVOL(4)		Can use up to twelve core volume numbers.

(113) Core Model Numerical Coupling Card 400018. (See Ref. 2, II-1.7.) This card allows the selection of the numerical coupling of the liquid entrainment and vapor superheating models to the basic homogeneous model for all core volumes for which the models are specified. The default value is 0 (i.e. explicit coupling).

W1-I	ISUPEX	=	Core model coupling indicator.
		0	= Use the explicit coupling scheme.
		1	= Use the implicit coupling scheme.

(116) Ice Condenser Data Cards 51XXX0 - CONT. (See Volume I, Section 3.12 of the RELAP4/MOD5 Manual.) This card is optional and is used only if ISPROG = 3 (W18 on Card 010001).

Data are required only for volumes containing ice. A card numbered 51XXX0 is required for each of these volumes where the XXX is the RELAP4 volume number defined by the 05XXX0 cards. The volumes (number XXX) containing ice may be randomly distributed. Data items on each card include:

W1-R	NVOLI	=	Number of ice columns (may be a nonintegral value).
W2-R	RCICE	=	Radius of ice columns (ft).
W3-R	HCICE	=	Height of ice columns (ft).
W4-R	INTICE	=	Initial mass of ice (lbm).
W5-R	TINICE	=	Initial ice temperature (°F) (≤ 32.018 °F).
W6-R	ALSUBC	=	Condensate thickness in heat transfer correlation (ft).
W7-R	FRHEAT	=	Fraction of melted ice which is to be raised in temperature.
W8-R	THEAT	=	Temperature to which melted ice will be raised (°F).

If input value is less than 32.018°F, it is set to 32.018°F.

W9-R	HTCLIM	=	Upper limit for the calculated heat transfer coefficient for ice columns (Btu/hr-ft ² -°F).
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W10-R C1 = User input constant, C_1 , to be used to modify the calculated heat transfer coefficient (dimensionless).

W11-R C2 = User input constant, C_2 , to be used to modify the calculated heat transfer coefficient ($\text{Btu/hr-ft}^2\text{-}^\circ\text{F}$).

2.3 Input for Tape Editing

An old plot tape must be mounted on FORTRAN Unit 3. The normal RELAP4 program is used with the following input definitions.

(1) Title Card. The first 12 columns of the last title must be identical to the first 12 columns of the title card of the problem which is to be edited.

(2) Problem Dimensions Data Card 010001.

W1-I LDMP = -3.

W2-I NEDI = Number of minor edit variables where $0 \leq \text{NEDI} \leq 9$.

W3-I NTC = Edit frequency control card count where $1 \leq \text{NTC} \leq 20$.

W4-I NTRP = 0.

W5-I IUNITS = Units selection control where 1 is English output and 2 is SI output.

These are the only control integers required for a tape edit.

(3) Edit Variable Data Card 020000. One card is required if NEDI (on Card 010001) > 0, and the same rules apply as for the original problem. The quantities being edited need not have any relation to those of the original run.

(4) Edit Frequency Control Data Cards 03XXX0. The number of cards totaling NTC (on Card 010001) must be entered with XXX = 001, 002, . . . , NTC.

W1-I	NMIN	=	Number of plot records per minor edit (0 is interpreted as 1).
W2-I	NMAJ	=	Number of minor edits per major edit (0 is interpreted as 50).
W3-R	DELT	=	Time step size (sec) between plot records, if known (0 < DELT).
W4-R	TLAST	=	End of current edit frequency control data ($TLAST_{i-1} < TLAST_i$).

2.4 Input for Restarting

An old restart data tape to be used must be mounted on FORTRAN Unit 3 and a blank tape must be mounted on Unit 4. The RELAP4 program is used with the following input definitions.

(1) Title Card. The first 12 columns of the last title must be identical to the first 12 columns of the title card of the problem which is to be restarted.

(2) Problem Dimensions Data Card 010001.

W1-I LDMP = N, the restart number of the old problem
where restart is to begin where
 $1 \leq \text{LDMP} \leq 999$.

W2-I NEDI = Number of minor edit variables where
 $0 \leq \text{NEDI} \leq 9$.

W3-I NTC = Time step card count where
 $1 \leq \text{NTC} \leq 20$.

W4-I NTRP = Number of trip control cards where
 $0 \leq \text{NTR} \leq 20$.

NTRP = 0 will cause the trip control values
from the restart tape to be used.
Item (5), trip control data Cards
04XXX0, discusses the use of NTRP.

W5-I IUNITS = Units selection control where 1 is English
output and 2 is SI output.

(3) Edit Variable Data Card 020000. One card is required if
NEDI (on Card 010001) > 0 , and the same rules apply for the original
problem. The quantities being edited on the new run need not have any
relation to those of the original run.

(4) Time Step Data Cards 03XXX0. The number of cards totaling
NTC (on Card 010001) must be entered with $\text{XXX} = 001, 002, \dots, \text{NTC}$.
The same rules apply as for the original problem. The time step sequence
on the new run need not have any relation to that of the old run. No
cards referring to problem times previous to the point of restart will
be used, but they may be entered. A TLAST equal to the transient time
at restart causes difficulties unless that TLAST value was used in the
old run to be restarted.

(5) Trip Control Data Cards 04XXX0. The number of cards totaling NTRP (on Card 010001) must be entered with XXX = 001, 002, . . ., NTRP. If no trip cards are submitted (NTRP = 0), the trip information will be retrieved from tape as if no break in the problem has occurred. However, if any trip cards are used upon restart, then a complete set of trip cards with the same sequence numbers (NTRP) and IDTRP's must be used. Submission of a new card with an IDSIG not equal to 0 will turn the trip off and substitute the new specifications. For a trip to remain actuated once tripped, a card corresponding to the original card should be submitted with IDSIG set equal to 0.

Since the use of trip cards on restart is frequently a source of confusion to users, it is safest to avoid using them when possible. This may be done by using a very large end of problem time trip and stopping the run by the ENDCPU option or by going beyond the end of the time step tables.

(6) Optional Restart Cards. Certain data and data tables may be read into RELAP4 upon restart. Following is a list of the data cards which are allowed to be used in this manner and which require some additional explanation. (The user should refer to Ref. 2, II-2.2 for descriptions of these data cards).

(a) Junction Data Cards (08XXXY). These cards may be supplied upon restart for any existing junction. For restart, the first three words of input on each card set (IW1, IW2, IPUMP) are ignored, but must still be supplied. The correct value of WP must be given. If the old values of FJUNF (forward form loss coefficient), FJUNR (reverse form loss coefficient), and DIAMJ (junction diameter) are to be retained for restart, these must be entered with the same values shown on the initialization printout for the previous problem run under "Junction Data Actually Used." If different values for these parameters are desired, the actual values must be supplied -- they will not be computed upon restart.

(b) Valve Data Cards (11XXX0). Valve data cards may be supplied upon restart for some or all of the existing valves. If the user wishes, he may also supply data for additional valves.

(c) Time-dependent Volume Data Cards (07XXYY). Data may be supplied for some or all of the existing time-dependent volume tables.

(d) Pump Head Multiplier, Pump Torque Multiplier, Pump Motor Torque, Pump Speed vs Time Data Cards (0910YY, 0920YY, 0970XY, 098XXY). Data may be supplied upon restart for any existing table.

(e) Pump Head and Torque Data Cards (10XXYZ). These cards may be supplied for any existing table within a pump curve set. If any of these cards are used, the 100000 Data Card (Pump Curve Input Indicator) must also be supplied.

(f) Leak Table Data Cards (12XXYY). These cards could already be supplied for existing tables, but now the user may provide data for additional tables if he wishes.

(g) Fill Table Data Cards (13XXYY). Use of any of these cards upon restart will require all fill data to be supplied. Data for an arbitrary number of fill tables may be entered.

(h) Scram Table Data Cards (14YYXX). All scram table data must be supplied if any of these cards are used for restart. Data for an arbitrary number of tables, up to the allowed maximum (10), may be entered.

(i) Density Reactivity Table, Doppler Table Data Cards (1420XX, 1430XX). Data may be supplied for any existing table.

(j) Thermal Conductivity, Volumetric Heat Capacity, Linear Expansion Coefficient Data Cards (18XXYY, 19XXYY, 20XXYY). Data may be provided for any existing table.

(k) Heat Exchanger Data Cards (21XXYY). All heat exchanger data must be provided if any of these cards are used upon restart. Data for an arbitrary number of heat exchangers may be entered.

(l) Multiple Pin Clad Rupture, Multiple Pin Flow Blockage, Single Pin Clad Rupture, Single Pin Flow Blockage Data Cards (2700XX, 2800XX, 2900XX, 3000XX). Data may be provided for any existing table.

(7) Additional Restart Considerations. There are certain limitations on the use of new options on restart which were not present on the original run. These limitations exist because the problem dependent overlay (Ref. 2, IV-4) is not coded to handle additional subroutines on restart not present in the original run. If the user attempts to use an option on restart requiring a routine which was not present originally, the program will normally fail with a program range error.

If this situation is anticipated, it is possible to avoid this problem on the original run by arranging to have input access but not activate the routine which may be needed for the restart job.

Currently the only common occurrence of this problem is with the mixture level smoothing Card 030004. Therefore, this case will be used as an example. To access this routine on the original run, but not activate it, input the variable XMLCFA with a large value less than the default of 1000000, such as 90000. This will ensure that the mixture level smoothing subroutine will be present when the job is restarted. Any value of XMLCFA may then be used for the restart job.

2.5 PLOTR4M Plotting Program

A separate INEL computer program used in conjunction with REALP4 is the PLOTR4M program which produces both Calcomp and microfilm plots of appropriate variables-versus-time from a RELAP4 data tape. The PLOTR4M program processes RELAP4 plot/edit tapes in conjunction with user-specified card input parameters to produce graphs. Options are available to the user to select the data to be plotted, with a choice of linear or logarithmic scales, axis lengths, scaling divisor, range of variables, and axis labels. Default values are provided for

most option choices, and the normal plot is a single variable versus time. Other options provide for parameter versus parameter plots, plots of the difference of two similar variables, and for multiple ordinates from a single run or from a few different RELAP4 runs. For multiple ordinate graphs, multiple ordinate axis labels may also be requested.

As mentioned above, the organization of a plot set and the plot characteristics are defined by the card input. The card input not only defines what functions to associate on one graph and the graph characteristics but, more importantly, what data to retrieve from the RELAP4 data tape.

(1) Data Input. Two types of data are input into the PLOTR4M program: card input data and data residing on magnetic tape. The input card data group is composed of input control and edit variable cards. The first card must be a title card. The first 12 characters must match the title card which was used for the RELAP4 problem unless the multi-tape option is used. [The leading equal sign (=) used on the RELAP4 problem title is replaced by a blank.] Fifty-two columns are available for a title. Columns 53-80 will be used by the PLOTR4M program for the RELAP4 program name, modification number, date of last program correction, and date the tape was written. This title and information will appear on all output.

(a) Request Card Format and Options. Plot request cards or control cards follow the title. The format for these cards is given in Table XII. PLOTR4M prints the input cards as they are processed. Messages for any errors discovered and descriptive messages for most control options are also printed. The edit variable names and indexes are the same as those allowed on RELAP4 Edit Variable Data Card for a minor edit, plus TI to refer to time. Three additional control identifiers, PL, TA, and OV are discussed in Subsection (1) (b) which follows.

In the common case where TA and OV cards are not used, each request card identifies a variable for the y axis and causes a graph to be generated. The y axis options are specified on the request card. Blank fields on any card result in the default values shown in Table XI.

The arrangement, labeling, and scaling options are outlined as follows:

TABLE XI
FORMAT FOR PLOT REQUEST CARDS AND CONTROL CARDS

Card Column	Format	Quantity	Default Value	
			x axis	y axis
1-2	A2	Variable name	TI	--
3-5	I3	Variable index	0	--
6	A1	Log scale flag or modification flag	Linear	Linear
7-8	I2	Length of axis	10 in.	7 in.
9-14	E6.2	Variable minimum value	Automatic scaling	
15-20	E6.2	Variable maximum value		
21-26	E6.2	Scaling divisor	1.0	1.0
27-80	13A4,A2	Axis label	Time (sec)	A brief label

Axis Scale. To produce a logarithmic scale on an axis, use the character L in column 6. Any other symbol (except X or 0) results in a linear scale and blank is the usual choice. If either X or 0 is the symbol, the previous choice of linear or log scale for that axis remains in effect. If a change is desired for the x axis, an extra TI card may be inserted to set the choice. Do not use X or 0 on a TI card.

Difference Plots. A difference plot is defined by the character D in column 6, and the integer in card columns 7-8 is interpreted as a second index. The quantity plotted is the given variable for the node specified by index 2 (columns 3-5) minus the same variable for the node specified by index 2 (columns 7-8). Here the word "node" means either volume number, junction number, or slab number. A log scale is not allowed for a difference plot. If a special y axis length is needed, see the PL card description.

Axis Length. An axis length may be chosen for the Calcomp plots. If none is chosen, PLOT4M will use 10 inches for the x axis and 7 inches for

the y axis. The program will increase an axis length to fit the label if the user has chosen too small a value. The program will reduce any larger request to 10 inches for the y axis and 18 inches for the time axis. The axis length cannot be varied for the microfilm plots.

Automatic Scaling. For automatic scaling, the data values are scanned and the limits used to select an appropriate scale. The axis maximum must be larger than the minimum unless automatic scaling is desired. These values will be used for the graph boundaries, subject to a few limitations. These limitations include, but may not be limited to:

Increments are 1 inch apart on the Calcomp graphs.

Increments are 1, 2, 4, or 5 times a power of ten on the Calcomp graphs and are 1, 2, 2.5, or 5 times a power of ten on the microfilm graphs.

The marked increments are a multiple of the increment size.

Zero is included if it is relatively close to an end of the graph.

Logarithmic scales contain only full decades.

Note: that all of the data values and the axis minimum and maximum are divided by the scaling divisor given on the input card. If the scaling divisor is not given, 1.0 will be used. When the scale range is defined by input, any out-of-range data are plotted on the graph boundary.

Axis Label. An axis label may be inserted anywhere in columns 27-80. PLOT4M centers the label starting at the first nonblank character and ending at the last nonblank character. The input label is followed on the plot by the variable name and index. If no label is inserted, the program will choose a brief label from among a standard set. For example, J_W 20 would use "FLOW LB/SEC J20."

Plot Variables. If parameter versus parameter plots are desired, an X in column 6 indicates that the variable name and index given in columns 1-2 and 3-5, respectively, are to be used as the abscissa function.

The specifications for the x axis remain in effect until redefined by another x axis card. The initial default value is time, as shown in Table XII.

Time Scaling. Automatic scaling for the time axis means data are retrieved from every plot record on the tape, followed by selection of an appropriate scale. If all of the time axes have a maximum defined, tape reading is terminated when a time value from the tape is obtained which exceeds any TMAX from the "block of 20" requests being processed. This conserves tape read costs and also permits partial plots from damaged or incomplete tapes. The TI card is the only one in which a minimum value is effective with a blank maximum value. Data from the time minimum to end of tape are stored, followed by normal scaling.

(b) Input Control Cards. The following special variables are used to allow the user certain control options:

<u>Symbol (Col. 1,2)</u>	<u>Variable</u>
PL	Plot type
TA	Multiple data set processing
OV	Overlay options
Blank	Comment in card columns 27-80.

The use of these is detailed as follows:

Plot Type. The PL card defines certain broad characteristics of the plots. An integer in column 5 determines the plot type according to the following code:

- 0 = both microfilm and Calcomp type plots
- 1 = microfilm (IGS system) plots only
- 2 = Calcomp type plots only.

When these options are used to select a single plot type, the graphic subroutines to generate the other type are completely bypassed. The use of this card is recommended when using PLOT4M if only one type of plot is needed. A PL card may be placed at any point after the title. If more than one PL card is used, the plot type is taken from the last PL card before the end of the specifications for a group of plots. The plot type from this last card is used for the entire group of plots.

An integer in columns 7 and 8 of the PL card redefines the default value of the y axis length for Calcomp plots. That is the value used if this position is left blank on a request card. The default axis length remains in effect for all following request cards until redefined by another PL card. A zero or blank in this field of the PL card has no effect.

Multiple Plots. Some terms will be precisely defined for the following discussion of control options for multiple plots. A graph means a set of axes with labels (for the microfilm plots a full grid), a title, and one or more curves. A graph might also be called a page. A curve means a series of line segments connecting points defined by pairs of data values. A request is a card that specifies a particular y axis variable and certain other choices. A request defines a set of data values to be retrieved from a RELAP data tape and that describe a curve when paired with the values of an x axis variable. Cards with variable name blank, OV, PL, TA, TI, or with an X in column 6 are not request cards. A plot set is a group of one or more curves, one from each tape in use. An overlay card specifies groups of plot sets to be collected on one graph. A request card may specify the full plot set, or several request cards may be needed, according to the TA card option.

Whenever multiple plots are produced, the curves on the microfilm graphs are identified by symbols in the order * + 0 X \$ =. This selection of symbols may be included in the title or axis labels to aid in identifying the curves. Single-curve graphs are marked with dots. The symbols are plotted at every nth data point where n is the smallest integer such that the total number of symbols plotted will not exceed 200. There is no provision for plotting symbols on Calcomp graphs.

Multiple Data Sets. The TA control card signals the processing of overlay plots from multiple tapes. It has the format shown in Table XII.

TABLE XII
FORMAT FOR MULTIPLE DATA SET PROCESSING CARD

<u>Columns</u>	<u>Format</u>	<u>Symbol</u>	<u>Meaning</u>
1-2	(A2)	TA	Card identification
3-5	(I3)	n	Number of tapes (0 through 6)
7-8	(I2)	j	= 0 or blank, each following request card is for all tapes
		j	= 1 (not zero), the following cards have a separate request card for each tape (that is, for each curve)
6 and 9-80			Not used, but columns 9 to 26 may not be alphabetic.

The number of tapes may only be specified immediately following the title card; after that, it is ignored. If n is not zero, n header cards (discussed below) must follow immediately after the TA card. The core j may be changed at any point, and the new value applies to subsequent requests. The curves from the n tapes are considered one plot set and are always placed on one graph. Unless special options are selected with the OV card (described later), only one axis and label is produced; and automatic scaling uses only the data for the first curve. The axis and minimum and maximum should usually be specified since automatic scaling often results in the later curves being cut off by the graph boundaries.

The tapes are read and the curves on each graph are plotted in the sequence defined by the order of the tapes specified by the job control cards. When a TA card is encountered, the designated number of tapes are opened, the header labels checked, and information necessary for further processing is obtained from each tape and stored. A TA card with n equal to zero or blank causes the tape count to be set to 1. The first 12

characters of the tape title are then compared with the first 12 characters of the problem title as described in Section 2. If no TA card is encountered, a TA card with $n = 0$ is simulated.

If a TA card with $n > 0$ is entered, the plot title may be defined without regard to the RELAP job title. Immediately following this TA card, a header or title check card must be entered for each of the n RELAP4 data sets. As described previously for the title card, the first 12 characters of the header cards must match the title records on the corresponding tapes. If the titles do not agree or any tape errors are encountered, the job is terminated.

If a TA card with $n > 1$ is encountered (which specifies multiple input tapes), all 80 columns of the title card are available to the user. The automatic RELAP4 run identification is bypassed, so it becomes the responsibility of the user to adequately identify the runs from which the plots were obtained. If nothing is entered in columns 73-80 of the title card, the PLOTR4M run date is entered. If $n < 0$; the magnitude of n defines the number of tapes but the job continues on the usable tapes even if some are invalid. Header cards must still be entered as with a positive n .

Overlay Plots. The OV control card provides for overlay plots from one tape and a multiple axis option. The format is shown in Table XIII.

TABLE XIII

FORMAT FOR OVERLAY PLOT REQUEST CARD

Columns	Format	Symbol	Meaning
1-2	A2	OV	Identifies "overlay" plots
3-5	I3	i	Overlay count, greater than 0
7-8	I2	k	Axis count, 0 is changed to 1
6 and 9-80			Not used, but columns 9-26 may not be alphabetic.

The OV card instructs the program to include the next i plot sets on one graph. The OV card is not usually used with multiple tapes, but if it is, the graph will include i curves from each of the n tapes, or a total of i times n edit request cards are input for the graph. A new OV card always resets i and k .

The plotting space is shifted to allow for the extra y axes, if multiple ordinates are specified in columns 7-8. For the Calcomp plots, the shift extends the overall size of the graph. For the microfilm plots, the extra axes reduce the space available for the curves. Thus, multiple axes should be used sparingly.

If more than one y axis is specified, the additional y axes are represented by a line segment with tic marks, numeric identification, and a label. The axis definitions are taken from the next k request cards which do not contain the letter O in column 6. The axis information may be explicit on the card or default. Data defined by a request card with O in column 6 will be plotted according to the last specified axis. Axis information is ignored on the card even though the scaling divisor remains effective. After all the axes are generated, all additional plot requests apply to the last axis generated. These subsequent cards associated with a given axis should all have a letter O in column 6 to avoid confusion for log plots.

Note: that when multiple tapes are in use and on the last TA card j was not zero, all request cards (one for each tape) are candidates for defining the k axes. Thus, an OV card with $i = 1$, but $K > 1$ may be used to produce different axes for each tape.

Comment Cards. Comment cards may be inserted with columns 1-2 blank and alphanumeric information in columns 27-80. Non-numeric characters in card columns 3-5 or 7-26 will generate data conversion error messages. Note, however, that a completely blank card signals the end of data and that zero in a numeric field is equivalent to blanks. A blank card marks the end of data for a problem, and may be followed by a title card to start a new problem. However, there is no provision for mounting any different data tapes. The x-axis choice will remain the same as the previous problem. The multi-tape option is cleared and the plot type is set to both.

(c) Special Options. Additional options have been provided to the CDC version of the RELAP4 plot program PLOTR4M. These options are described as follows:

SI Units. Data may be plotted in SI Units using this option. In order to utilize the SI units options of PLOTR4M, a card containing the characters "SI" in columns 1 and 2 is input with the plot data deck. This card may come anywhere in the input stream after the main title card, except between title cards pertaining to overlay plot requests or after the 20th plot request. Data conversion and axis labeling appropriate to SI units output is done automatically. All options available with ordinary PLOTR4M plots in English units are also available when the SI units option is requested.

The user should be aware that if scaling factors are supplied, they are applied after conversion of the plot data to SI units.

Character Sizes. The user may select from two different character sizes for the axis labels and plot points on the PLOTR4M IGS graphs. To use this option, a card with the characters "GS" in columns 1 and 2 must be entered into the plot data deck anywhere after the title card, but before the 20th plot request. Putting a 2 or -2 in columns 4-5 (right justified) of this card will result in characters being used for axis labels and plot points which are approximately 50% larger than those used in normal PLOTR4M runs. If any number other than 2 or -2 is used, or if the GS card is not supplied in the input data deck, normal size characters will be used on the graphs.

Grid Lines. Plots without grid lines may be generated by supplying a -1 or a -2 on the GS card (columns 4-5, right justified) described above. If any number other than -1 or -2 is used, or if the GS card is missing, PLOTR4M will produce graphs which have normal grid lines.

Axis Length Ratio. x-to-y axis length ratio may be specified for microfilm plots. The user can implement this option by supplying the desired ratio as a real number in columns 21-26 of the GS card. The ratio specified must lie in the range 0. to 10. (0. and 10. are excluded.) A specified ratio outside this range, or absence of a specified ratio on the

GS card, will result in an x-to-y axis length ratio of 1.47:1 being used on the IGS plots, as is used in normal PLOTR4M runs.

(d) Input Tape. The input magnetic data tape must be in the format produced by the RELAP4 program. The three preliminary control records and the plot/edit records must be present as written by RELAP4. Restart records are ignored by PLOTR4M. Plot records are recognized by the characters PLOT in the first word. Plots can be retrieved even from damaged tapes in many cases.

(2) Data Output. The printed output consists of an interpreted list of the input cards as they are processed, together with descriptive messages for the control options and error messages for tape reading or plotting errors. The graphic output consists of microfilm plots and/or Calcomp plots.

(3) Plot Job Processing. Specific directions for using the IBM and CDC versions are presented in the following subparagraphs.

(a) IBM Job Control Cards. The PLOTR4M program procedure is invoked by the following card:

```
// EXEC PLOTR4M, options
```

where the options have the following values:

TPIN = the data set name of the RELAP4 data tape
 this option must be used.

SER = the tape number of the RELAP4 data tape.
 This option must be used unless the data
 set is passed from a previous step, or is
 catalogued.

TP2 = the data set name of an additional RELAP4
 data tape.

SR2	=	the tape number of the additional RELAP4 data tape.
TP3	=	the data set name of an additional RELAP4 data tape.
SR3	=	the tape number of the additional RELAP4 data tape.
TP4	=	the data set name of an additional RELAP4 data tape.
SR4	=	the tape number of the additional RELAP4 data tape.
TP5	=	the data set name of an additional RELAP4 data tape.
SR5	=	the tape number of the additional RELAP4 data tape.
TP6	=	the data set name of an additional RELAP4 data tape.
SR6	=	the data set name of an additional RELAP4 data tape.
XTIME	=	unless otherwise specified, an execution time of two minutes is allowed.
PLOT	=	unless the option is used, the Calcomp plots will be output on Calcomp plot paper. If Calcomp-like plots on microfilm are desired, this option should be specified: '(Y,,0003)'.

A complete job deck has the form:

```
Job cards (including COR card at INEL)
// EXEC PLOT4M, options
// SYSIN DD * optional at INEL
Title card for plots
Control and request cards
/* pink job terminator.
```

Plots may also be generated in the same job submittal that generates a RELAP4 data tape. The only changes needed are an FT04 card in the RELAP4 job step to change the normal tape disposition and the omission of the SER = tape number in the PLOT4M step. In most cases, the condition code COND=EVEN is useful, which permits execution of the plot step even if the RELAP step aborts. The deck outline is:

```
// job card
// COR card
//RELAP EXEC RELAP4,TPOUT= tapename, other options
//X.FT04F001 DD DISP=(NEW,PASS,KEEP)
//X.SYSIN DD *
    RELAP data cards
. period card
//PLOT EXEC PLOT4M, COND=EVEN,TPIN=tapename
// other options, but omit SER = number.
    Title and other plot data cards
/* pink end of job card.
```

Just as when the procedures are executed separately, the data set name for TPIN in the plot step must be identical to the one for TPOUT in the RELAP step, and the first twelve characters of the titles must agree. The job CPU time specified on the JOB/COR card should be a few minutes longer than the XTIME for the RELAP step, so time will always be available for generating the plots. The ENDCPU value on RELAP4 Data Card 030010 may also be used.

(b) CDC Job Control Cards. The following cards may be used to generate plots at INEL.

RCYAABB, STMFZ.

ACCOUNT, required information.

ATTACK, PLOTR4M.

STAGE, TAPE1, PE, NR, E, SG, VSN = data tape number/number.

DISPOSE, TAPE10, *FL = C02.

PLOTR4M.

7-8-9 separator card

Title card

Control and request cards

6-7-8-9 End of file card.

When multiple sets of data sets are to be plotted, additional STAGE Cards will be needed. The normal sequence of files is TAPE 1, TAPE2, TAPE3, TAPE4, TAPE8, and TAPE9. Other file names may be substituted on the PLOTR4M card with the tape file names occupying the first six positions.

Plots may also be generated in the same job with a RELAP4 execution. The user will want to release as much as possible of the facilities allocated for RELAP4, and provide for abnormal termination. Since the plot/edit data set is written to TAPE4, the PLOTR4M card will normally be written as:

PLOTR4M, TAPE4.

which causes the file TAPE4 to be processed for plotting.

(4) Problem Limits. To conserve computer time and storage, each graph can contain a maximum of 5,000 points. If the number of points pulled off of the data tape exceeds 5,000, only every nth point will be plotted where n is the smallest odd integer such that the total number of points plotted will not exceed 5,000. This limit is applied to each graph separately so that the same run could contain both detailed and abbreviated plots. The number of data points read from the data tape is not limited.

The plots are processed in groups of 20 curves, and the data tape(s) are read for each block of 20 curves or fraction thereof. If more than 20 curves are requested, the tapes are rewound and the card input/tape read cycle is repeated. This is handled automatically by the program and no special action is required by the user except scheduling of additional execution time. However, the IBM system will not fully rewind a long RELAP data set which requires more than one tape volume. Such jobs must be restricted to 20 curves or less, unless the data is compressed to one tape or copied to disk. An accessory program is available to compress RELAP restart tapes to a shorter plot/edit version. In most cases, the tape-read time for a compressed tape is significantly reduced.

(5) Computer Requirements. The PLOTR4M program is operational on the IBM 360-370 computer systems and CDC 7600 or 6600 systems. It is written in FORTRAN IV except for the BUFIO subroutine and some of the system plotting routines. The BUFIO subroutine is the same assembly language routine normally used in RELAP on IBM machines for overlapped input and output of the data tape. The CDC versions of PLOTR4M use a modular substitute of BUFIO written in FORTRAN Extended 4.

PLOTR4M requires several intermediate areas of temporary storage (disk), at least one input tape, card input, printer output, and one or both of a Calcomp or IGS graphical system. The versions of PLOTR4M in use at INEL employ 20 scratch data sets and provide for up to 6 input data tapes with output to either or both Calcomp and IGS microfilm. The core storage required is 200K bytes for the IBM and 77000 (octal) words for the CDC installations.

(6) Installation Notes. PLOTR4M has been put into operation at a number of IBM and CDC installations. However, differences in graphical system requirements at each location make a general version impossible. This section is intended for those who need to modify the code or want to understand the organization and principles of operation. Interfaces with the system graphics routines are found at the end of MAIN and in PLOTMC. XPLOT and XPLOTA also call Calcomp routines.

Most parameters are passed between subroutines through common blocks to reduce the overhead of long argument lists. The routines are also made serially reusable by storing certain data items in common. Initial default values are defined by a Block Data routine and by a few statements in MAIN. An overlay structure is employed at INEL, using the (IBM) link editor cards in Table XIV.

TABLE XIV

OVERLAY STRUCTURE CARDS (IBM FORMAT) FOR PLOT4M

```

INSERT MAIN,BUFOUT,PACKZZ,WRTPLT,PLTSEP
OVERLAY ONE
INSERT PAGE,REQST,SETUP,COUNT,PACK,SHIFT
OVERLAY ONE
INSERT TAPER
OVERLAY ONE
INSERT PLOT, PLOTMC,MUTT,JEFF,IHCSSCN,IHCSLOG,IHCFRXPI,PLOT
OVERLAY TWO
INSERT GRAPHG,PAGEG,MODESG,RSETMG,SETSMG,GRIDG,LABELG,LINESG
INSERT POINTG,SETUPG,SUBJEG,TITLEG,JBIDZZ,VECIG,LEGNDG,DBJCTG
INSERT MLTPLG,SEGMTG,KADZ,LOCZ,NVEZ,GETCZZ,PUTCZZ,UNSCZZ,VECTZZ
INSERT NUMBRG,FMTSG,IFMZZ,EXITG,METZAA,SCALZZ,VECSZZ,ISCSQRT
INSERT ERRZZ,XMODZ,YMODZ,IHCFMAXR,IHCFIXPI,IHCSTNCT,IHCSATN2
OVERLAY TWO
INSERT XPLOT,XPLOTA,LAXIS,ASIX,SYMBL4,NORMAL,NUMBER,PSCALE
INSERT  PLTJOB,PLOTS
ENTRY MAIN

```

A short MAIN routine reads the title card, calls the three major links of PLOT4M, and closes the plot files at normal termination. Some installations may require changes in these final plot routine calls. Subroutine PAGE defines the program identification which heads each printed page.

Subroutine REQST reads all the request and control cards and supplies the default values for blank card fields. A table of edit variable codes is scanned to identify a particular request. These codes are stored in the table in the order that the corresponding data variables are stored in a plot record by the RELAP4 routine PLTAPE. They are grouped by system, volume, junction, and slab variables as described for the RELAP4 Edit Variable

Data Card. The three control symbols follow at the end of the table. Blanks appear in the table where space locations exist on the RELAP plot tape. New plot variables are easily handled by inserting the chosen code in the proper location and providing a suitable default label in the corresponding positions of the next tables in REQST. At a TA card or the first true request card, routine SETUP is called to check the tape title(s) and to extract information on the problem dimensions.

As each card is processed, REQST calculates the location of the variable in the plot record and sets flags to identify various options. These flags are fairly complex but are defined by comment statements and are not dependent on the computer installation. Checks for valid input cards are also made by REQST. Cards are processed in groups that will not cause the limit of data storage for 20 curves to be exceeded.

The subroutine TAPER is called by MAIN to read the plot records from the RELAP data tape. The requested variables are extracted, and X,Y point pairs for each plot curve are written to the scratch data sets.

The routine PLOTR retrieves data from one scratch data set at a time, skipping points and scaling if necessary, and calls PLOTMC.

Subroutine PLOTMC interprets the flags stored by REQST and calls either Calcomp or IGS routines to produce the plots. The chief differences encountered to date depend on whether Calcomp buffer space is to be provided by the calling routine or by the system package and whether PLOTS is to be called only once per job, or for each graph. Some systems also have differing argument lists for the basic routine PLOT.

The known uses of PLOTR4M with the IGS system were installed by INEL personnel. These are branches of the same system, and are compatible. The routine GRAFG is a modification of the IGS routine GRAPHG to provide log plots and line curves with symbols.

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APPENDIX A

RELAP4 - FRAP-T LINK INFORMATION

APPENDIX A

RELAP4 - FRAP-T LINK INFORMATION

Communication between FRAP-T and RELAP4 is performed through the common block FRAPC. The following list defines the information used or returned by the two codes.

COMMON/FRAPC/NCARD2, NREST2, NROD2, NCOOL2, NDTADV, NBUGSW, T12, T22, TMPRLP (20,24, 12), RMRLP (20, 12), TPRLP (12), NFORLP (12), NCIRLP (12), NCORLP (12), PCLRLP (24, 12), ELVRLP (24,12), KMXRLP (12), KMXFRP (12), ELVFRP (20,12), HGPFRP (2),12), DRDFRP (20, 12), IFFRP (20, 12), VRLFRP (20, 12), PGPFRP (20, 12), GSFRP (9, 12), BUFRP (20, 12), GSMFRP (12)

INFORMATION PASSED TO FRAP-T

NCARD2 = Control switch on input card read
 1 = Read input cards this call (first call for given rod)
 0 = Do not read cards

NREST2 = Control switch on restart
 0 = Calculations starting from scratch
 New calculations stored on tape
 1 = Calculations starting from data set stored on tape
 2 = Calculations starting from data set stored in LCM
 Advanced time calculations stored in LCM

NROD2 = Number of fuel rods

NCOOL2 = Control switch on thermal/hydraulic - fuel rod type of link.
 7 = RELAP4-FRAP link
 2 = COBRA-FRAP link

T12 = Start time for FRAP-T calculations (sec)

T22 = End time for FRAP-T calculations (sec)

NDTADV = Switch to advance in time or perform calculations only at time T12.
 0 = Advance in time
 1 = Only perform calculations at time T12

NBUGSW = Switch to turn on debug printout
 0 = No
 1 = Yes

R = radial node, K = axial node (heat slab), N = fuel rod number

TMPRLP (R, K, N) = RELAP4 computed temperature (F)

RMPLP(R,N) = Radial coordinate (clad state) (FT) (from RELAP)
 Radius to radial node L of fuel rod N

TPRLP(N) = Plenum gas temperature (F) (from RELAP)

NFORLP(N) = Radial node at fuel pellet surface (from RELAP)

NCIRLP(N) = Radial node at cladding inside surface (RELAP)

NCORLP(N) = Radial node at cladding outside surface (RELAP)
 PCLRLP(K,N) = Coolant pressure (PSIA) (RELAP)
 ELVRLP(K,N) = Elevation of RELAP axial node (heat slab) K, FT
 KMXRLP(N) = Number of axial nodes in fuel rod N (RELAP)
 KMFRP(N) = Number of FRAP axial nodes, rod N (FRAP)
 ELVFRP(K,N) = Elevation of FRAP K-TH axial node, FT (FRAP)
 HGPFRP(K,N) = Gap conductance (BTU/ft²-sec- F) (FRAP)
 PEPFRP(K,N) = Internal gas pressure (PSIA) (FRAP)
 DRDFRP(K,N) = Fuel rod outer diameter (FT) (FRAP)
 IFFRP(K,N) = Cladding failure indicator, 0 = No, 1 = Yes (FRAP)
 VRLFRP(K,N) = Fuel crack volume generated by relocation (ft³/ft)
 (FRAP)
 GSFRP(9,N) = Gas fractions in each fuel rod (FRAP)
 BUFRP(K,N) = Burnup (MWD/MTU) (FRAP)
 GSMFRP(N) = Total moles of gas in each rod (FRAP)

APPENDIX B

FRAP-T FUEL MODEL INPUT DATA
REQUIREMENTS

APPENDIX B

FRAP-T FUEL MODEL INPUT DATA REQUIREMENTS

The FRAP-T input data stream has been modified to minimize the amount of information necessary to run a fuel rod problem as the first part of producing a user convenient input for the RELAP4/FRAP-T link. These modifications were made to permit a user with limited knowledge of the fuel rod modeling to construct and perform a RELAP4 analysis including a fuel pin model. These modifications will continue to reduce the complexity of both the FRAP-T and RELAP4 input stream in the second phase of the link development. The following section discusses the input data requirements for the modified FRAP-T program. The input data discussed must be entered for each core stack and in the same consecutive numbering as they are input to RELAP4 under the Core Slab Data Cards.

For the purpose of better describing the contents of FRAP-T input data cards, the data deck has been divided into several data blocks. Each data block is read in by a different input subroutine. The information contained in each data block is summarized in Table B-I. The data blocks are described below in the order they follow in the input data deck. The type of data contained in each data block is identified, and the column location, format, name, and definition of each piece of input data given.

The input data cards for the RELAP/FRAP combination are a subset of those used for the stand alone FRAP-T. As shown in Table B-I, data blocks 2 through 5 are eliminated. Also, some parameters on the remaining data blocks are ignored. So the input instructions for FRAP-T

are taken verbatim from the FRAP-T4 input manual, with deletion of input instructions for data not used in the RELAP/FRAP combination. As a result, some input cards contain only a sparse amount of data and there are gaps in the figure, table and card group numbers.

The set of data blocks shown in Table B-I must be input for each RELAP heat slab stack. For example, if the RELAP input contains three heat slab stacks, there must be three sets (input decks) of FRAP-T data blocks. The first set must correspond with RELAP heat slab stack number 1, the second set with RELAP heat slab stack number 2, etc. The sets of data blocks are not separated by an end of file card. The first card in the second set of FRAP-T data blocks follows immediately after the last card in the first set.

The input data can be in either the British or SI system of units. The two systems of units cannot be mixed. If SI units are specified, all data must be input in SI units. Within either system, the required unit for each input quantity is given herein.

TABLE B-I

INFORMATION CONTAINED IN EACH DATA BLOCK

<u>Data Block</u>	<u>Information</u>
1	Nodalization, numerical solution control, fuel rod geometry, options for phenomena models, fuel and cladding design parameters.
6	Fuel and cladding surface roughness.
7	Internal gas content and quantity, plenum size, plenum spring geometry.

Input format is indicated by the characters F, I, and A. F denotes that floating point numbers are to be input. For this case, exponents must be right hand adjusted and a decimal point must be present. An I denotes that integer numbers are to be input. The integers must be right hand adjusted. No decimal point can be present. An A denotes that alpha-numeric characters are to be input.

Data Block 1. General Data.

Card 1.1

<u>Columns</u>	<u>Format</u>	<u>Name</u>	<u>Quantity</u>
1-5	I	NROD	Always set NROD = 1.
5-10	I	NCHN	Always set NCHN = 1.
11-15	I	NAXN	Number of axial nodes ($NAXN \leq 20$). If $NGSFL\emptyset = 1$ (columns 31-35), $NAXN \geq 3$. If no minus sign in front of NAXN, code generates evenly spaced mesh. An example of generated mesh is shown in Figure B-1. At each axial node, calculations of fuel rod state from fuel center to cladding sur- face are performed on a plane perpendicular to fuel rod longitudinal axis and passing through the center of the axial node. If minus sign input, axial node lengths are specified by card group 1.12.

Fig. B-1 Example of evenly spaced axial node mesh for case NAXN=5.

26-30	I	NUNIT	<p>If this field is zero or left blank, data are input in British units. If the integer 1 is put in column 30, data are input in SI units. Code output for NUNIT = 0 or 1 is in the same system of units that is selected for input. If the integer 2 is put in column 30, data are input in British units, but calculations and plots are output in SI units.</p>
31-35	I	NGSFLO	<p>If NGSFLO = 0, gas flow between plenum and gas gap is not modeled. Instead, pressure equilibrium is assumed to instantly occur, so that plenum and gas gap are always at the same pressure. If NGSFLO = 1, gas flow between plenum and gas is modeled. (NOTE: In either case RELAP4 will use plenum pressure for the entire rod.)</p>
41-45	I	MODFD	<p>If MODFD = 0, the FRACAS-I deformation model is used with the fuel assumed to have radial cracks extending from fuel surface to fuel center (free thermal expansion), and 0.25% times fuel pellet radius fuel relocation for structural calculations. No relocation in pressure calculations. If MODFD = 1, the GAPCON-THERMAL-1 code fuel deformation model and FRACAS-I cladding deformation model are used. No fuel relocation assumed. If MODFD = 2, same as MODFD = 0, but no fuel relocation.</p>

If MØDFD = 3, same as MØDFD = 0, but fuel relocation according to Coleman correlation assumed in pressure calculations. No relocation assumed in structural calculations.

46-50 I MODGPC

If MODGPC = 0, the Ross and Stoute gap conductance model is used. If MODGPC = 1, the MacDonald-Broughton gap conductance model is used. This model should only be used for unpressurized fuel rods.

51-55 I NFASTF

If NFASTF = 0, fast neutron flux assumed to be axially uniform. Otherwise, NFASTF = number of pairs of normalized fast neutron flux versus elevation used to prescribe axial distribution of fast neutron flux on card group 1.13. $NFASTF \leq 25$.

Card 1.2

<u>Columns</u>	<u>Format</u>	<u>Name</u>
36-40	I	NFCMI

Quantity

Switch to force calculations by the FRACAS-I subcode after cladding failure predicted. 0 = no, 1 = yes. If NFCMI = 1, however, the balloon model calculations are bypassed. If NFCMI = 0, the only deformation assumed to occur after cladding failure is that due to thermal expansion.

Card 1.3

<u>Columns</u>	<u>Format</u>	<u>Name</u>
21-30	F	DT

Time step (seconds). For accident analysis, $DT \leq 0.5$.

41-50	F	RL	Cold length of fuel pellet stack (ft or m)
51-60	F	DROD	Cold outer diameter of fuel rod (ft or m)
61-70	F	TEMPO	Cold state temperature of fuel rod ($^{\circ}\text{F}$ or K). The fuel rod dimensions given in the input must correspond with this temperature.
71-80	F	COLDW	Reduction of cross-sectional area of cladding by cold working process. $\text{COLDW} = (A_0 - A)/A_0$ where A_0 = cross-sectional area prior to cold working, A = cross-sectional area after cold working.

Card 1.4 Pellet Data.

<u>Columns</u>	<u>Format</u>	<u>Name</u>	<u>Quantity</u>
1-10	F	RHØF	Cold state density of fuel (lb/ft^3 or kg/m^3)
11-20	F	RSHD	Cold state radius to pellet shoulder (ft or m). Shoulder defined to be point of primary contact at pellet interfaces. See Figure B-2.
21-30	F	DISHD	Cold state depth of pellet dish (ft or m)
31-40	F	PELH	Cold state height of fuel pellet (ft or m)

Fig. B-2 Definition of pellet shoulder radius.

41-50	F	DISHVO	Cold state volume of pellet dish (ft ³ or m ³) (sum of top and bottom dish volumes)
51-60	F	FRP02	Fraction by weight of fuel that is PuO ₂
61-70	F	BU	Burnup of fuel (MWs/kg). Burnup (MWd/MT) x 86.4 = Burnup (MWS/kg)

Card 1.6 Numerical Solution Control and Cladding Flux History

<u>Columns</u>	<u>Format</u>	<u>Name</u>	<u>Quantity</u>
1-10	F	PRSACC	Minimum fractional difference in internal fuel rod pressure at a given axial node calculated by two successive iterations before convergence is declared. If these columns left blank, program sets a value of 0.001. This minimum difference must occur at every axial node before convergence is declared. The test is (p ^{r+1} - p ^r) / p ^r < PRSACC, where p ^r symbolizes pressure at iteration number r.
41-50	F	CFLUX	Axially averaged and time averaged fast neutron flux cladding exposed to during lifetime (neutrons/m ² - sec). Fast neutron is defined to be a neutron with an energy greater than 1 Mev.
51-60	F	TFLUX	Time span of cladding exposure to fast neutron flux (sec). The quantity CFLUX*TFLUX must equal axially averaged fast neutron fluence received by cladding.

61-70

F

PFAIL

If probability for fuel rod failure exceeds PFAIL, then fuel rod assumed to be failed. If these columns left blank, PFAIL set to value of 1.0. Then, fuel rod not failed until cladding hoop strain exceeds cladding circumferential strain at rupture.

Card Group 1.11 Rod-to-Coolant Channel Connection Data.

Input for card group 1.11 consists of one card with a 1 in column 5, 1 in column 15, and 1.0 in columns 16-20; rest of card is blank.

<u>Columns</u>	<u>Format</u>	<u>Name</u>	<u>Quantity</u>
1-5	I	RØDNØ	Number of a rod in cluster being analyzed. Set RØDNØ = 1.
11-15	I	CHNNØ1	Number of a subchannel cooling RØDNØ. Set CHNNØ1 = 1.
16-20	F	FRP1	Fraction of surface area of RØDNØ bordering CHNNØ1. Set FRP1 = 1.0.

Card Group 1.12 Axial Node Length Data.

If no minus sign is put in front of NAXN of card 1.1, omit this card group.

<u>Columns</u>	<u>Format</u>	<u>Name</u>	<u>Quantity</u>
1-10	F	Z(1)	Length of axial node 1 (ft or m)
11-20	F	Z(2)	Length of axial node 2 (ft or m)
21-30	F	Z(3)	Length of axial node 3 (ft or m).

Continue as necessary with eight lengths per card until NAXN lengths have been put on cards. The node lengths must sum to within 0.0005 ft of RL on card 1.3. An example of the axial node mesh layout generated by card group 1.12 is shown in Figure B-3 for the case of NAXN = 5.

Card Group 1.13 Normalized Fast Neutron Flux Axial Distribution.

(Omit this card group if NFASTF = 0 on card 1.1). Fast neutrons considered to be those with energy greater than 1 Mev. The time averaged fast neutron axial distribution during normal reactor operation should be input rather than that during a reactor transient.

<u>Columns</u>	<u>Format</u>	<u>Name</u>	<u>Quantity</u>
1-10	F	FLUXZ(1)	Ratio of fast neutron flux at elevation FLUXZ(2) to axially averaged fast neutron flux. $FLUXZ(1) * CFLUX * TFLUX = \text{fast neutron fluence (neutrons/m}^2 \text{) at elevation FLUXZ(2). (CFLUX and TFLUX input on card 1.6.)}$
11-20	F	FLUXZ(2)	Elevation above bottom of fuel stack (ft or m)
21-30	F	FLUXZ(3)	Ratio of fast neutron flux at elevation FLUXZ(4) to axially averaged fast neutron flux.
31-40	F	FLUXZ(4)	Elevation above bottom of fuel stack (ft or m)

Repeat until NFASTF pairs of data have been placed on cards, 4 pairs per card. Maximum of 6 and 1/4 cards of data. $FLUXZ(4) > FLUXZ(2)$, etc.

Card 1.14 Restart Switches.

11-15	I	NRADFS	If NRADFS = 0, restart tape created by steady-state fuel rod code not to be read. If NRADFS = 1, steady-state restart tape to be read.
21-30	F	TREST	Time of fuel rod conditions on restart tape that will be used to specify initial fuel rod condition (sec). Leave blank if NRADFS = 0.

ANCA-9119

Fig. B-3 Example of axial node mesh specified by card group 7.12 for case NAXN=5.

Data Block 6. Gap Conductance Subcode Input Data.

Card 6.1

Specification of surface roughness of fuel and cladding

<u>Columns</u>	<u>Format</u>	<u>Name</u>	<u>Quantity</u>
1-10	F	RC	Arithmetic mean roughness of inside surface of cladding (microns) (leave blank if MacDonald-Broughton model is specified on card 1.1)
11-20	F	RF	Arithmetic mean roughness of outside surface of fuel pellets (microns) (leave blank if MacDonald-Broughton model is specified on card 1.1).

Data Block 7. Internal Gas and Plenum Data. Cards 7.1 and 7.2 must be input as pairs for each fuel rod being analyzed.

Card 7.1

<u>Columns</u>	<u>Format</u>	<u>Name</u>	<u>Quantity</u>
1-5	I	N	Number of fuel rod in rod bundle being analyzed. Always input the integer "1".
6-10	I	NC(N)	Number of coils in plenum spring of rod N ($NC(N) \geq 1$).
11-20	F	GSMS(N)	Amount of gas in fuel rod N (gram-moles) (leave blank if $TGASO(N) > 0$ in columns 71-80 of this card or $NRADFS = 1$ on card 1.14).
21-30	F	VPLEN(N)	Cold state plenum volume of fuel rod N (ft^3 or m^3) (include volume of plenum spring).
31-40	F	PO(N)	Cold state pressure in fuel rod N (psia or N/m^2). If $TGASO(N)=0$, only use of this quantity is that of supplying guess of internal fuel rod pressure on first iteration

of first time step. Accurate value, therefore, is not required. But, if $TGASO(N) > 0$, $PO(N)$ is term in calculation of moles of gas in fuel rod. Accurate value, then, is required. Leave blank if $NRADFS = 1$ on card 1.14.

41-50	F	SL(N)	Height (coiled) of plenum spring of fuel rod N (ft or m).
51-60	F	CD(N)	Outer diameter of plenum spring coils of fuel rod N (ft or m).
61-70	F	DS(N)	Wire diameter of plenum spring of fuel rod N (ft or m).
71-80	F	TGASO(N)	Temperature of fuel rod gas when at cold state pressure $PO(N)$ ($^{\circ}F$ or K). This temperature is term in calculation to compute moles of gas in fuel rod. If moles of gas input in columns 11-20, leave these columns blank. Leave blank if $NRADFS = 1$ on card 1.14.

Card 7.2 Gas Composition Data

Mole fractions of gas components specified. Total of fractions should sum to 1. If they do not, the code normalizes them so that sum is 1. If $NRADFS = 1$ on card 1.14, input blank card for card 7.2.

<u>Columns</u>	<u>Format</u>	<u>Name</u>	<u>Quantity</u>
1-10	F	GF(1)	Fraction of helium in fuel rod N
11-20	F	GF(2)	Fraction of argon in fuel rod N
21-30	F	GF(3)	Fraction of krypton in fuel rod N
31-40	F	GF(4)	Fraction of xenon in fuel rod N
41-50	F	GF(5)	Fraction of hydrogen in fuel rod N
51-60	F	GF(6)	Fraction of air in fuel rod N
61-70	F	GF(7)	Fraction of water vapor in fuel rod N.