

JAERI-M

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RELAP4/MOD6/U4/J3

A JAERI IMPROVED VERSION OF RELAP4/MOD6
FOR TRANSIENT THERMAL-HYDRAULIC ANALYSIS
OF LWR INCLUDING EFFECTS OF
BWR CORE SPRAY

March 1981

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RELAP4/MOD6/U4/J3

A JAERI Improved Version of RELAP4/MOD6
for Transient Thermal-Hydraulic Analysis of LWR
Including Effects of BWR Core Spray

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The RELAP4/MOD6/U4/J3 code is the latest version of RELAP4/MOD6/Update4 improved in JAERI. The major improvements and modifications included in this version have been carried out aiming at small break LOCA analysis and BWR-LOCA analysis after core spray initiation. For example, a CCFL calculation model and a spray heat transfer model have been added for BWR-LOCA analysis. Using these models, through calculation from the beginning of blowdown to the end of reflood in BWR-LOCA was made practicable. Furthermore, the analyses of operational transients of LWR were facilitated greatly by an addition of a trip reset function.

In this report, the description of the improvements and modifications included in this version, the input data description, and the results of two sample problems are contained.

Keywords: PWR, BWR, LOCA, Small Break Analysis, Core Spray, CCFL, Computer Code, Thermal-Hydraulic Analysis.

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RELAP 4 / MOD 6 / U 4 / J 3
BWR 炉心スプレー効果も含めた軽水炉の熱水力過渡解析
のための RELAP 4 / MOD 6 原研改良版

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(1981年2月6日受理)

RELAP 4 / MOD 6 / U 4 / J 3 コードは、RELAP 4 / MOD 6 / Update 4 コードの原研改良版のうちで、最も新しい改良版である。この改良版に含まれる主要な改良、修正は、軽水炉の小破断LOCA解析および、沸騰水型炉のLOCA解析において炉心スプレー系作動中の熱水力解析のために行なったものである。たとえば、沸騰水型炉のLOCA解析のために、CCFL計算モデルあるいは、スプレー熱伝達モデルが、組み込まれている。これらのモデルを使うことにより沸騰水型原子炉のLOCA解析の一貫計算が可能になった。また、トリップ・リセット機能の追加により、異状過渡変化の解析が容易になった。

本報告書には、改良・修正の説明、新しいモデルの説明、変更・追加になった入力データの説明、およびサンプル問題の入力と結果の説明が含まれている。

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CONTENTS

1.	Introduction	1
2.	Improvements for Small Break LOCA Analysis	1
2.1	Modification of Single Mixture Level Calculation in Vertically Stacked Volumes	1
2.2	Modification of Vertical Slip Junction Model	3
2.2.1	Modification of Slip Velocity Calculation Method	3
2.2.2	Trip Control of Vertical Slip Junction Model	4
2.3	Modification of Junction Enthalpy Smoothing	5
3.	Improvements for BWR-LOCA Analysis	5
3.1	Purpose and Abstract of Improvements	5
3.2	Spray Heat Transfer Model	6
3.2.1	Heat Transfer Coefficients	6
3.2.2	Assumption for Coolant Behavior along Clad Surface during Core Spray	7
3.2.3	Calculation about Liquid Film	8
3.3	CCFL Calculation Model	10
3.4	Bypass-Lower Plenum Leakage Model	11
3.5	Fission Product Decay Heat Calculation by (GE + 3 σ)	12
4.	Special Features in RELAP4/MOD6/U4/J3	17
4.1	Trip Reset Option	17
4.2	Change of Input about Bubble Index on Volume Data Cards	17
4.3	Trip Control Option of Volume Data Retrieval	17
4.4	Addition of New Independent Variable of Leak Table	18
4.5	Fill Junction Enthalpy Calculation Option	18
4.6	Steam Condensation Heat Transfer Model and Adiabatic Calculation Option	18
4.7	Addition of Changeable Data Cards upon Restart	19
5.	Input Data Description	19
6.	Sample Problems	30
6.1	BWR Large Recirculation Line Break	30
6.1.1	Introduction	30
6.1.2	System Model and Assumptions	31
6.1.3	Calculated Results	32

6.2 BWR Small Recirculation Line Break	47
6.2.1 Introduction	47
6.2.2 System model and Assumptions	47
6.2.3 Calculated Results	48
Acknowledgement	62
References	62
Appendix A Plotter Program; "PLT4CAL"	64

目 次

1. まえがき	1
2. 小破断解析のための改良	1
2.1 鉛直方向に複数個に分割された個所で单一水位を計算するための改良	1
2.2 垂直スリップジャンクションモデルの改良	3
2.2.1 スリップ速度計算方法の修正	3
2.2.2 垂直スリップジャンクションモデルのトリップ信号による制御	4
2.3 ジャンクションエンタルビの平滑化のための改良	5
3. BWR-LOCA 解析のための改良	5
3.1 改良の目的と概要	5
3.2 スプレー熱伝達モデル	6
3.2.1 热伝達係数	6
3.2.2 炉心スプレー作動中の燃料棒表面におけるスプレー水の 挙動に関する仮定	7
3.2.3 液膜の諸量の計算	8
3.3 CCFL 計算モデル	10
3.4 炉心バイパス下部プレナム漏水モデル	11
3.5 GE + 3 σ による核分裂生成物崩壊熱計算	12
4. RELAP4/MOD6/U4/J3 特有の機能	17
4.1 トリップリセット機能	17
4.2 ボリュームデータのIBUB の入力方法の変更	17
4.3 ボリュームデータ・リトリープ機能のトリップシグナルによる制御	17
4.4 リークテーブルの独立変数の追加	18
4.5 フィル・ジャンクションのエンタルピ計算オプションの追加	18
4.6 蒸気凝縮熱伝達モードと断熱計算オプションの追加	18
4.7 リスタート時に変更可能な入力の追加	19
5. 入力データの説明	19
6. サンプル問題	30
6.1 BWR 再循環配管大破断解析	30
6.1.1 はじめに	30
6.1.2 計算モデルと仮定	31
6.1.3 計算結果	32
6.2 BWR 再循環配管小破断解析	47
6.2.1 はじめに	47
6.2.2 計算モデルと仮定	47

6.2.3 計算結果	48
謝 辞	62
参考文献	62
附録 プロッタ・プログラム "PLT4CAL"	64

LIST OF TABLES

- Table 3.1 Radioactive Decay Constants
Table 6.1 Volume and Junction Identification for BWR Large Break
Table 6.2 Major Events Summary for BWR Large Break
Table 6.3 Input List for BWR Large Break
Table 6.4 Volume and Junction Identification for BWR Small Break
Table 6.5 Major Events Summary for BWR Small Break
Table 6.6 Input List for BWR Small Break
Table A.1 Source List of Subroutine PLTCAL
Table A.2 Input List of PLT4CAL for Void Fraction Plot
Table A.3 JCL for PLT4CAL Program at JAERI

LIST OF FIGURES

- Fig. 2.1 Vapor-Mixture Layering in Vertically Stacked Volumes
Fig. 2.2 Illustration for Vertical Slip Junction Model
Fig. 3.1 Illustration of Spray Heat Transfer Model
Fig. 3.2 Illustration of CCFL Calculation Model
Fig. 3.3 Schematic of Reactor Assembly Showing the Leakage Flow Paths
Fig. 6.1 Nodalization for BWR Large Break
Fig. 6.2 Lower Plenum Pressure - BWR Large Break
Fig. 6.3 Core Inlet Flow Rate - BWR Large Break
Fig. 6.4 Mixture Level in Shroud - BWR Large Break
Fig. 6.5 Clad Surface Temperature - BWR Large Break
Fig. 6.6 Nodalization for BWR Small Break
Fig. 6.7 Lower Plenum Pressure - BWR Small Break
Fig. 6.8 Break Flow Rate - BWR Small Break
Fig. 6.9 Mixture Level in Shroud - BWR Small Break
Fig. 6.10 Clad Surface Temperature - BWR Small Break

1. Introduction

Many modifications and improvements of RELAP4/MOD5 and MOD6 have been carried out in JAERI for the last several years.

Our improved versions are

- (a) RELAP4/MOD5/U2/J1
- (b) RELAP4/MOD6/U4/J1
- (c) RELAP4/MOD6/U4/J2

and our most latest improved version is

- (d) RELAP4/MOD6/U4/J3

The code (a) is an improved version for small break LOCA analysis, the second version (b) includes the improvements made for the preliminary analysis of the TMI accident⁽¹¹⁾, and third improved version (c) has been used in the latest analysis of the accident^{(12), (13)}. And RELAP4/MOD6/U4/J3 includes the improvements made for the thermal-hydraulic analysis of the core spray period in a BWR-LOCA. In virtue of these modifications and improvements, LOCA analysis capability of RELAP4/MOD6 has been greatly increased for BWR large and small breaks and for PWR small breaks.

Fifty-four modified subroutines and three new subroutines are contained in RELAP4/MOD6/U4/J3.

2. Improvements for Small Break LOCA Analysis

2.1 Modification of Single Mixture Level Calculation in Vertically Stacked Volumes

The purpose of the single mixture level calculation is to avoid unrealistic vapor-mixture layering in a series of connected control volumes representing vertical sections. In the original RELAP4, the method of single mixture level calculation in vertically stacked volumes is as follows:

At first, the mixture level of each control volume is calculated based on the bubble rise model independently of other control volume conditions. And if single mixture level calculation option is taken, the mixture level is corrected as follows,

$$z' = \frac{2M_{lk}}{A_i \rho_i}$$

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$$z' = \frac{2M_{lk}}{A_i \rho_i}$$

where

M_{lk} = liquid mass in Vol. K

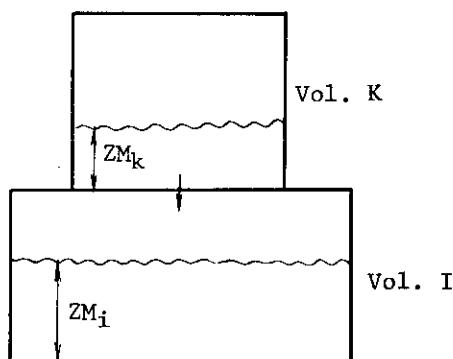
$A_i = V_i / ZVOL_i$

V_i = volume of Vol. I

$ZVOL_i$ = volume height of Vol. I

ZJ_i = junction elevation

Z' = the correction value for ZM_i



Using Z' , ZM_i is corrected as follows,

Fig. 2.1 Vapor-Mixture Layering
in Vertically Stacked
Volumes

$$ZM'_i = ZM_i + Z' \quad \text{for} \quad ZM_i \leq ZM_i + Z' \leq ZVOL_i$$

$$ZM'_i = ZJ_i \quad \text{for} \quad ZJ_i \leq ZM_i + Z'$$

$$ZM'_i = ZVOL_i \quad \text{for} \quad ZM'_i < ZVOL_i$$

and, mixture conditions are recalculated based on new mixture level ZM' .

$$MIXV_i = ZM' \cdot A_i$$

where

$MIXV_i$ = mixture volume of Vol. I

$BUBM_i = M_{gi} - (V_i - MIXV_i) / SATVG_i$

where

$BUBM_i$ = bubble mass in mixture of Vol. I

M_{gi} = vapor mass in Vol. I

$SATVG_i$ = saturated vapor specific volume in Vol. I

$MIXQ_i = BUBM_i / (BUBM_i + M_{li})$

where

$MIXQ_i$ = mixture quality in Vol. I

M_{li} = liquid mass in Vol. I

The defect of this method is that unrealistic vapor-mixture layering is calculated when this model is applied where large area change exists such as between core and lower plenum (aside from propriety of using this model in such a location). If this model is applied between core and lower plenum, $ZVOL$ is greater than ZM' in lower plenum, so that mixture levels are calculated in both control volumes. To avoid such a situation, the method of single level calculation is changed as below.

If the mixture level in the upper volume (in Fig. 2.1) is greater

than 0.05 ft, only bubble gradient in mixture is calculated and mixture level (ZM_j) is set equal to it's volume height ($ZVOL_j$).

This modification was done when RELAP4/MOD5/U2/J1 version was made, and in RELAP4/MOD6/U4/J2, a new input ZMABV, threshold of mixture level in the upper volume, was added. The default value of ZMABV is 0.05 ft. Input method is described in subsection (5.3).

2.2 Modification of Vertical Slip Junction Model

2.2.1 Modification of Slip Velocity Calculation Method

Slip velocity calculation method in original RELAP4/MOD5 and MOD6 is as follows,

$$AVEVS = \frac{GASV(I) + GASV(K)}{GASM(I) + GASM(K)}$$

$$AVEVL = \frac{LIQV(I) + LIQV(K)}{LIQM(I) + LIQM(K)}$$

$$SUMMS = GASM(I) + GASM(K) + LIQM(I) + LIQM(K)$$

$$AVX = \frac{GASM(I) + GASM(K)}{SUMMS}$$

$$\text{ALPHA} = \frac{AVEVS \cdot AVX}{AVEVL (1 - AVX) + AVEVS \cdot AVX}$$

$$ATOP = \frac{XTOP \cdot VS(I)}{VTOP}$$

$$ABOT = \frac{XBOT \cdot VS(K)}{VBOT}$$

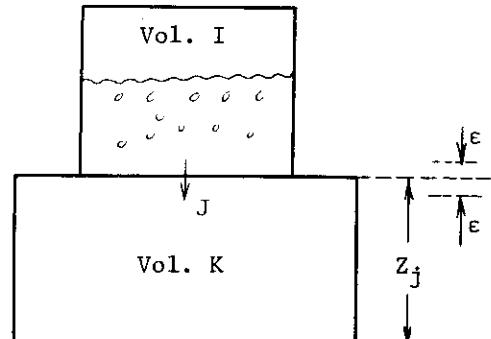


Fig. 2.2 Illustration for Vertical Slip Junction Model

$$VSLIP = \{10. + 4.(\text{ABOT} - \text{ATOP})\} \text{ ALPHA} \cdot (1. - \text{ALPHA})^{(1. - 1.25 \cdot \text{ALPHA})}$$

where

$GASV(I)$ = vapor volume in Vol. I

$LIQV(I)$ = liquid volume in Vol. I

$GASM(I)$ = vapor mass in Vol. I

$LIQM(I)$ = liquid mass in Vol. I

$AVEVS$ = average vapor specific volume at Jun. J

$AVEVL$ = average liquid specific volume at Jun. J

AVX = average quality at Jun. J
 ALPHA = average void fraction at Jun. J
 XTOP = quality at $Z_j + \epsilon$
 XBOT = quality at $Z_j - \epsilon$
 VTOP = specific volume at $Z_j + \epsilon$
 VBOT = specific volume at $Z_j - \epsilon$
 VS(I) = average vapor specific volume in Vol. I
 VSLIP = slip velocity at Jun. J

As described above, the average void fraction (ALPHA), which is used in the calculation of VSLIP, is obtained from the average values of the upper and lower control volumes. It can be interpreted that ALPHA may be the void fraction in the neighborhood of the junction. This procedure may be correct when both control volumes are homogeneous, but if the mixture level exists in the upper control volume or a bubble gradient in mixture is calculated in the lower and/or upper volumes, it is incorrect. Therefore the calculation procedure of AVEVS, AVEVL, and AVX are changed as below.

$$\text{AVEVS} = \frac{\text{XTOP} \cdot \text{RTOP} \cdot \text{VS}(I) + \text{XBOT} \cdot \text{RBOT} \cdot \text{VS}(K)}{\text{XTOP} \cdot \text{RTOP} + \text{XBOT} \cdot \text{RBOT}}$$

$$\text{AVEVL} = \frac{(1-\text{XTOP}) \cdot \text{RTOP} \cdot \text{VL}(I) + (1-\text{XBOT}) \cdot \text{RBOT} \cdot \text{VL}(K)}{(1-\text{XTOP}) \cdot \text{RTOP} + (1-\text{XBOT}) \cdot \text{RBOT}}$$

$$\text{AVX} = \frac{\text{XTOP} \cdot \text{RTOP} + \text{XBOT} \cdot \text{RBOT}}{\text{RTOP} + \text{RBOT}}$$

where

RTOP = average density at $Z_j + \epsilon$

RBOT = average density at $Z_j - \epsilon$

VL(I) = average liquid specific volume in Vol. I

This correction is included in all the JAERI improved version.

2.2.2 Trip Control of Vertical Slip Junction Model

Vertical slip junction model in RELAP4/MOD5 or MOD6 is postulated on the assumption that gravity forces govern the slip between phases and therefore the model is especially applicable during relatively slow transients when inertia effects are negligible. Except these conditions,

this model is useless. So the function of trip control of vertical slip junction model has been introduced in RELAP4/MOD6. The detail of input is described in section (5.4).

2.3 Modification of Junction Enthalpy Smoothing

When the mixture level changes continuously between vertically stacked control volumes, the junction enthalpy changes rapidly when the mixture level passes the junction elevation point. And it leads the calculation to numerical instability. To avoid this instability, a tricky smoothing technique has often been used that is simultaneous use of volume overlapping and JVERTL = 1. If this technique is used, some liquid remains in the upper control volume and single mixture level calculation option in our improved version does not function well. Therefore, instead of such a tricky technique, new enthalpy smoothing option is introduced. This new option functions when JVERTL = 1, and DIAMJ \leq 0.0 are inputted. And junction enthalpy is determined by integrating the bubble distribution function over the vertical circular area centered at ZJUN. The diameter of vertical circular area is equal to |DIAMJ|, and if DIAMJ = 0.0, its diameter is set equal to 0.1 ft.

3. Improvements for BWR-LOCA Analysis

3.1 Purpose and Abstract of Improvement

In BWR-LOCA analysis, original RELPA4 (MOD3, MOD5, and MOD6) cannot calculate well the thermal-hydraulic behavior after the core spray initiated. Major causes of this weakness are as follows; 1) RELAP4 can not calculate appropriately CCFL (Counter-Current Flow Limiting) phenomena by upward steam flow at the core upper tie-plate, and 2) RELPA4 does not have a proper heat transfer model at the clad surface during core spray falling through the core. Therefore, several improvements of RELAP4/MOD6 have been done for BWR-LOCA analysis, and it has made a through calculation from the beginning of blowdown to the end of reflood practicable.

It should be noted that these improvements described in this section are for use in the EM calculation and that these models and assumptions are rather crude.

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It should be noted that these improvements described in this section are for use in the EM calculation and that these models and assumptions are rather crude.

Major improvements for BWR-LOCA analysis in RELAP4/MOD6/U4/J3 are;

1. Spray Heat Transfer Model,
2. CCFL Calculation Model,
3. Bypass-Lower Plenum Leakage Model and
4. Fission Product Decay Heat (GE + 3σ).

3.2 Spray Heat Transfer Model

This model calculates heat transfer at the clad surface during core spray dropping into the core. This model starts when spray water begins to penetrate into the core at the first time following LPCS or HPCS initiation, and stops when the mixture level of the core becomes greater than the value specified by an input. Figure 3.1 is a illustration of this model.

3.2.1 Heat Transfer Coefficients (H.T.C.)

During core spray dropping, three types of heat transfer are considered. One is heat transfer in the uncovered core region, the second one is in the rewetted region by top quench, and the last one is in the two phase mixture by bottom reflooding.

The heat transfer model in the uncovered core region is based on the GE FLECHT experiment⁽⁵⁾, i.e. the fuel rods in the assembly are divided into some groups, and acceptable convective heat transfer coefficients are given by inputs for each groups. For example, convective heat transfer coefficients of 3.0, 3.5, and 1.5 Btu/hr·ft²·°F (H_{conv}^i in Figure 3.1) are applied to the fuel rods in the outer corners and outer rows, and to those remaining in the interior, respectively, of the assembly. The core coolant temperature is assumed equal to saturation temperature. These recommended experimental heat transfer coefficients contain the effects of steam cooling, radiative heat transfer, and cooling by spray droplet.

The heat transfer mode at rewetted clad surface by topdown liquid film is assumed to be nucleate boiling. The acceptable heat transfer coefficient is given by an input H_{wet} , and its recommended value is 1000 Btu/hr·ft²·°F.

For the heat slab that contains the quench front of falling liquid film (like heat slab S_3 in figure 3.1), its heat transfer coefficient is set equal to the average value of H_{wet} and H_{conv}^i wieghed by each area.

For the heat slab in the two phase mixture by bottom reflooding, the heat transfer mode is assumed to be film boiling when the local quality in the neighborhood of the slab becomes less than an input value XCRFD which is a threshold of quality for bottom reflooding. A heat transfer coefficient for film boiling H_{flood} is given by an input. $H_{flood} = 25 \text{ Btu/hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}$ and $XCRFD = 0.05$ are recommended.

Based on conservatism, during the period following lower plenum flashing prior to core spray penetration into the core, the convective heat transfer coefficient is assumed to vanish for all the uncovered heat slabs.

3.2.2 Assumption for Coolant Behavior along Clad Surface during Core Spray

As shown in Figure 3.1, it is assumed that all of spray water (W) flowing into the core first falls down along the clad surface as a liquid film, and then it is divided into the steam flow ($W_{s\ell}$) vaporizing from liquid film, the liquid film flow (W_ℓ) remaining on clad surface, and the droplet flow (W_d) leaving from liquid film. That is, the relationship between W , W_ℓ , $W_{s\ell}$, and W_d in Figure 3.1 is;

$$W = W_\ell + W_{s\ell} + W_d \quad (3.1)$$

W_ℓ is obtained from the next equation, which is explained in detail in section (3.2.3),

$$W_\ell = U_{fr} \cdot \delta \cdot Perim \cdot \rho_\ell \quad (3.2)$$

where

U_{fr} = Quench front velocity of liquid film

δ = Liquid film thickness

$Perim$ = Wetted perimeter

ρ_ℓ = Liquid density

And $W_{s\ell}$ is calculated from heat transfer rate (Q_ℓ) at the wetted clad surface by liquid film.

$$W_{s\ell} = Q_\ell / (h_g - h_\ell) \quad (3.3)$$

where

h_ℓ = Saturated liquid enthalpy

h_g = Saturated vapor enthalpy

W_d is obtained from equations (3.1), (3.2), and (3.3).

3.2.3 Calculation about Liquid Film

Quench front velocity, liquid film flow rate, and quench front elevation are calculated by subroutines "MQFRON" and "ZQUEN" which is contained in the source of RELAP4/MOD6 as an inactive subroutine to be used for MOD7.

Quench front velocity on clad surface is calculated by Duffey-Porthouse's correlation which is modified for inner heat generation.

The correlation is as follows;

$$U_{fr} = \frac{1}{\rho C} \sqrt{\frac{h_{fr} \cdot k}{d}} \cdot \frac{T_o - T^*}{\{(T_\infty - T^*)(T_\infty - T_o)\}^{1/2}} \quad (3.4)$$

where

ρ = liquid density

C = specific heat capacity of liquid

k = thermal conductivity of liquid

T_∞ = surface temperature of next heat slab down from the quench front

T_o = sputtering temperature ($= T_s + T_{dif}$)

T_s = saturation temperature

T_{dif} = input (default value = 144 °F)

d = clad thickness

h_{fr} = heat transfer coefficient at quench front

$$= 27500 [2.04 + 2.4 P \log_{10} P] G \frac{0.153}{P} \quad (3.5)$$

Yu's correlation

P = coolant pressure

D_{mfbdt} = liquid flow rate into core

$Perim$ = total perimeter of rods

$$T^* = \frac{Q_{gen}}{h_{fr} Perim} + T_s \quad (3.6)$$

= correction term for inner heat generation

Q_{gen} = linear heat generation rate

The Anderson's correlation can be used for calculation of quench front velocity on channel box surface, i.e.,

$$U_{fr} = \frac{k}{\rho \cdot C \cdot d} \cdot \theta^{\left(\frac{\sqrt{\pi}}{2} - 1\right)} \left\{ (B_i \cdot \theta^{-\sqrt{\pi}})^{1.5} + 0.398 (B_i \cdot \theta^{-\sqrt{\pi}})^3 \right\}^{\frac{1}{3}} \quad (3.7)$$

where

$$B_i = \frac{h_{fr} \cdot d}{k}$$

$$\theta = \left\{ \frac{(T_\infty - T_s)(T_\infty - T_0)}{(T_0 - T_s)^2} \right\}^{\frac{1}{2}}$$

$$h_{fr} = 1.99 \times 10^5 \quad (\text{Btu/hr} \cdot \text{ft}^2 \cdot {}^\circ\text{F})$$

$$T_0 = T_s + 117 \quad ({}^\circ\text{F})$$

d = channel box thickness

And quench front elevation (Z_q) are obtained from the next equation.

$$Z_q = Z_q(\text{old}) - U_{fr} \cdot \Delta t \quad (3.8)$$

where

Δt = time step size

Liquid film flow rate (W_ℓ) is calculated following the Wallis' es method⁽⁷⁾.

$$W_\ell = U_{fr} \cdot \delta \cdot P_{\text{perim}} \cdot \rho_\ell \quad (3.9)$$

where

U_{fr} = quench front velocity

P_{perim} = wetted perimeter of rods or channel box

ρ_ℓ = density of liquid

δ = liquid film thickness

$$= \frac{\delta s t \cdot \mu^{\frac{2}{3}}}{\{32.2 \cdot (\rho_\ell - \rho_g) \cdot \rho_\ell\}^{\frac{1}{3}}} \quad (3.10)$$

where

μ = liquid viscosity

ρ_g = density of vapor

$$\delta_{st} = \begin{cases} 0.115(\text{Regama})^{0.6} & \text{for } \text{Regama} > 10^3 \\ 0.909(\text{Regama})^{\frac{1}{3}} & \text{for } \text{Regama} \leq 10^3 \end{cases}$$

where

$$\text{Regama} = \left| \frac{4 \cdot D_{mfbdt}}{\mu \cdot P_{\text{perim}}} \right|$$

If W in equation (3.1) is less than W_ℓ , W_ℓ is set equal to W . Then the quench front velocity is the minimum of U_{fr} obtained by equation (3.4) and $W_\ell / (\delta \cdot P_{\text{perim}} \cdot \rho_\ell)$.

3.3 CCFL Calculation Model

The calculation scheme of CCFL is illustrated in Figure 3.2. The form of CCFL correlation in RELAP4/MOD6/U4/J3 is similar to Wallis' es flooding correlation;

$$J_g^{\frac{1}{2}} D^{\frac{1}{4}} + k_1 J_\ell^{\frac{1}{2}} D^{\frac{1}{4}} = k_2 \quad (3.11)$$

$$J_g^* = V_g \cdot \rho_g^{\frac{1}{2}} \{ g \cdot D \cdot (\rho_\ell - \rho_g) \}^{-\frac{1}{2}} \quad (3.12)$$

$$J_\ell = V_\ell \cdot \rho_\ell^{\frac{1}{2}} \cdot \{ g \cdot D \cdot (\rho_\ell - \rho_g) \}^{-\frac{1}{2}} \quad (3.13)$$

where

V_g , V_ℓ = vapor and liquid velocity

ρ_g , ρ_ℓ = vapor and liquid density

g = gravitational constant

D = equivalent diameter of core outlet

k_1 , k_2 = correlation parameter

It is assumed that CCFL phenomena take place at the core outlet and the core bypass outlet only. The correlation parameters k_1 and k_2 depend on the geometry of outlet, so that k_1 and k_2 must be inputted for each outlet.

In RELAP4/MOD6/U4/J3, a new kind of fill junction named CCFL fill junction is added to simulate CCFL. CCFL fill junctions can be specified by IFLOOD on Junction Data Cards. Core spray flow is injected directly to the core or the core bypass region by a CCFL fill junction, the flow rate through which is controlled by the CCFL correlation automatically and its maximum flow rate is the rated core spray flow rate falling on

each area. Therefore, the fill table read by CCFL fill junction is equal to the core spray flow available to the core (bundle) or the core bypass region.

Upward steam flow rate causing CCFL phenomenon is assumed to be equal to that at core outlet junction which is obtained from the solution technique of RELAP4. And at the core bypass outlet, the same assumption is applied.

Using steam upflow rate (W_{co}) at the outlet, the liquid flow limited by CCFL is calculated and compared to the available flow (W_{sc}). The minimum of the two flow (W_{sci}) is assumed to penetrate into the core. The spray water not dropping into the core, W_{sco} , is added to the flow available to the core bypass (W_{sb}). Then, the CCFL condition is examined at the core bypass outlet. Similarly at the core bypass outlet, the lower of the available flow rate and the CCFL flow rate is assumed to enter the core bypass region. The excessive liquid flow (W_{sbo}) is assumed to be lost from the system.

It is noticed that the present CCFL calculation model in this version is not acceptable when liquid phase water exists in the upper plenum volume because of the assumption that the steam upflow rate is equal to the junction steam flow rate obtained from RELAP4's solution procedure. Therefore, in the BWR-LOCA analysis by RELAP4/MOD6/U4/J3, it is necessary that the liquid in the core bypass region is controlled so as not to overflow into the upper plenum from the core bypass region filled with ECC water.

3.4 Bypass-Lower Plenum Leakage Model

During the refill or reflood period in a BWR-LOCA, the lower plenum is fed by leakage flows through the control rod guide tubes. And, after control rod guide tubes are full, ECC water also passes through holes in the core support-plate and other normal leakage flow paths. Figure 3.3 is a schematic of fuel assembly showing the leakage flow paths. The REFLOOD code, which has been developed by General Electric Campany for the analysis of refill/reflood in BWR-LOCA, computes these leakage flows by using experimental correlation. Therefore, in the RELAP4/MOD6/U4/J3, the leakage flow calculation option using these GE's correlation is provided for BWR-LOCA analysis. Refer to GE report "NEDO-20566"⁽⁵⁾ about the detail of this model. In this section, only the correlation

forms are shown.

$$W_{\text{g1}} = 2.73(\text{NGT}) \cdot \Delta P^{\frac{1}{2}} + 0.96(\text{NGT}) \cdot \Delta P + 0.023(\text{NGT}) \cdot \Delta P^2 \quad (\text{lb/hr}) \quad (3.14)$$

$$W_{\text{g2}} = C_1 \Delta P^{\frac{1}{2}} + C_2 \Delta P + C_3 \Delta P^2 \quad (3.15)$$

where

$$C_1 = 2810.97(\text{NGT}) + 11656.(\text{NHOLES}) + 101.4(\text{NINST}) + 6.86(\text{NBUNT}) + 14965.7 \quad (3.16)$$

$$C_2 = -70.76(\text{NGT}) - 8.61(\text{NINST}) + 15.55(\text{NBUNT}) + 1084.3 \quad (3.17)$$

$$C_3 = 1.95(\text{NGT}) + 0.2(\text{NINST}) - 0.058(\text{NBUNT}) - 12.3 \quad (3.18)$$

where

NGT = Number of guide tubes

NHOLES = Number of core plate poles

NINST = Number of instrument guide tubes

NBUNT = Number of bundle

This option applies when a valve is placed in the junctions modeling leakage flow paths and ITCV on valve data card is set equal to (trip number + 100). Then these junction's flows are determined by the GE correlation if trip is on and the junction elevation point is under the mixture level of the guide tube or core bypass region. The detail of the inputs is described in section (5.7).

3.5 Fission Product Decay Heat Calculation by (GE + 3σ)

Five options are available to describe internally generated power. These are (a) data retrieved from a previous RELAP4 calculation (NODEL = -1), (b) a normalized power supplied by a table of power-versus-time (NODEL = 0), (c) program solution of the space-dependent reactor kinetics equation (NODEL = 1), (d) program solution of space-dependent reactor kinetics equation with fission product (FP) decay heat (NODEL = 2), (e) program solution of space-dependent reactor kinetics with fission product and Actinides decay heat (NODEL = 3). NODEL is a power calculation indicator on the Kinetics Constants Data Card, and, in these power calculation, fission product decay heat is based on ANS standard model.

In addition to these options, two options (NODEL = 4 or 5) are available in RELAP4/MOD6/U4/J3. In the new options NODEL = 4 and 5,

fission product decay heat is replaced by $GE + 3\sigma$ in NODEL = 2 and 3, respectively. This improvement is for use in the EM calculation.

The outline of program modifications for this option is as follows: ANS standard FP decay heat data are fitted by a polynomial of eleven exponentials of the form

$$\Gamma_d = \sum_{j=1}^{11} E_j e^{-\lambda_j t} \quad (3.19)$$

where

Γ_d = normalized fission product decay energy

E_j = amplitude of j -th term

λ_j = decay constant of j -th term

t = elapsed time since shutdown

In the similar manner, $(GE + 3\sigma)$ FP decay heat experimental data⁽⁶⁾ are fitted by a polynomial of nine exponentials. E_j and λ_j for $(GE + 3\sigma)$ are shown in table 3.1. If NODEL = 4 or 5, E_j , λ_j are changed from ANS standard's E_j , λ_j to $(GE + 3\sigma)$'s E_j , λ_j in the program. Input for this option is described in section (5.10), and the detail of this modification is explained in reference (10).

Table 3.1 Radioactive Decay Constants

Group	E_j	λ_j (sec^{-1})
1	0.014293	4.0374×10^{-1}
2	0.014586	9.3893×10^{-2}
3	0.011817	2.2065×10^{-2}
4	0.009664	4.5052×10^{-3}
5	0.007925	8.9024×10^{-4}
6	0.006125	1.7214×10^{-4}
7	0.003890	2.9417×10^{-5}
8	0.002901	4.1247×10^{-6}
9	0.003734	1.9633×10^{-7}

$$h_4 = H_{\text{wet}} \text{ (input)}$$

$$h_3 = \frac{\Delta L \cdot H_{\text{wet}} + (L - \Delta L) \cdot H_{\text{conv}}^i}{L}$$

$$h_2 = H_{\text{conv}}^i \text{ (input)}$$

1	2	1
2	3	2
1	2	1

$$H_{\text{conv}}^i = 3.0$$

$$H_{\text{conv}}^2 = 3.5$$

$$H_{\text{conv}}^3 = 1.5 \text{ (Btu/hr}\cdot\text{ft}^2\cdot\text{F)}$$

$$h_1 = H_{\text{flood}} \text{ (input)}$$

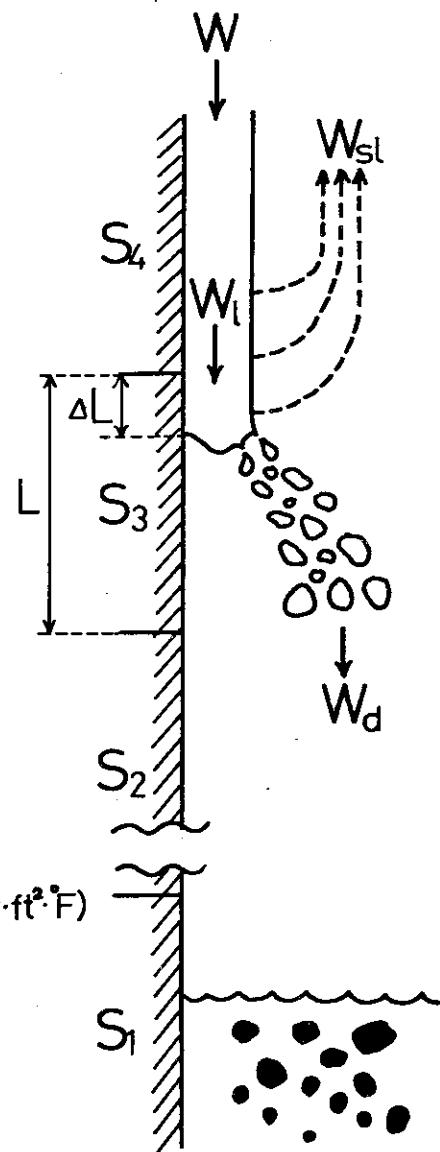


Fig. 3.1 Illustration of Spray Heat Transfer Model

CCFL CALCULATION MODEL

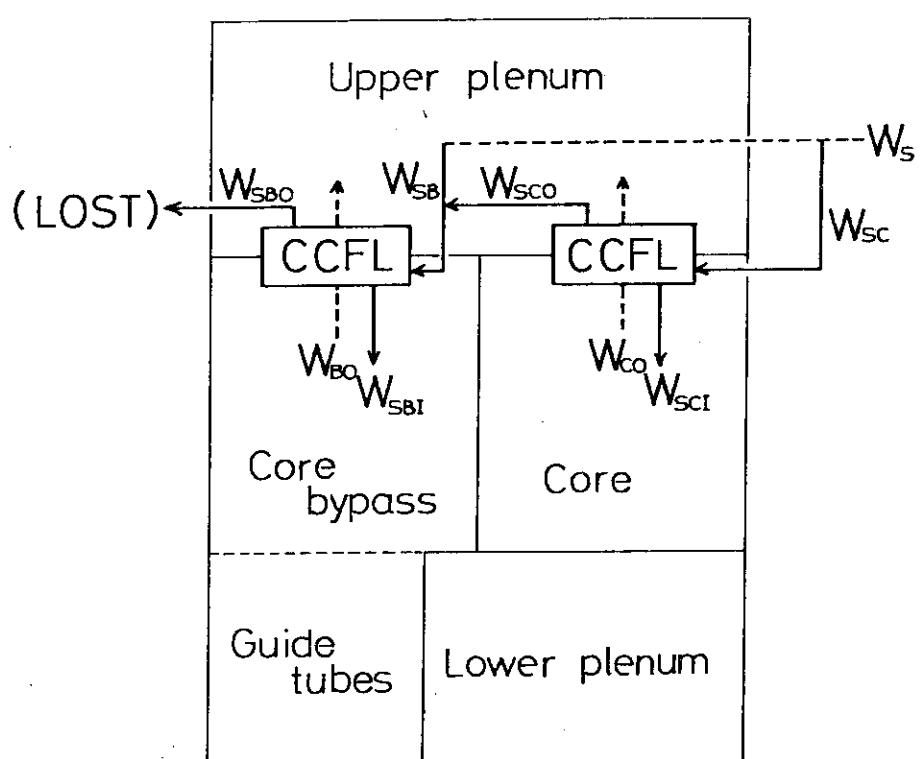
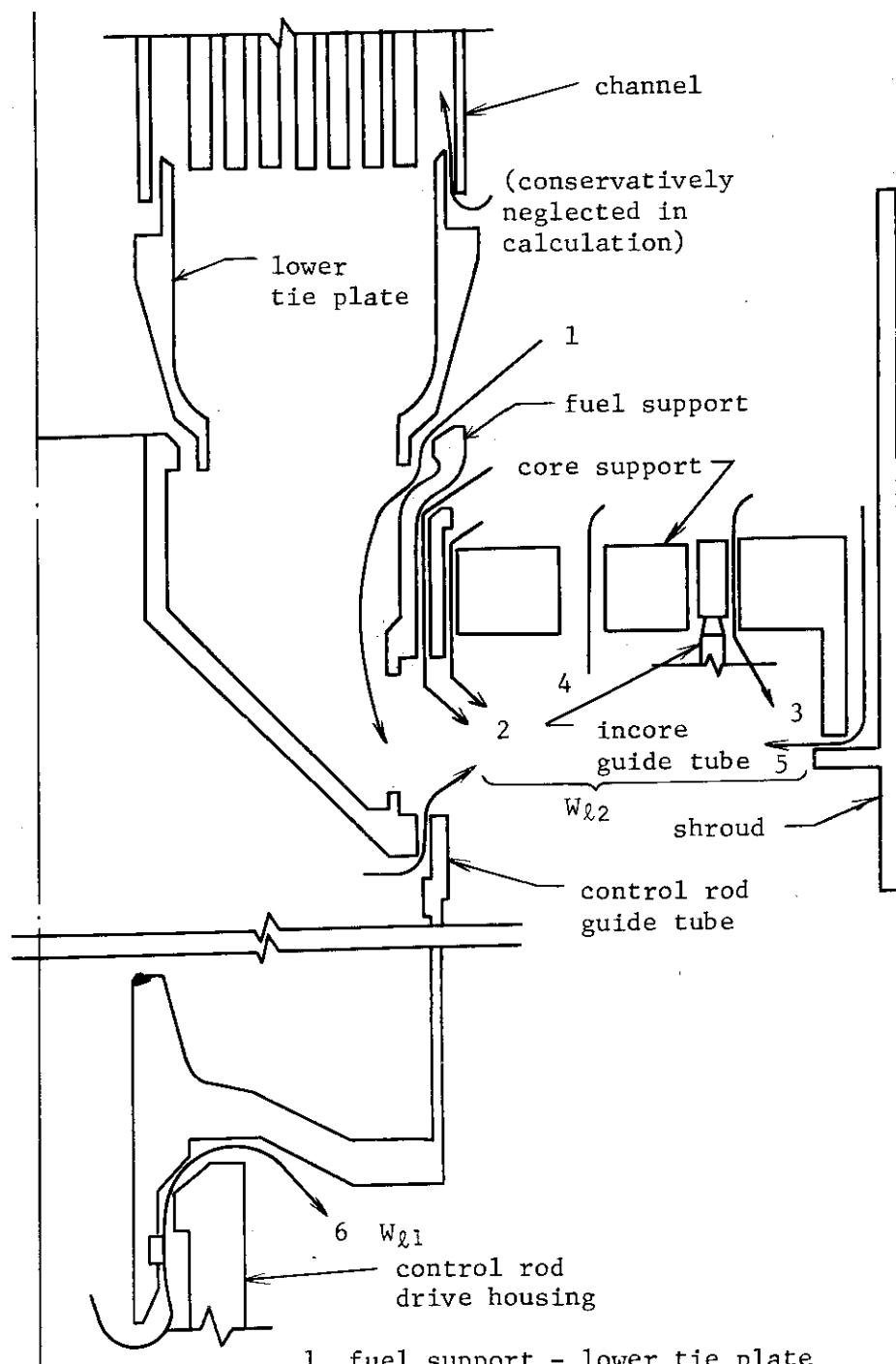


Fig. 3.2 Illustration of CCFL Calculation Model



1. fuel support - lower tie plate
2. control rod guide tube - fuel support and control rod guide tube - core support plate
3. core support plate - incore guide tube
4. support plate holes
5. core support plate - shroud (single path - $W_{\ell 1}$)
6. control rod guide tube - drive housing

Fig. 3.3 Schematic of Reactor Assembly Showing the Leakage Flow Paths
(from NEDO-20566)

4. Special Features in RELAP4/MOD6/U4/J3

4.1 Trip Reset Option

Usually, the original RELAP4 trips never again can be turned off at any time once they have been turned on. It is very inconvenient to the LWR's operational transient analysis by RELAP4. Therefore, the trip reset function is added to RELAP4/MOD6/U4/J3. Using this function, for example, the open-close action of relief valves or safety valves, which is important for an operational transient analysis, can be modeled. Secondly, the restriction placed on trip control data inputting upon restart is loosened. In the original RELAP4/MOD6, if any trip cards are used upon restart, a complete set of trip cards with the same sequence numbers and the same IDTRP symbols as the initial set must be inputted. And, for a trip to remain actuated once tripped, a new card corresponding to the original card should be submitted with IDSIG set equal to zero. This procedure may be very troublesome and cause one to make mistakes. In the RELAP4/MOD6/U4/J3, however, such problems have been solved since it is enough to submit only cards which are to be used upon restart with NTRP on Problem Dimension Data Card 010001 must be equal to the number of all the trips.

4.2 Change of Input about Bubble Index on Volume Data Cards

An option to turn the bubble rise model on or off in a volume during the transient calculation is provided in the original RELAP4/MOD6. But, if this option is used, the bubble parameter and trip number, which controls the action of bubble rise model, must be equal. This input restriction about input is inconvenient. Therefore, in the RELAP4/MOD6/U4/J3, the trip number and bubble parameter index can be selected independently.

4.3 Trip Control Option of Volume Data Retrieval

In RELAP4/MOD6/U4/J3, thermal-hydraulic conditions in a normal control volume can be specified from the time-dependent volume data table given by inputs at any time which the user can specify. In addition a time-dependent control volume can be made a normal control volume governed by the three conservation equations at any time which the user can specify. Input manner about this option is described in section 5.

4.4 Addition of New Independent Variable of Leak Table

In the original RELAP4/MOD5 or MOD6, a valve flow area can be controlled by the leak table. In this usage of the leak table, time-versus-normalized flow area table must be inputted. In RELAP4/MOD6/U4/J3, instead of time, average pressure or mixture level in a control volume can be used as independent variable of the leak table. To use these leak tables, average pressure or mixture level in the volume adjacent to the junction with a valve can be maintained constant. Because of this improvement, a new integer input variable (ITYPE) is added to the Leak Table Data Cards.

4.5 Fill Junction Enthalpy Calculation Option

In the RELAP4/MOD6/U4/J3, fill junction enthalpy can be set equal to liquid phase enthalpy, vapor phase enthalpy, or average enthalpy of an arbitrary control volume at each time steps. Using this option, unrealistic pressure drop because of the subcooled water mixing during refill and reflood can be avoided.

4.6 Steam Condensation Heat Transfer Model and Adiabatic Calculation Option

In the RELAP4/MOD6, two types of heat transfer logic are provided, one of them is MOD5 blowdown heat transfer logic (using subroutine HTRC and QDOT) and the other is MOD6 heat transfer logic (using subroutine TWQW and TWFIND) which has four heat transfer correlation sets. In the MOD5 blowdown heat transfer logic, which is one of these heat transfer model selection, two new heat transfer mode are added. They are steam condensation heat transfer mode and adiabatic mode.

Steam condensation heat transfer may be selected when a heat slab under consideration is in the steam atmosphere and its surface temperature is lower than the saturation temperature. But in RELAP4/MOD6/U4/J3, another artificial condition must be satisfied, i.e., a trip signal specified by an input is on. The trip numbers and steam condensation heat transfer coefficients are inputted by 082022 card (see Input Data Description). Two pairs of trip number and steam condensation H.T.C. can be inputted.

Adiabatic mode will be selected if the trip signal is on or junction

flow specified by an input is equal to zero when a slab under consideration is in steam atmosphere. When this heat transfer mode is selected, the convective heat transfer coefficient of zero is assumed in the heat transfer calculation. But the adiabatic calculation is not allowed at the left surface of a slab because of RELAP4's heat conduction equation form. The detail of the inputs is explained in section (5.5) and (5.10).

4.7 Addition of Changeable Data Cards upon Restart

In the original RELAP4/MOD6, certain data and data tables can be changed upon restart. In addition to these data, control volume data, reactivity coefficient data, core section data, and bubble parameter data also can be changed upon restart in RELAP4/MOD6/U4/J3.

The changeable data on Control Volume Data Cards 050XXY are as follows;

IBUB	= Bubble index
IREAD	= Volume data retrieval index
JTPMV	= Two-phase friction index
IAMBLO	= Single mixture level calculation
ZMABV	= New input variable for single mixture level calculation (refer to section (2.1))

The other data on Control Volume Data Cards are ingnored, but arbitrary values must be inputted.

Reactivity coefficient data (140XX0) and core section data except ISLB (160XX0) can be also changed upon restart. Using this capability, power distribution can be changed in the process of a calculation. In RELAP4/MOD6, the calculation will fail when explosive oxidation of fuel clad takes place. In RELAP4/MOD6/U4/J3, however, clad oxidation calculation will not be performed in such a situation by inputting CLTI = 0.0 (on card 160XX0), but rest of the calculation will continue.

5. Input Data Description

In the following description of data cards, the added input data and the changed input data for RELAP4/MOD6/U4/J3 are only described. Please refer to the RELAP4/MOD6 User's Manual for all the other input data.

flow specified by an input is equal to zero when a slab under consideration is in steam atmosphere. When this heat transfer mode is selected, the convective heat transfer coefficient of zero is assumed in the heat transfer calculation. But the adiabatic calculation is not allowed at the left surface of a slab because of RELAP4's heat conduction equation form. The detail of the inputs is explained in section (5.5) and (5.10).

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5. Input Data Description

In the following description of data cards, the added input data and the changed input data for RELAP4/MOD6/U4/J3 are only described. Please refer to the RELAP4/MOD6 User's Manual for all the other input data.

The order of the data (W1, W2, . . .), the format (I, R, or A), the variable name, and the input requirements are given below. The format of the field (integer, real or floating, or alphanumeric) is indicated by I, R, or A, respectively.

5.1 Program Option Card 010003

W2-I IEMHT = EM heat transfer logic flag
 0 = do not use EM heat transfer logic.
 1 = use EM heat transfer logic.
 $1 < \text{IEMHT} \leq \text{NTRP}$ = trip signal number to start
 EM heat transfer logic.
 $-1 > \text{IEMHT} \geq -\text{NTRP}$ = trip signal number to stop
 EM heat transfer logic.

5.2 Trip Control Data Cards 04XXXX

W1-I IDTRP = Action to be taken.
 W2-I IDSIG = Signal being compared to.
 W3-I IX1 = Volume or junction index.
 W4-I IX2 = Optional Volume.
 W5-R SETPT = Signal setpoint.
 W6-R DELAY = Delay time.
 W7-R SETPTR = Signal setpoint for trip off.
 default value = 0.0
 W8-R DELAYR = Delay time for trip off.
 default value = 0.0
 W9-I IDSIGR = Signal for trip off
 if no input for IDSIGR and IDTRP < 0,
 IDSIGR = -IDSIG
 W10-I IX1R = Volume or junction index.
 if no input for IX1R and IDTRP < 0,
 IX1R = -IX1.
 W11-I IX2R = Optional volume.
 if no input for IX2R and IDTRP < 0,
 IX2R = -IX2.

After a trip has been reset, if the set point condition will be satisfied, the trip will turn on again.

5.3 Volume Data Cards 05XXXX

W1-I IBUB = Bubble index and trip selection.

$0 \leq IBUB \leq NBUB$ = bubble index, no trip.

= IDTRP $\times 10 + IIBUB$
Bubble rise velocity calculation will start with trip on.

= -(IDTRP $\times 10 + IIBUB$)
Bubble rise velocity calculation will stop with trip on.

= (IDTRP + 20) $\times 10 + IIBUB$
Bubble rise velocity and gradient calculations will start with trip on.

= -{(IDTRP + 20) $\times 10 + IIBUB\}}$
Bubble rise velocity and gradient calculations will stop with trip on, where:

IDTRP = Trip number, and
IIBUB = Bubble parameter index.

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.

$0 \leq IREAD \leq NTDV$ = use the time dependent volume condition table. No. IREAD table will be used.

= IDTRP $\times 100 + IIREAD$
The time dependent volume condition will be used after trip on.

= (IDTRP + 20) $\times 100 + IIREAD$
The time dependent volume condition will be used until trip on, where:

IDTRP = Trip number, and
IIREAD = Time dependent volume condition table index.

5.4 Junction Data Cards 08XXXX

- W3-I IPUMP = Pump, leak, or fill index.
- (a) If IW1>0, IW2>0, and IPUMP=0, this is a normal junction not connected to a pump volume.
 - (b) If IW1>0, IW2>0, and IPUMP≠0, this junction uses the pump data.
 - (c) If IW1>0, IW2=0, IPUMP is the leak table index, $0 < \text{IPUMP} \leq \text{NLK}$.
 - (d) If IW1=0, IW2>0, IPUMP is the fill table index, $0 < \text{IPUMP} \leq \text{NFLL}$.
 - (e) If IW1=0, IW2>0, and IPUMP>100, this is a special fill junction for Spray Heat Transfer Model.
 $\text{IPUMP} = \text{IFILL} + 100, \quad 0 < \text{IFILL} \leq \text{NFLL}$
 This fill junction is used for injection of steam vaporizing from liquid film, or injection of droplet falling from liquid film quench front.
- W15-R DIAMJ = Junction diameter.
 This value is used for junction quality and enthalpy calculation.
- If DIAMJ = 0., the program will calculate DIAMJ as $2\sqrt{A_{\text{JUN}}/\pi}$.
- If DIAMJ $\leq 0.$, and JVERTL = 1, junction quantites are determined by integrating the bubble-distribution function over a circular area having a diameter of |DIAMJ|, even if volume IW1 and IW2 are not overlapped. In this case, if DIAMJ = 0.0, it will be set equal to 0.1 ft.
- W19-R SRCOS = Slip velocity direction indicator and multiplier.
- 1. $\leq \text{SRCOS} < 0.$ = vertical slip will be used at this junction. The positive flow direction is upward.
- SRCOS = 0. = no vertical slip for this junction.
1. $\geq \text{SRCOR} > 0.$ = vertical slip will be used at this junction. The positive flow direction is downward.
- SRCOS = $\pm(\text{IDTRP} \times 10 + \text{SRCS})$
 Vertical slip calculation will stop with trip on.

$SRCOS = \pm\{(IDTRP + 20) \times 10 + SRCS\}$
 Vertical slip calculation will start with trip on,

where:

IDTRP = Trip number.

SRCS = Multiplier $0 < SRCS \leq 1$.

(+) ; positive flow direction is downward.

(-) ; positive flow direction is upward.

W20-I IFLOOD = Wallis flooding correlation number and junction number of upward steam flow for CCFL calculation.

0 = no flooding correlation specified for this junction.

define K = IFLOOD,

$1 \leq K \leq 6$ = use the Wallis flooding parameters WCL1(K) and WCL2(K) specified on Card 0600X2 where $K = X + 1$ should be used only when the PWR fallback model is utilized.

$= \pm(IJUN 10 + K)$

If IW1=0, IW2>0, and IFLOOD>10, this fill junction injects core spray flow into core or core bypass directly. This junction flow is determined by CCFL correlation whose coefficients are specified on Card 0600X2 where $K = X + 1$.

where

IJUN = Core outlet junction or core bypass outlet junction.

(+) ; positive direction of IJUN is upward.

(-) ; positive direction of IJUN is downward.

5.5 Steam Condensation H.T.C. Dial Card 082022

W1-I IDTRP(1) = Trip number.

W2-R HTCND(1) = Steam condensation H.T.C. ($\text{Btu}/\text{hr} \cdot \text{ft}^2 \cdot {}^\circ\text{F}$)

W3-I IDTRP(2) = Trip number.

W4-R THCND(2) = Steam condensation H.T.C. ($\text{Btu}/\text{hr} \cdot \text{ft}^2 \cdot {}^\circ\text{F}$)

If IDTRP(I) turns on, HTCND(I) will be used when steam condensation heat transfer criterion is satisfied.

If IDTRP(1)<0, HTCND(1) is used until IDTRP(2) turns on. After IDTRP(2) turns on, HTCND(2) is used as steam condensation H.T.C..

NSUR on 150000 Card must be equal to -1 when this dial card is used.

5.6 Valve Data Cards 11XXXX

The data regarding to GE leakage correlation option are only described.

W1-I ITCV	= IDTRP 100 IDTRP is a trip number which actuates this option. If ITCV > 100, RELAP4 regards the data on this card as input data for GE leakage correlation.
W2-I IACV	= Volume number of core bypass region. = IW1 or -IW2 IW1 or IW2 are volume number connected by this junction which refers to XXX valve data. If IACV = 0, it is set equal to IW1.
W3-I LATCH	= 0, not used.
W4-R PCV	= Mixture level (ft) If mixture level of IACV is greater than PCV and IDTRP is on, GE leakage correlation will be used. If PCV = 0., it is set equal to the junction elevation above the bottom of volume IACV.
W5-R CV1	The coefficients of GE leakage correlation.
W6-R CV2	= $W = CV1 \cdot \Delta P + CV2 \cdot \Delta P + CV3 \cdot \Delta P^2$
W7-R CV3	where W = leakage flow rate (lb/sec) ΔP = pressure differential (psi)

5.7 Leak Table Data Cards 12XXXX

W1-I NAREA	= Number of data points (1 ≤ NAREA ≤ 20)
W2-I ITLEAK	= Trip signal number IDTRP to open leak. (2 ≤ ITLEAK ≤ NTRP)
W3-I ITYPE	= Indicator of independent variable in table. 0 = Independent variable is time or angle.

1 = Independent variable is average pressure
in the volume which is upstream of junction
whose flow area is controlled by this leak table.

-1 = Independent variable is average pressure
in the volume which is downstream of the
junction.

2 = Independent variable is mixture level in
the volume which is upstream of the junction.

-2 = Independent variable is mixture level in
the volume which is downstream of the junction.

W4-R SINK	= Sink pressure (psia)
W5-R TAREA(1)	= Time (sec), angle (degree), pressure (psia), or mixture level (ft) for first point.
W6-R TAREA(2)	= Leak area normalized to full open area AJUN for first point.
W7-R TAREA(3)	= Independent value for second point.
W8-R TAREA(4) ,	Until NAREA points are entered, where the independent values are in ascending order.

5.8 Fill Table Data Cards 13XXXX

W4-I ICALC	= Thermodynamic variable indicator.
	1 = PORT = pressure (psia) HORX = enthalpy (Btu/lb)
	2 = PORT = pressure (psia) HORX = quality
	3 = PORT = temperature (°F) HORX = quality
	4 = PORT = pressure (psia) HORX = temperature (°F)
	< 0 = Fill enthalpy is set equal to the volume enthalpy specified by this data
	ICALC = -(NVOLH + IHTYP×100)
	NVOLH = Volume number whose enthalpy is used as fill enthalpy
	IHTYP = 0 = average enthalpy is used for fill enthalpy

1 = saturated liquid enthalpy is used when NVOLH is saturated. If NVOLH is not saturated, average enthalpy is used.

2 = saturated vapor enthalpy is used when NVOLH is saturated. If NVOLH is not saturated, average enthalpy is used.

3 = saturated liquid enthalpy is used every time.

4 = saturated vapor enthalpy is used every time.

If ICALC < 0 and unit of flow rate is 'GAL/MIN', the density of fluid must be inputted as HORX.

NVOLH is not needed to be equal to IW2 of the junction which uses this fill table.

5.9 Kinetics Constants Data Card 140000

W1-I NODEL = Power calculation indicator.
-1 = retrieve data from FORTRAN Unit 02.
0 = explicit power versus time.
1 = one prompt neutron group plus six groups of delayed neutrons.
2 = same as 1 above plus eleven delayed gamma emitters.
3 = same as 2 above plus U²³⁹ and Np²³⁹.
4 = same as 1 above plus F.P. decay (GE + 3σ)
5 = same as 4 above plus U²³⁹ and Np²³⁹.

W2-I KMUL = multiplying factor for decay energy.

Inputting NODEL > 3 and KMUL ≠ 0 at the same time leads to program stopping.

5.10 Heat Slab Data Cards 15XXXX

W5-I IXLO = The indicator for slab quality (X) calculation and adiabatic calculation indicator.

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.
= IDTRP \times 10 + IXLO
Adiabatic calculation will be done when
IDTRP is on and X = 1.
= IDTRP \times 10 + IXLO + 1000
Adiabatic calculation will be done when
IDTRP is on.
= -(IJUN \times 10 + IXLO)
Adiabatic calculation will be done when
junction flow of IJUN is equal to zero and
X = 1.
= -(IJUN \times 10 + IXLO + 1000)
Adiabatic calculation will be done when
junction flow of IJUN is equal to zero.

where

IDTRP = Trip number controlling adiabatic
calculation

IJUN = Junction number whose flow rate
controls adiabatic calculation.

W6-I IMCL = The indicator for film boiling heat transfer,
DNB correlation, and steam condensation heat
transfer at slab left surface.

= L \times 100 + J \times 10 + K

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, used for
NSUR \leq 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

L(hundred's place) = steam condensation heat transfer indicator only for NSUR = -1.

L = 1 or 2. Use HTCND(L) for steam condensation H.T.C. when IDTRP(L) is on. HTCND(L), IDTRP(L) are data on 082022.

W7-I IMCR = The indicator for film boiling heat transfer, DNB correlation, and steam condensation heat transfer at slab right surface.

5.11 Data for Spray Heat Transfer Model

(1) Core Spray Stack Indicators 205000

W1-I JSTK(1,1) = The indicator of 1st slab stack in 1st group.

W2-I JSTK(2,1) = The indicator of 2nd slab stack in 1st group.

... maximum number of groups = 3

W11-I JSTK(3,3) maximum number of stacks in each group = 4

W12-I JSI (4,3)

(2) ON and OFF Signal of Spray Model 2050X0

X = 1, . . . , NGR (NGR = Number of groups)

W1-I JON = $J_1 \times 10^6 + J_2 \times 10^4 + J_3 \times 10^2 + J_4$ J_1 = The junction number whose first non-zero flow is the signal to turn on spray heat transfer model. J_2 = Number of the junction number which injects droplet flow falling from quench front into core or another volume. J_3 = Number of the junction number which injects steam generated in liquid film into core or upper plenum. J_4 = The core outlet junction number.W2-R TON = Delay time (sec) associated with JON signal.
If JON = 0, TON is the elapsed time when spray heat transfer model turns on.

W3-R ZLL = Mixture level (ft) signal to turn off spray heat transfer model.

W4-R TOF = Time (sec) to turn off spray heat transfer model.

(3) Constant Value for All Stacks 205100, 205110, 205120

a) 205100

W1-R RECRIT = Critical Reynolds number for NSUR = 4
Not used in RELAP4/MOD6/U4/J3, but an arbitrary real number must be inputted.

b) 205110

W1-R TDIF = Sputtering temperature - T_{sat} ($^{\circ}$ F)

W2-R BTM = Multiplier in average gas temperature calculation, not used but an arbitrary real number must be inputted.

W3-R DDROP = Droplet diameter (ft)
Not used, but an arbitrary real number must be inputted.

W4-R EMDRY = Dry slab emissivity
Not used, but an arbitrary real number must be inputted.

c) 205120

W1-R HWETB = H.T.C. for wet channel box (Btu/hr.ft². $^{\circ}$ F)

W2-R HWETR = H.T.C. for wet rod (Btu/hr.ft². $^{\circ}$ F)

W3-R HSPUT = H.T.C. for quench spattering (Btu/hr.ft². $^{\circ}$ F)
HSPUT = 0 leads internal calculation in RELAP4.

W4-R HFID = H.T.C. for bottom flooding (Btu/hr.ft². $^{\circ}$ F)

W5-R XCRFL = Critical quality of bottom flooding.

(4) Dry Slab Heat Transfer Coefficients Data 2052X0

X = 1, . . . , NGR

W1-R HCONV(1,X) = Dry slab H.T.C. (Btu/hr.ft². $^{\circ}$ F) for 1st stack in X group.

W2-R HCONV(2,X) = Dry slab H.T.C. for 2nd stack in X group.

W3-R HCONV(3,X) = Dry slab H.T.C. for 3rd stack in X group.

W4-R HCONV(4,X) = Dry slab H.T.C. for 4th stack in X group.

(5) Slab Wall Thickness Data 2053X0
 $X = 1, \dots, NGR$: Used for quench front velocity calculation.

W1-R WALLTK(1,X) = Slab wall thickness (ft) of 1st stack in X group.

W2-R WALLTK(2,X) = Slab wall thickness of 2nd stack in X group.

W3-R WALLTK(3,X) = Slab wall thickness of 3rd stack in X group.

W4-R WALLTK(4,X) = Slab wall thickness of 4th stack in X group.

(6) Area Fraction to Total Flow Area for Stack Groups 2054X0
 $X = 1, \dots, NGR$

W1-R AFRAT(1,X) = Area fraction of 1st stack in X group.

W2-R AFRAT(2,X) = Area fraction of 2nd stack in X group.

W3-R AFRAT(3,X) = Area fraction of 3rd stack in X group.

W4-R AFRAT(4,X) = Area fraction of 4th stack in X group.

$$\sum_{i=1}^{NGR} AFRAT(i,X) = 1.0$$

(7) Extra Printout for Debugging 205770

W1-I IGRW = Stack group number for extra printout.

W2-I IWRIT = Extra printout indicator
 > 0 Extra printout will be done.

W3-R TWON = Time to begin extra printout.

W4-R TWOF = Time to end extra printout.

6. Sample Problems

6.1 BWR Large Recirculation Line Break

6.1.1 Introduction

A typical BWR plant was modeled using RELAP4/MOD6/U4/J3 to represent a 200 % double-ended offset shear break in the pump suction side of one of the jet pump recirculation lines. The system model and assumptions used and the calculated results are presented in the following sections. The calculation was carried out from break initiation until core recovery. Major part of the data were obtained from RELAP4/MOD5 User's Manual Volume 3⁽²⁾.

(5) Slab Wall Thickness Data 2053X0
 X = 1, . . . , NGR: Used for quench front velocity calculation.

W1-R WALLTK(1,X) = Slab wall thickness (ft) of 1st stack in X group.

W2-R WALLTK(2,X) = Slab wall thickness of 2nd stack in X group.

W3-R WALLTK(3,X) = Slab wall thickness of 3rd stack in X group.

W4-R WALLTK(4,X) = Slab wall thickness of 4th stack in X group.

(6) Area Fraction to Total Flow Area for Stack Groups 2054X0
 X = 1, . . . , NGR

W1-R AFRAT(1,X) = Area fraction of 1st stack in X group.

W2-R AFRAT(2,X) = Area fraction of 2nd stack in X group.

W3-R AFRAT(3,X) = Area fraction of 3rd stack in X group.

W4-R AFRAT(4,X) = Area fraction of 4th stack in X group.

$$\sum_{i=1}^{NGR} AFRAT(i,X) = 1.0$$

(7) Extra Printout for Debugging 205770

W1-I IGRW = Stack group number for extra printout.

W2-I IWRIT = Extra printout indicator
 > 0 Extra printout will be done.

W3-R TWON = Time to begin extra printout.

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6. Sample Problems

6.1 BWR Large Recirculation Line Break

6.1.1 Introduction

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6.1.2 System Model and Assumptions

The nodalization describing the BWR system is shown in Figure 6.1. It consists of 25 volumes, 41 junctions and 32 core heat slabs. The volumes and fill junctions shown in Figure 6.1 are identified in Table 6.1.

The interior of the reactor vessel is described by 17 volumes, as follows. Volume 1 is the upper plenum region and includes the steam separators. Volume 2 is the upper downcomer region and extends from the feedwater entry location upward to the bottom of the steam driers. Volume 3 is the steam dome and contains high quality steam above the driers. Volume 4 is lower downcomer region and contains the subcooled water between the feedwater entry location and the bottom of the downcomer. Volume 14 and 15 represent the broken and intact loop jet pumps, respectively. Each bank of 10 jet pumps (broken and intact loop) is modeled as a single volume with areas and volumes 10 times those of each actual BWR jet pump. Volume 11 represents the lower plenum region. Volume 13 represents the guide tubes and the core bypass comprising the region between the fuel bundles. Volume 18 through 25 are used to represent the hottest bundle in the core, and remainder of the core is represented by Volume 12 which is called average core. Volume 5 through 7 with Volume 16, and Volume 8 through 10 represent the broken loop and the intact loop, respectively. Volume 6 and 9 are the recirculation pumps. Volume 17 represents the containment.

The bubble rise model was used in the upper and lower downcomers, the upper and lower plenums, the average core, the core bypass, and the jet pumps. The bubble rise velocity was calculated by the Wilson bubble velocity correlation. The bubble density gradient in the two phase mixture was not calculated except the lower plenum and the lower downcomer. And the mixture level calculation started when the middle volume (Volume 21) of the hottest bundle became a superheated condition after lower plenum flashing. We think that, in this period, the transient in the pressure vessel is relatively mild and the application of bubble rise model is acceptable.

The single mixture level calculation in the vertically stacked volumes in the shroud was not applied.

The vertical slip model was used at the following junctions. These were the core inlet junction (Jun 14), the core outlet junction (Jun 15),

the core bypass outlet junction (Jun 17), and the jet pump discharge junctions (Jun 18 and Jun 19). The vertical slip model was applied with the same trip signal as the bubble rise model.

The Henry-Fauske / Moody critical flow model was used in the break junctions (Jun 22, Jun 23), both with multipliers of 1.0. The stagnation property option was not used.

The low pressure coolant injection (LPCI), high pressure core spray (HPCS), and auto-depressurization system (ADS) were modeled for ECCS. The lower pressure core spray (LPCS) was not simulated according to the single failure assumption. 46 percent of HPCS water was assumed to be available to the core and the remainder was assumed to fall on the core bypass region. The LPCI was modeled to inject directly ECC water to the core bypass region. And the relief valves and safety valves were also simulated by using the trip reset option and the leak table.

CCFL was considered at the core outlet and the core bypass outlet by using CCFL fill junctions (Jun 26 and Jun 27 respectively). And Jun 29 and Jun 30, which were fill junction, were utilized for the droplet flow leaving liquid film and the steam flow vaporizing from liquid film, respectively. Jun 29 was connected with the core volume and Jun 28 was connected with the upper plenum volume.

The bypass-lower plenum leakage model was applied at the core bypass inlet junction (Jun 16). This junction flow was calculated when the mixture level in the core bypass volume is higher than the elevation of the core bypass junction after LPCI initiation. The coefficients of the correlation was obtained on the assumption that NGT=201, NHOLES=166, NINST=55 and NBUNT=764.

6.1.3 Calculated Results

In this calculation RELAP4/MOD6/U4/J3 ran without any troubles. The physical time from the break initiation until the core recovery was calculated to be 160 sec. This required 360 minutes of CPU time on the FACOM M200 at the JAERI Computing Center.

The major events which occurred during the transient are given in Table 6.2. The output data traces are shown in Figure 6.2 through 6.5 at the end of this section. A summary discussion of the transient follows.

The transient began when the break junctions (Jun 22 and 23) and

the power to the recirculation pump was tripped. The trips for the reactor scram and for the feedwater and steamline valve closure were initiated shortly thereafter.

The vessel pressure began to drop when the break opened as shown in Figure 6.2. When the steamline valve closed at 3 sec, the pressure rose rapidly and reached a relief valve set point of 1,084 psia, then the valve was opened shortly at about 6 sec. A sharp pressure drop at 7 sec was caused by the downcomer mixture level crossing at the location of the junction which connected the upper downcomer with the lower downcomer, and it was an unrealistic phenomenon. The pressure began to decrease when the core flow decreased, and it decreased more rapidly after the lower downcomer emptied. The vessel pressure continued to decrease until it equaled the containment pressure near 20 psia.

The core inlet flow rate is shown in Figure 6.3. The effect of uncovering at the top of the intact loop jet pump can be seen at 10 sec in the figure. That is, when the top of the jet pump uncovered, the flow into lower plenum through the jet pump was greatly reduced. Therefore the core inlet flow decreased rapidly, and reversed. A lower plenum flashing occurred at 15 sec and it caused the core inlet flow to increase sharply in the positive direction. The core inlet flow quickly returned to negative, and the coolant in the upper plenum fell back through the core.

The mixture levels in the shroud are shown in Figure 6.4 the mixture level calculation began to start at 22 sec. Soon after calculation started, the mixture level in each volume decreased rapidly, and the active core was uncovered completely at 35 sec. HPCS and LPCI started at 34 sec and 49 sec, respectively. HPCS could not contribute to the increase of mass inventory in lower plenum. But, the lower plenum mixture level increased slowly after guide tubes were filled up by LPCI water. A bubble velocity in lower plenum was changed to 1.0×10^6 ft/sec upon restart at 65 sec in order to avoid the calculational instability in the rest of the analysis. After 76 sec, the core bypass water level was controlled to remain constant. The bottom reflooding of the core began to start at 132 sec.

The clad surface temperature are shown in Figure 6.5. The clad surface temperature followed the fluid saturation temperature until the DNB (Departure from Nucleate Boiling). The heat transfer mode then

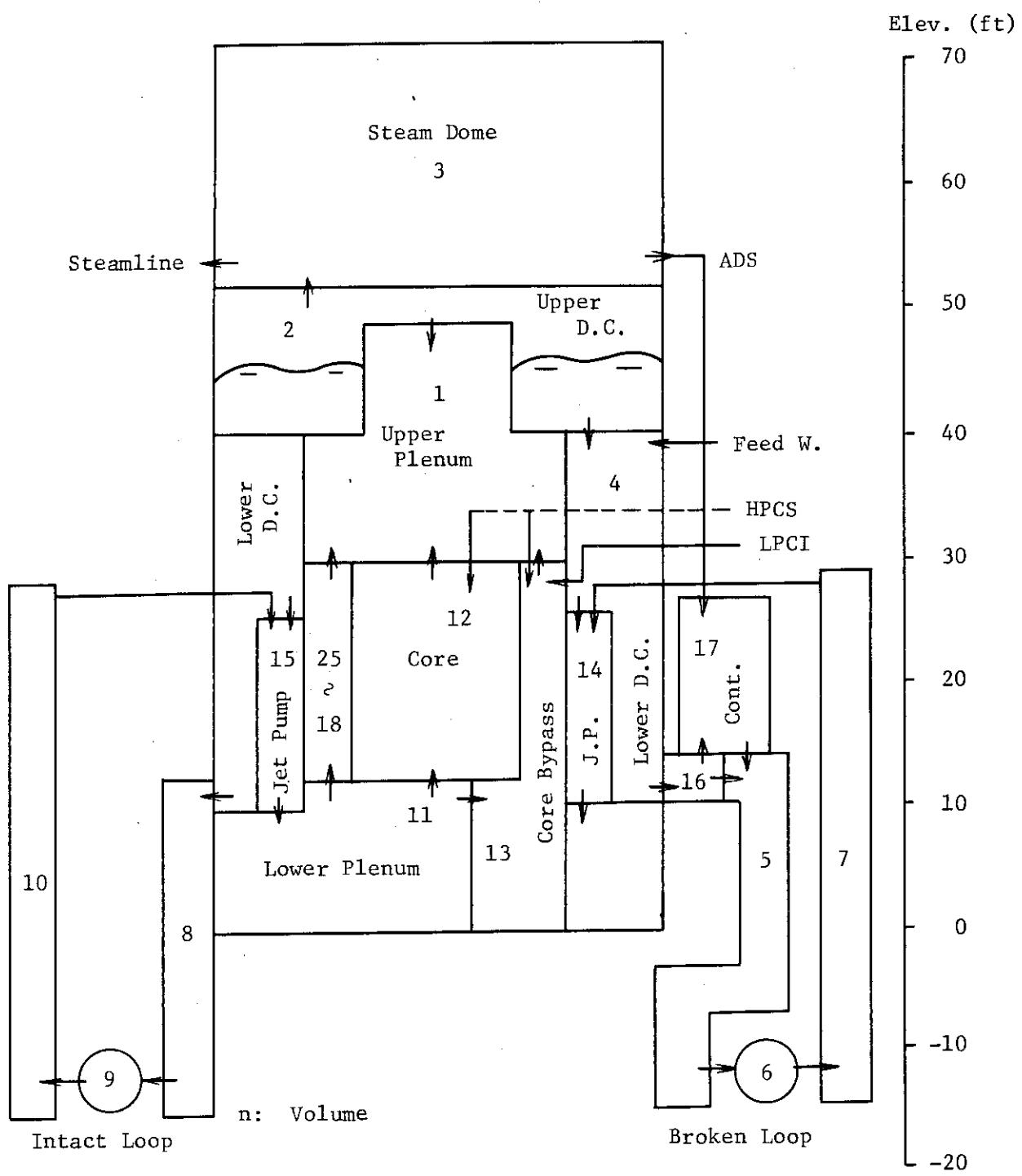


Fig. 6.1 Nodalization for BWR Large Break

Table 6.1 Volume and Junction Identification for BWR Large Break

<u>Volume No.</u>	<u>Description</u>
1	Upper Plenum and Steam Separator
2	Upper Downcomer
3	Steam Dome
4	Lower Downcomer
5	Broken Loop Recirculation Suction Line
6	Broken Loop Recirculation Pump
7	Broken Loop Recirculation Discharge Line
8	Intact Loop Recirculation Suction Line
9	Intact Loop Recirculation Pump
10	Intact Loop Recirculation Discharge Line
11	Lower Plenum
12	Average Core
13	Core bypass and Guide Tubes
14	Broken Loop Jet Pump
15	Intact Loop Jet Pump
16	Break Volume in Broken Loop
17	Containment
18 ~ 25	Hottest bundle
<u>Fill Function No.</u>	
	Feedwater Inlet
24	Feedwater Inlet
25	Steam Outlet
26	HPCS Water Injection into Average Core
27	HPCS Water Injection into Core Bypass
28	Low Pressure Coolant Injection
29	Liquid Flow Injection Simulating Liquid Droplet Flow Leaving from Quench Front
30	Steam Flow Injection Simulating Steam Flow Vaporizing from Liquid Film

Table 6.2 Major Events Summary for BWR Large Break

Time (sec)	Event
0.001 to 0.002	Break opened, pump power off, scram tripped
1 to 4	Feedwater stopped
3	Steamline closed
10	Jet pump suction uncovered
15	Lower plenum flashing occurred
34	HPCS started
49	LPCI started
60	Liquid mass in lower plenum begin to increase
133	Bottom reflooding started

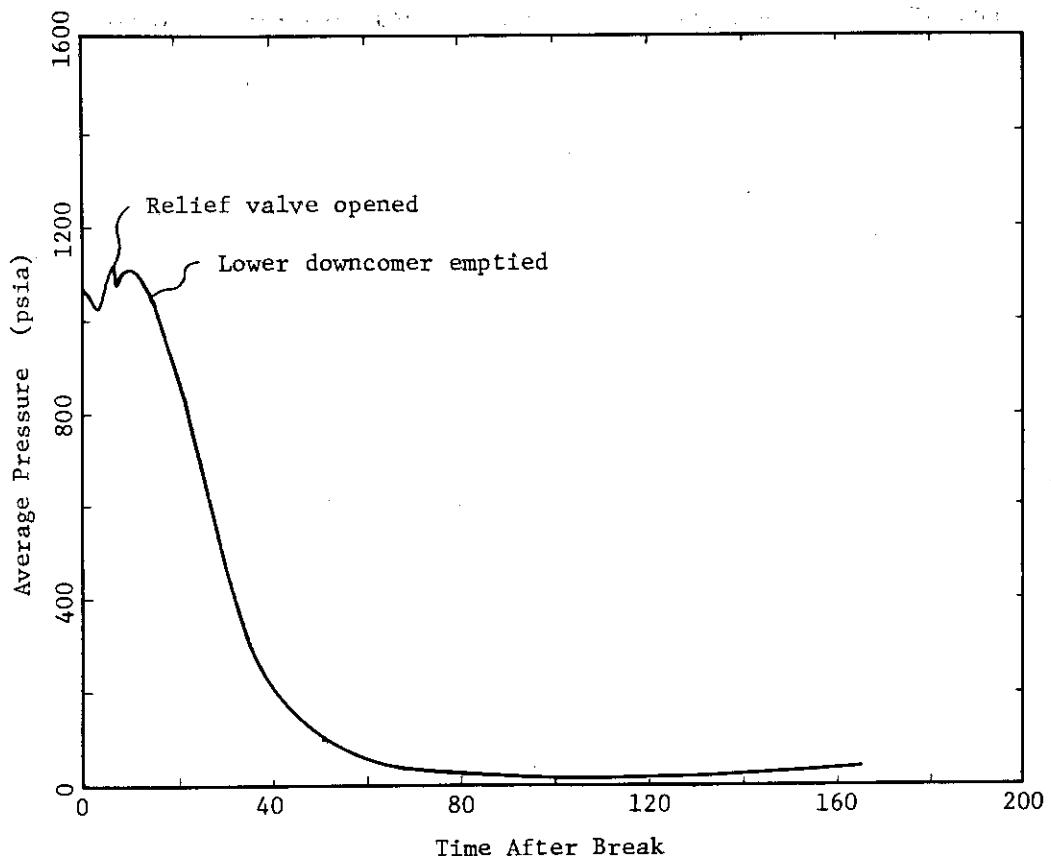


Fig. 6.2 Lower Plenum Pressure - BWR Large Break

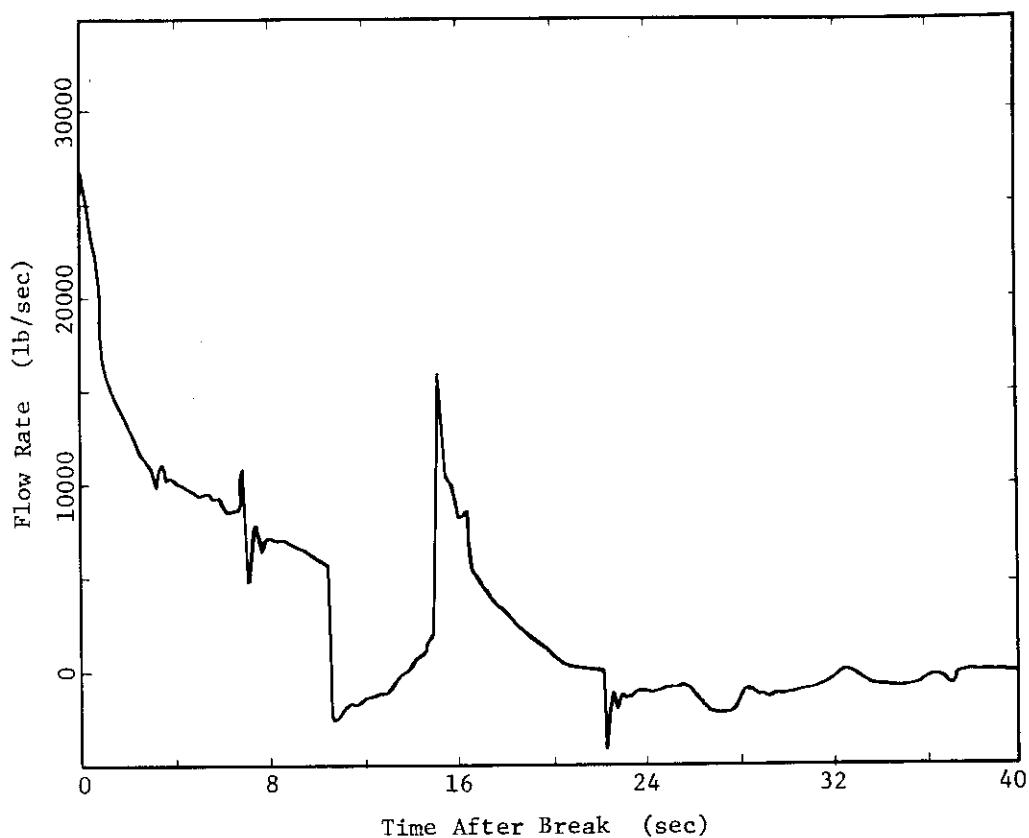


Fig. 6.3 Core Inlet Flow Rate - BWR Large Break

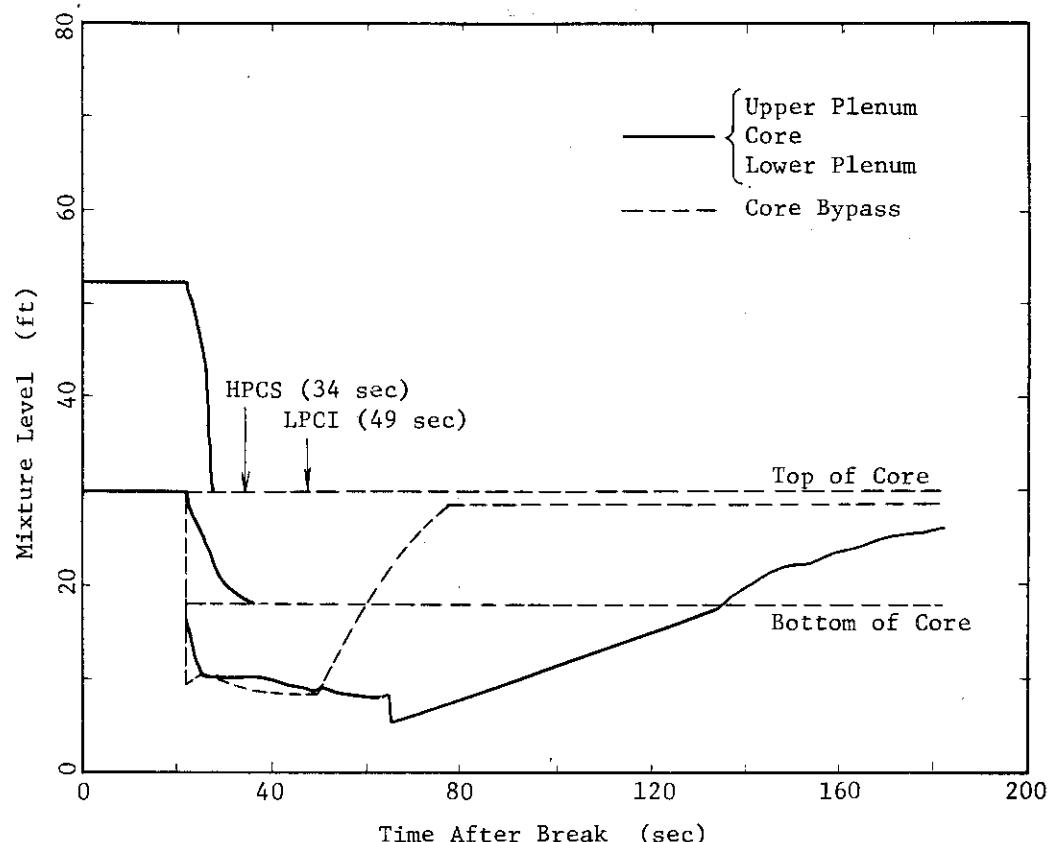


Fig. 6.4 Mixture Level in Shroud - BWR Large Break

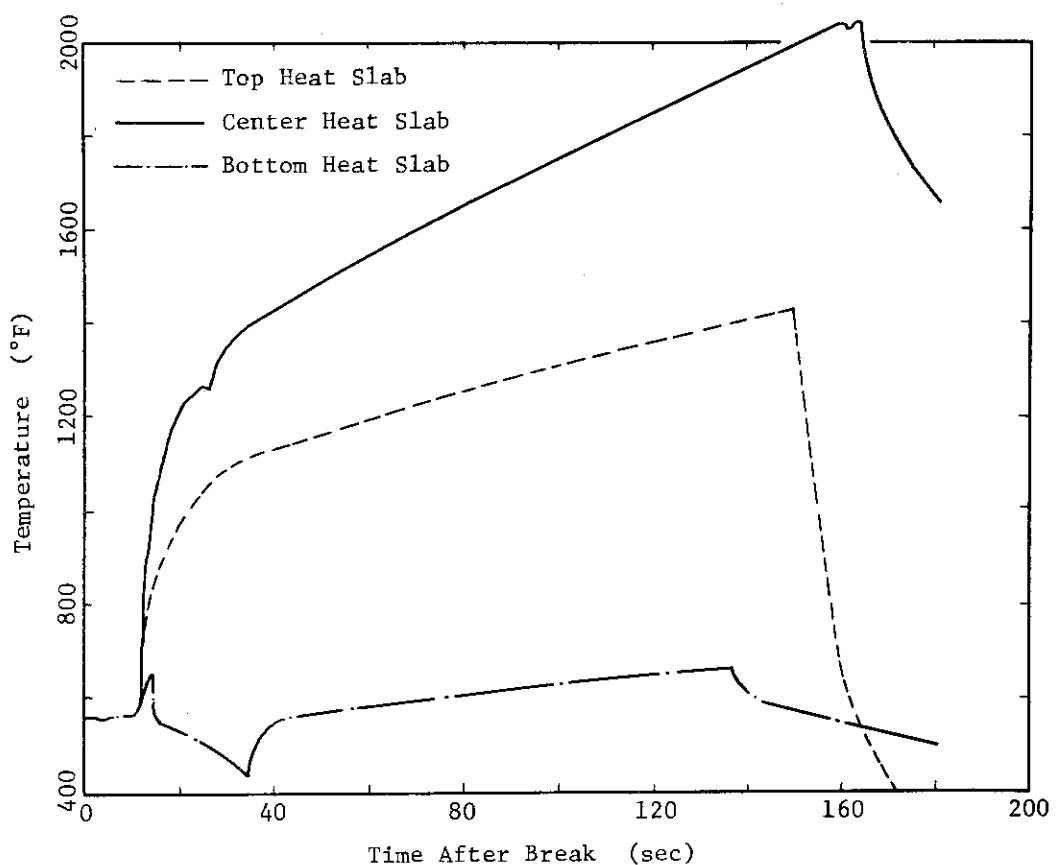


Fig. 6.5 Clad Surface Temperature - BWR Large Break

Table 6.3 Input List for BWR Large Break

```

* RELAP4/MOD6/U4/J3 - BWR LARGE BREAK ANALYSIS
*
* PROBLEM DIMENSION
*
010001 -2 9 6 -13 25 5 0 41 2 10 5 6 32 10 5 32 1 0
*
* POWER OMEGA
*
010002 3388. 1.0
*
* IPROGM IEMHT IEMPS IEMEC
*
010003 1 1 1 0 0
*
* EDIT VARIABLES
*
020000 ML 11 ML 12 AX 21 ML 1 JW 14 JW 15 JW 26 JW 29 JW 30
*
* TIME STEP CONTROL CARD
*
030010 2 1 5 0 .001 .00001 .01 7170.
030020 5 40 5 0 .01 .000001 .5
030030 5 40 5 0 .01 .000001 5.
030040 10 50 5 0 .01 .000001 25.
030050 10 100 1 0 .01 .000001 100.
030060 10 50 1 0 .01 .000001 1.0E6
*
* TRIP CONTROL CARD
*
040010 A 1 0 0 1.0E6 0.
040020 B 1 0 0 0. 0.
040030 C 1 0 0 .001 0.
040040 D 1 0 0 .002 0.
040050 E 1 3 0 3.0 0.
040060 F 1 0 0 1000. 0.
040070 G -5 4 0 30.78 27. * HPCS
040080 H 1 0 0 20.0 0. * MIX. LVL CAL. START
040090 I -5 4 0 21.48 120. * ADS
040100 J 1 0 0 35.01 0.
040110 K 1 0 0 40. 0.
040120 L -5 4 0 21.48 40. * LPCI
040130 M -5 21 0 0.0 0. 0. 0. 5 21 0
040140 1 '=' 'A' 'END'
040150 2 '=' 'B' 'END'
040160 3 '=' 'C' 'END'
040170 4 '=' 'D' 'END'
040180 5 '=' 'E' 'END'
040190 6 '=' 'F' 'END'
040200 7 '=' 'G' 'END'
040210 8 '=' 'H' 'AND' 'M' 'END'
040220 9 '=' 'I' 'END'
040230 10 '=' 'J' 'END'
040240 11 '=' 'K' 'END'
040250 12 '=' 'L' 'END'
*
* VOLUME DATA
*
050011 82 0 1039. -1. .139857 1543. *00004800
050021 2 0 1028.28 -1. .002448 6703. *00004900
050031 1 0 1024.93 -1. .999 3777. *00005000
050041 5 0 1031.93 532.3 -1. 3177. *00005100
050051 0 0 1024. 532.3 -1. 125.25 *00005200
050061 0 0 1125.17 532.40 -1. 53. *00005300
050071 0 0 1226.17 532.52 -1. 366. *00005400
050081 0 0 1024. 532.29 -1. 136. *00005500
050091 0 0 1126.17 532.40 -1. 63. *00005600
050101 0 0 1226.17 532.52 -1. 366. *00005700
050111 53 0 1062.16 532.33 -1. 2152. *00005800
050121 82 0 1049.78 -1. .058008 973.094 *00005900
050131 84 0 1045.1 -1. .00001 1477. *00006000
050141 82 0 1059.2 532.33 -1. 115. *00006100

```

Table 6.3 (continued)

050151	82	0	1059.2	532.33	-1.	115.	*00006200
050161	0	0	1030.3	532.3	-1.	16.75	*00006300
050171	4	0	14.7	100.	0.6	1.98E8	*00006400
050181	0	0	1054.35	537.69	-1.	.21223	*00006500
050191	0	0	1053.78	-1.	.005420	.21223	*00006600
050201	0	0	1052.52	-1.	.049155	.15921	*00006700
050211	0	0	1051.52	-1.	.086948	.10614	*00006800
050221	0	0	1050.64	-1.	.117279	.10614	*00006900
050231	0	0	1049.77	-1.	.144990	.10614	*00007000
050241	0	0	1048.72	-1.	.174299	.15921	*00007100
050251	0	0	1047.37	-1.	.202947	.21223	*00007200
*							*00007300
050012	22.25		22.25	0	224.	0.	29.92
050022	12.25		5.27	0	165.	0.	42.
050032	21.25		21.25	0	204.	0.	51.25
050042	31.98		31.98	0	165.	0.	10.02
050052	26.		26.	0	3.67	0.	-14.
050062	3.		3.	0	4.0	0.	-14.
050072	40.53		40.53	0	3.2	0.	-14.
050082	25.		25.	0	3.67	0.	-14.
050092	3.		3.	0	4.0	0.	-14.
050102	40.53		40.53	0	3.2	0.	-14.
050112	17.42		17.42	0	120.	0.	0.
050122	12.5		12.5	0	51.091	.0473	17.42
050132	29.92		29.92	0	43.635	0.	0.
050142	15.7		15.7	0	19.69	0.	10.02
050152	15.7		15.7	0	19.69	0.	10.02
050162	2.2		2.2	0	3.67	0.	10.
050172	250.		0.0	1	100000.	100.	-10.
050182	2.5		2.5	0	.10614	.04726	17.42
050192	2.0		2.0	0	.10614	.04726	19.92
050202	1.5		1.5	0	.10614	.04726	21.92
050212	1.0		1.0	0	.10614	.04726	23.42
050222	1.0		1.0	0	.10614	.04726	24.42
050232	1.0		1.0	0	.10614	.04726	25.42
050242	1.5		1.5	0	.10614	.04726	26.42
050252	2.0		2.0	0	.10614	.04726	27.92
*							*00009900
*			CDEF. OF CCFL CORR.				*00010000
*							*00010100
060002	1.0		.46				*00010200
060012	0.7		.47				*00010300
*			BUBBLE DATA				*00010400
*							*00010500
*							*00010600
060011	1.0	0.0					*00010700
060021	0.0	-1.0					*00010800
060031	1.0	-1.0					*00010900
060041	0.0	1.E6					*00011000
060051	0.0	3.0					*00011100
*			JUNCTION DATA				*00011200
*							*00011300
*							*00011400
080011	1	2	0	0	29583.	191.1	52.17
080021	2	3	0	0	4139.	312.	52.25
080031	2	4	0	0	25444.	165.	42.0
080041	4	15	0	0	10041.5	3.112	25.0
080051	4	15	0	0	4750.	3.67	11.0
080061	5	5	-1	0	4750.	3.67	-13.
080071	6	7	1	0	4750.	3.2	-13.
080081	7	15	0	0	4750.	0.538	25.
080091	4	3	0	0	4750.	3.67	11.
080101	3	9	-2	0	4750.	3.67	-13.
080111	9	10	2	0	4750.	3.2	-13.
080121	10	14	0	0	4750.	0.538	25.
080131	4	14	0	0	10041.5	3.112	25.
080141	11	12	0	0	25638.96	25.2958	17.42
080151	12	1	0	0	25638.96	37.0e16	29.92
080161	13	11	0	7	-2944.	2.834	17.42
080171	1	13	0	0	-2944.	43.635	29.92
080181	14	11	0	0	14791.5	19.69	10.02
							*** JS
							*00013100
							*00013200

Table 6.3 (continued)

080191	15	11	0	0	14791.5	19.69	10.02	0.	*00013300
080201	16	5	0	1	4750.	3.67	11.	0.	*00013400
080211	3	17	0	3	0.	.484	55.	1.	*00013500
080221	16	17	0	4	0.	3.67	11.	0.	*00013600
080231	17	5	0	4	0.	3.67	11.	0.	*00013700
080241	0	4	1	0	4139.	4.712	40.	0.	*00013800
080251	0	3	2	2	-4139.	14.75	72.	0.	*00013900
080261	0	12	4	0	0.	.4591	29.91	0.	*00014000
080271	0	13	4	3	0.	.5403	29.91	0.	*00014100
080281	0	13	3	3	0.	1.	18.	1.	*00014200
080291	0	12	105	0	0.	1.	29.	0.	*00014300
080301	0	1	106	0	0.	37.0818	31.	0.	*00014400
080311	11	18	0	0	34.8678	.0266	17.42	0.	*00014500
080321	18	19	0	0	34.8678	.10614	19.92	0.	*00014600
080331	19	20	0	0	34.8678	.10614	21.92	0.	*00014700
080341	20	21	0	0	34.8678	.10614	23.42	0.	*00014800
080351	21	22	0	0	34.8678	.10614	24.42	0.	*00014900
080361	22	23	0	0	34.8678	.10614	25.42	0.	*00015000
080371	23	24	0	0	34.8678	.10614	26.42	0.	*00015100
080381	24	25	0	0	34.8678	.10614	27.92	0.	*00015200
080391	25	1	0	0	34.8678	.0486	29.92	0.	*00015300
080401	3	17	0	9	0.	.1993	72.	1.	*00015310
080411	3	17	0	10	0.	.1993	72.	1.	*00015320
*									*00015400
080012	0.	0.	1	0	3	0	0.	0.	*00015500
080022	0.	0.	1	0	3	0	0.	0.	*00015600
080032	0.	0.	1	0	3	0	0.	0.	*00015700
080042	.2084	1.17	2	0	0	2	0.	0.	*00015300
080052	0.	0.	1	0	3	0	0.	0.	*00015900
080062	0.	0.	1	0	3	0	0.	0.	*00016000
080072	0.	0.	1	0	3	0	0.	0.	*00016100
080082	.2373	5.8	1	0	0	2	0.	0.	*00016200
080092	0.	0.	1	0	3	0	0.	0.	*00016300
080102	0.	0.	1	0	3	0	0.	0.	*00016400
080112	0.	0.	1	0	3	0	0.	0.	*00016500
080122	.2373	6.8	1	0	0	1	0.	0.	*00016600
080132	.2084	1.17	2	0	0	1	0.	0.	*00016700
080142	0.	0.	1	0	3	0	0.	0.	-281.
080152	0.	0.	1	0	3	0	0.	0.	*00016800
080162	0.	0.	1	0	3	0	0.	0.	*00016900
080172	0.	0.	1	0	3	0	0.	0.	*00017000
080182	0.	0.	1	0	3	0	.05	0.	*00017100
080192	0.	0.	1	0	3	0	.05	0.	*00017200
080202	0.	0.	1	0	3	0	0.	0.	*00017300
080212	1.	1.	1	0	3	0	0.	0.	*00017400
080222	1.	.5	1	0	2	0	0.	0.	*00017500
080232	.5	1.	1	0	2	0	0.	0.	*00017600
080242	0.	0.	1	0	3	0	0.	0.	*00017700
080252	0.	0.	1	0	3	0	0.	0.	*00017800
080262	0.	0.	0	0	3	0	0.	0.	*00017900
080272	0.	0.	0	0	3	0	0.	0.	0. 301 *00018000
080282	0.	0.	0	0	0	0	0.	0.	0. -172 *00018100
080292	0.	0.	0	0	0	0	0.	0.	*00018200
080302	0.	0.	0	0	0	0	0.	0.	*00018300
080312	0.	0.	1	0	3	0	0.	0.	*00018400
080322	0.	0.	1	0	3	0	0.	0.	*00018500
080332	0.	0.	1	0	3	0	0.	0.	*00018600
080342	0.	0.	1	0	3	0	0.	0.	*00018700
080352	0.	0.	1	0	3	0	0.	0.	*00018800
080362	0.	0.	1	0	3	0	0.	0.	*00018900
080372	0.	0.	1	0	3	0	0.	0.	*00019000
080382	0.	0.	1	0	3	0	0.	0.	*00019100
080392	0.	0.	1	0	3	0	0.	0.	*00019200
080402	1.	1.	0	0	1	0	0.	0.	*00019300
080412	1.	1.	0	0	1	0	0.	0.	*00019310
*									*00019320
*									*00019400
*									*00019500
*									*00019600
*									*00019700
090011	3	4	0	1	0	1668.	1.0	44943.	710.3 22200. 20000. 47.17 0. 0
090021	3	4	0	1	0	1668.	1.0	44943.	710.3 22200. 20000. 47.17 0. 0
*									*00019800
*									*00019900

Table 6.3 (continued)

*	PUMP HEAD MULTIPLIER DATA										*00020000			
*												*00020100		
091001	-11	0.	0.	.1	0.	.15	.05	.24	.8			*00020200		
091002		.3	.96	.4	.98	.6	.97	.3	.9			*00020300		
091003		.9	.8	.96	.5	1.	0.					*00020400		
*												*00020500		
*	PUMP TORQUE MULTIPLIER DATA										*00020600			
*												*00020700		
092001	-2	0.	0.	1.	0.							*00020800		
*												*00020900		
*	PUMP STOP DATA										*00021000			
*												*00021100		
095011	0.	0.	0.									*00021200		
095021	0.	0.	0.									*00021300		
*												*00021400		
*	PUMP CURVE INPUT INDICATOR DATA										*00021500			
*												*00021600		
100000	0	0	16	0								*00021700		
*												*00021800		
*	PUMP HEAD AND TORQUE DATA										*00021900			
*												*00022000		
103011	1	1	5	0.	1.31	.25	1.25	.5	1.20	.75	1.12	1.	1.0	*00022100
103021	1	2	5	0.	-0.9	.25	-.5	.5	-0.05	.75	.4	1.	1.0	*00022200
103031	1	3	5	-1.	2.1	-.75	1.775	-.5	1.54	-.25	1.4	0.	1.31	*00022300
103041	1	4	5	-1.	2.1	-.75	1.50	-.5	1.13	-.25	.92	0.	.825	*00022400
103051	1	5	5	0.	.4	.25	.53	.5	.625	.75	.8	1.	1.0	*00022500
103061	1	6	5	0.	.825	.25	.79	.5	.815	.75	.9	1.	1.0	*00022600
103071	1	7	5	-1.	-1.8	-.75	-1.	-.5	-0.4	-.25	.1	0.	0.4	*00022700
103081	1	8	5	-1.	-1.3	-.75	-1.72	-.5	-1.54	-.25	-1.27	0.	-0.9	*00022800
103091	2	1	5	0.	.55	.25	.63	.5	.71	.75	.66	1.	1.0	*00022900
103101	2	2	5	0.	-.55	.2	-0.175	.4	.0	.75	.58	1.	1.0	*00023000
103111	2	3	5	-1.	1.77	-.75	1.23	-.5	.83	-.25	.62	0.	.55	*00023100
103121	2	4	5	-1.	1.77	-.75	1.52	-.5	1.32	-.25	1.13	0.	1.0	*00023200
103131	2	5	5	0.	-0.8	.2	-.375	.5	-0.1	.75	.15	1.	.43	*00023300
103141	2	6	5	0.	1.0	.25	0.38	.5	0.75	.75	0.61	1.	.43	*00023400
103151	2	7	5	-1.	-3.45	-.75	-2.75	-.50	-2.0	-.25	-1.375	0.	-.8	*00023500
103161	2	8	5	-1.	-3.45	-.75	-2.62	-.50	-1.583	-.25	-1.15	0.	-.55	*00023600
*													*00023700	
*	VALVE DATA										*00023800			
*													*00023900	
110010	4	0	0	0.	0.	0.	0.	0.						*00024000
110020	5	0	0	0.	0.	0.	0.	0.						*00024100
110030	-9	0	0	0.	0.	0.	0.	0.						*00024200
110040	-3	0	0	0.	0.	0.	0.	0.						*00024300
110050	7	0	0	0.	0.	0.	0.	0.						*00024400
110060	-6	0	0	0.	0.	0.	0.	0.						*00024500
110070	1100	13	0	0.	685.339		-0.48106		.096206					*00024600
110080	12	3	0	0.	0.	0.	0.	0.						*00024700
110090	-4	4	0	0.	0.	0.	0.	0.						*00024710
110100	-4	5	0	0.	0.	0.	0.	0.						*00024720
*														*00024800
*	LEAK TABLE DATA										*00024900			
*														*00025000
120101	2	9	0	30.	0.	1.	1000.	1.						*00025100
120201	3	5	0	14.7	0.	1.	.01	.653		1000.	.853			*00025200
120301	4	12	-2	14.7	0.	1.	28.5	1.		28.6	0.			*00025300
120302					30.	0.								*00025400
120401	12	4	1	14.7	1.		0.		1084.29	0.				*00025410
120402	1084.3				1.		1094.19	1.		1094.2	3.			*00025420
120403	1104.19				3.		1104.2	5.		1114.09	5.			*00025430
120404	1114.1				7.		1124.09	7.		1124.1	9.			*00025440
120405	2000.				9.									*00025450
120501	12	4	1	14.7	1.		0.		1139.59	0.				*00025451
120502	1139.7				1.		1129.49	1.		1139.5	3.			*00025452
120503	1199.49				3.		1199.5	5.		1209.39	5.			*00025453
120504	1209.4				7.		1219.39	7.		1219.4	9.			*00025454
120505	2000.				9.									*00025455
*														*00025500
*	FILL TABLE DATA										*00025600			
*														*00025700
130100	2	1	4	4	0	'LBS/SEC'	1050.		420.18					*00025800

Table 6.3 (continued)

130101	0.	878.32	1.	878.32	4.	0.	*00025900
130102	10000.	0.					*00026000
*							*00026100
*							*00026200
130200	2 2 4 3 0	'LBS/SEC'	548.	.99			*00026300
130201	0.	940.	0.	1025.	-260.6		*00026400
130202	3300.	-230.6					*00026500
*							*00026600
*	LPCI*2						*00026700
130300	12 2 8 4 0	'LBS/SEC'	14.7	200.			*00026800
130301	14.7	2194.66	149.7	1242.16	164.7	1097.24	*00026900
130302	194.7	703.88	204.7	517.56	214.7	103.51	*00027000
130303	214.8	0.0	2000.	0.			*00027100
*							*00027200
*	HPCS						*00027300
130400	7 2 5 -101 0	'LBS/SEC'	14.7	0.			*00027400
130401	14.7	962.05	214.7	882.613	1124.7	229.48	*00027500
130402	1114.8	0.0	2000.	0.			*00027600
*							*00027700
*	DUMMY FILL TABLE---NET LIQUID FLOW INTO CORE, LOWER PLENUM						*00027800
130500	2 1 2 -112 0	'GAL/MIN'	14.7	.016719			*00027900
130501	0.	1000.	0.				*00028000
*	DUMMY FILL TABLE---STEAM GENERATION RATE IN LIQUID FILM						*00028100
130600	2 1 2 -212 0	'GAL/MIN'	14.7	.016719			*00028200
130601	0.	1000.	0.				*00028300
*							*00028400
*	KINETICS CONSTANTS DATA						*00028500
*							*00028600
140000	3 1 116. 0. 1.						*00028700
*							*00028800
*	SCRAM TABLE DATA						*00028900
*							*00029000
141001	-8 4 0. 0. 0.9 0. 1.075 -.4 1.6 -4. 2.7 -10. 5.7 -28.1 8. -30.						*00029100
141002	10. -30.						*00029200
*							*00029300
*	DENSITY REACTIVITY TABLE DATA						*00029400
*							*00029500
142001	-10 .2 -11.55 .3 -8.830 .4 -6.690 .5 -5.01 .6 -3.64 .7 -2.51						*00029600
142002	.8 -1.55 .9 -0.73 1. 0. 1.1 0.						*00029700
*							*00029800
*	DOPPLER TABLE DATA						*00029900
*							*00030000
143001	-6 0. 1.85 1000. 0. 2000. -1.71 3000. -3. 4000. -4.28 5000. -5.4	*00030100					
*							*00030200
*	REACTIVITY COEFFICIENTS DATA						*00030300
*							*00030400
140010	.08369 .08369 0. 0.						*00030500
140020	.17071 .17071 0. 0.						*00030600
140030	.17561 .17561 0. 0.						*00030700
140040	.12391 .12391 0. 0.						*00030800
140050	.11655 .11655 0. 0.						*00030900
140060	.10292 .10292 0. 0.						*00031000
140070	.12944 .12944 0. 0.						*00031100
140080	.09717 .09717 0. 0.						*00031200
140090	4(0)						*00031300
140100	4(0)						*00031400
140110	4(0)						*00031500
140120	4(0)						*00031600
140130	4(0)						*00031700
140140	4(0)						*00031800
140150	4(0)						*00031900
140160	4(0)						*00032000
140170	4(0)						*00032100
140180	4(0)						*00032200
140190	4(0)						*00032300
140200	4(0)						*00032400
140210	4(0)						*00032500
140220	4(0)						*00032600
140230	4(0)						*00032700
140240	4(0)						*00032800
140250	4(0)						*00032900

Table 6.3 (continued)

140260 4(0) *00033C00
 140270 4(0) *00033100
 140280 4(0) *00033200
 140290 4(0) *00033200
 140300 4(0) *00033400
 140310 4(0) *00033500
 140320 4(0) *00033600
 *00033700
 *00033800
 *00033900
 *00034000
 150000 -1 0 0 0 *00034100
 *00034200
 *00034300
 *00036000
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 *00036400
 *00036500
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 *00039800
 160010 1 7 9 15 .002667 .00696079 *00039900
 160020 2 7 9 15 .002667 .01420260 *00040000
 160030 3 7 9 15 .002667 .01461026 *00040100
 160040 4 7 9 15 .002667 .01030309 *00040200
 160050 5 7 9 15 .002667 .00969541 *00040300
 160060 6 7 9 15 .002667 .00856084 *00040400
 160070 7 7 9 15 .002667 .01075784 *00040500
 160080 8 7 9 15 .002667 .00803245 *00040600
 *00040700
 *00040800
 *00040900
 *00041000
 *00041100
 *00041200
 *00041300
 *00041400
 *00041500
 *00041600
 *** C.S 9--C.S 16: GROUP 2 RODS
 160090 9 7 9 15 .002667 .03480396 *00040700
 160100 10 7 9 15 .002667 .07101299 *00040800
 160110 11 7 9 15 .002667 .07305128 *00040900
 160120 12 7 9 15 .002667 .05154045 *00041000
 160130 13 7 9 15 .002667 .04647703 *00041100
 160140 14 7 9 15 .002667 .04280421 *00041200
 160150 15 7 9 15 .002667 .05383921 *00041300
 160160 16 7 9 15 .002667 .04041226 *00041400
 *** C.S 17--C.S 24: GROUP 3,4 RODS *00041500
 160170 17 7 9 15 .002667 .04176475 *00041600

Table 6.3 (continued)

160180	18	7	9	15	.002667	.03521558	*00041700	
160190	19	7	9	15	.002667	.03756154	*00041300	
160200	20	7	9	15	.002667	.06184854	*00041900	
160210	21	7	9	15	.002667	.05817244	*00042000	
160220	22	7	9	15	.002667	.05136506	*00042100	
160230	23	7	9	15	.002667	.06460705	*00042200	
160240	24	7	9	15	.002667	.04849471	*00042300	
*** C.S. 25--C.S. 32: HOT CHANNEL							*00042400	
160250	25	7	9	15	0.	.00014565	*00042500	
160260	26	7	9	15	0.	.00029716	*00042600	
160270	27	7	9	15	0.	.00030571	*00042700	
160280	28	7	9	15	0.	.00021569	*00042800	
160290	29	7	9	15	0.	.00020287	*00042900	
160300	30	7	9	15	0.	.00017913	*00043000	
160310	31	7	9	15	0.	.00022531	*00043100	
160320	32	7	9	15	0.	.00016912	*00043200	
*** C.S. 1--C.S. 9 : GROUP 1 RODS							*00043300	
160015	1	0	0.	.3	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00043400
160025	1	0	0.	.3	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00043500
160035	1	0	0.	.3	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00043600
160045	1	0	0.	.3	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00043700
160055	1	0	0.	.3	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00043800
160065	1	0	0.	.3	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00043900
160075	1	0	0.	.3	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00044000
160085	1	0	8.016	.3	.6	.965 .95 4(0)	.05 0 .08333 .08106	.01988 0 0 *00044100
*** C.S. 9--C.S. 16 : GROUP 2 RODS							*00044200	
160095	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00044300
160105	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00044400
160115	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00044500
160125	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00044600
160135	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00044700
160145	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00044800
160155	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00044900
160165	1	0	40.082	.3	.6	.965 .95 4(0)	.05 0 .08333 .40528	.01988 0 0 *00045000
*** C.S. 17--C.S. 24 : GROUP 3,4 RODS							*00045100	
160175	1	0	0.	.3	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00045200
160185	1	0	0.	.3	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00045300
160195	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00045400
160205	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00045500
160215	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00045600
160225	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00045700
160235	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00045800
160245	1	0	48.098	.8	.6	.965 .95 4(0)	.05 0 .08333 .48634	.01988 0 0 *00045900
*** C.S. 25--C.S. 32 : GROUP 3,4 RODS							*00046000	
160255	1	0	0.	.3	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00046100
160265	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00046200
160275	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00046300
160285	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00046400
160295	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00046500
160305	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00046600
160315	1	0	0.	.8	.6	.965 .95 4(0)	.05 0 .08333 0.	.01988 0 0 *00046700
160325	1	0	.1259	.3	.6	.965 .95 4(0)	.05 0 .08333 .00127	.01988 0 0 *00046800
*							*00046900	
* SLAB GEOMETRY DATA								
*							*00047000	
170101	2	3	1	6	0.0	.020071 1.0	*00047200	
170102	1	2	2			.000721 0.	*00047300	
170103	0	3	3			.00267 0.	*00047400	
170201	1	2	4	3	0.0	.4	*00047500	
170202	0	5	1			.0208 0.	*00047600	
170301	1	1	5	1	0.	.17 0.	*00047700	
170401	1	1	5	1	0.	.125 0.	*00047800	
170501	1	1	5	1	0.	.33 0.	*00047900	
170601	1	1	5	1	0.	.0138 0.	*00048000	
170701	1	1	5	1	0.	.0625 0.	*00048100	
170801	1	1	5	1	0.	.042 0.	*00048200	
170901	1	1	5	1	0.	.06 0.	*00048300	
171001	1	1	5	1	0.	.0234 0.	*00048400	
*							*00048500	
* THERMAL CONDUCTIVITY DATA								
*							*00048600	
*							*00048700	

Table 6.3 (continued)

180100	-20	500.	3.341	550.	2.971	300.	2.677	950.	2.439	1100.	2.242	*C0048800		
180101	1250.	2.078	1400.	1.940	1550.	1.823	1700.	1.724	1850.	1.639	*C0048900			
180102	2000.	1.558	2150.	1.507	2300.	1.457	2450.	1.415	2600.	1.382	*C0049000			
180103	3100.	1.323	3600.	1.333	4100.	1.406	4600.	1.538	5100.	1.730	*C0049100			
180200	2		32.		.41562		5400.		.41562		*C0049200			
180300	18	32.	7.812	212.	7.992	392.	8.203				*C0049300			
180301	572.	6.784	752.	9.540	932.	10.404					*C0049400			
180302	1112.	11.268	1292.	12.492	1472.	13.176					*C0049500			
180303	1652.	13.968	1832.	14.796	2012.	16.128					*C0049600			
180304	2192.	17.784	2372.	19.656	2552.	21.780					*C0049700			
180305	2732.	24.048	3092.	28.908	3360.	33.120					*C0049800			
180401	-5	32.	30.	212.	29.5	392.	28.3	572.	26.6	752.	24.7	*C0049900		
180501	-2	200.	5.33	1200.	12.92							*C0050000		
*												*C0050100		
*												*C0050200		
*												*C0050300		
190100	16	32.	34.45	122.	38.35	212.	40.95					*C0050400		
190101	392.	43.55	752.	46.8	2012.	51.35						*C0050500		
190102					2732.	52.65	3092.	56.55	3452.	63.05		*C0050600		
190103	3812.	72.8	4352.	89.7	4532.	94.25						*C0050700		
190104	4712.	98.15	4892.	100.1	5144.	101.4						*C0050800		
190105					8000.	101.4						*C0050900		
190200	2		32.		.000075	5400.		.000075				*C0051000		
190300	9	32.		25.92	212.	28.755	392.		30.375			*C0051100		
190301		572.		31.59	932.	33.615	1292.		35.235			*C0051200		
190302				1742.	36.855	1743.	35.235	3360.	35.235			*C0051300		
190401	-7	130.	56.9	350.	60.8	450.	62.3	530.	65.2	620.	67.2	710.	70.2	*C0051400
190402		800.		77.5									*C0051500	
190501	-10	68.	52.8	200.	56.7	400.	61.6	600.	64.	800.	66.	1000.	.67	*C0051600
190502				1200.	68.4	1400.	71.8	1600.	75.3	1800.	80.6		*C0051700	
*													*C0051800	
*													*C0051900	
*													*C0052000	
200101	-2	0.	3.718E-6	5000.	1.2653E-5								*C0052100	
200201	-2	0.	0.	5000.	0.								*C0052200	
200301	-4	0.	3.094E-6	1652.	4.706E-6	1653.	5.389E-6	5000.	5.389E-6				*C0052300	
200401	-2	0.	0.	5000.	0.								*C0052400	
200501	-2	0.	0.	5000.	0.								*C0052500	
*													*C0052600	
*													*C0052700	
*													*C0052800	
210101	4	3	13	0.	-.0207	1.0	-.0207	4.0	0.		10000.	0.	*C0052900	
*													*C0053000	
*													*C0053100	
*													*C0053200	
250001	1	2	3	0	.0615								*C0053300	
*													*C0053400	
*													*C0053500	
*													*C0053600	
270001	14	2500.	0.	2200.	98.7	1620.	197.	1730.	395.	1660.	592.		*C0053700	
270002		1600.	790.	1540.	987.	1480.	1184.	1440.	1382.	1400.	1579.		*C0053800	
270003		1370.	1777.	1335.	1974.	1310.	2172.	1250.	2369.				*C0053900	
*													*C0054000	
*													*C0054100	
*													*C0054200	
280001	4	34.	0.	34.	150.	21.	200.	21.	1000.				*C0054300	
*													*C0054400	
*													*C0054500	
*													*C0054600	
290001	14	2500.	0.	2200.	98.7	1620.	197.	1730.	395.	1660.	592.		*C0054700	
290002		1600.	790.	1540.	987.	1480.	1184.	1440.	1382.	1400.	1579.		*C0054800	
290003		1370.	1777.	1335.	1974.	1310.	2172.	1250.	2369.				*C0054900	
*													*C0055000	
*													*C0055100	
*													*C0055200	
300001	14	131.	0.	131.	98.7	62.	197.	47.	395.	69.	592.		*C0055300	
300002		95.	790.	116.	987.	131.	1184.	137.	1382.	131.	1579.		*C0055400	
300003		121.	1777.	100.	1974.	76.	2172.	58.	2369.				*C0055500	
*****													*C0055600	
*****													*C0055700	
*****													*C0055800	

Table 6.3 (continued)

205000	1	2	3	9(0)		*00055900
205010	26293015	0.	12.	1.E6		*00056000
205100	1000.					*00056100
205110	144.	.5	.003	.5		*00056200
205120	1000.	1000.	0.	25.	.05	*00056300
205210	3.	3.5	1.5			*00056400
205310	3(0.002667)					*00056500
205410	.08334	.41663	.50003			*00056600
*****	CORE SPRAY MODEL DATA	*****	*****	*****	*****	*00056700
						*00056800

switched from nucleate boiling to forced convection vaporization and shortly after to pool film boiling through transition boiling. During the lower plenum flashing, the heat transfer mode was film boiling because of the EM heat transfer logic selection, so that the clad surface temperature did not decreased. They increased until bottom reflooding started. The bottom heat slab temperature and the middle heat slab temperature turned around at 135 sec and 160 sec, respectively.

6.2 BWR Small Recirculation Line Break

6.2.1 Introduction

A typical BWR plant was modeled using RELAP4/MOD6/U4/J3 to represent a 4 % break in the pump suction side of one of the recirculation lines. The system model and assumptions used and the calculated results are presented in the following sections. The calculation was carried out from the break initiation until the core recovery.

6.2.2 System model and Assumptions

The nodalization describing the BWR system is shown in Figure 6.6. It consists of 16 volumes, 30 junction and 46 heat slabs including 24 core heat slabs. The volumes and fill junctions shown in Figure 6.6 are identified in Table 6.4.

The system nodalization for the BWR small break analysis differs from that used for the 200 % break (section 6.1) in the following respects. The nine volumes (one average core volume and eight hottest bundle volumes) were replaced by a single core volume for the small break analysis. The two break volumes used in the large break analysis were combined into a single volume.

The bubble rise model was used in the upper and lower downcomers, the upper and lower plenums, the core, the core bypass (including guide tubes), and the jet pumps. Bubble velocity in each volume was calculated by the Wilson bubble velocity correlation. The bubble density gradient in the two phase mixture was not calculated except in the lower downcomer. The single mixture level calculation in the vertically stacked volumes in the shroud was not applied.

The vertical slip model was used in the following junction. These were the core inlet junction (Jun 16), the core outlet junction (Jun 17),

the core bypass outlet junction (Jun 19), and the jet pump discharge junction (Jun 14 and Jun 15).

The HEM (Homogeneous Equilibrium Model) critical flow model with a multiplier of 1.0 was used at the break junction in both subcooled region and saturated region. The stagnation property option was not used.

The low pressure coolant injection (LPCI), low pressure core spray (LPCS), and auto-depressurization system (ADS) were modeled for ECCS. The high pressure core spray (HPCS) was not simulated according to the single failure assumption. 46 percent of LPCS water was assumed to be available to the core and the remainder was assumed to fall on the core bypass region. The LPCI was modeled to inject directly ECC water to the core bypass region. And the relief valves and safety valves were also simulated by using trip reset option and leak table.

CCFL was considered at the core outlet and the core bypass outlet by using CCFL fill junctions (Jun 24 and Jun 25 respectively). And Jun 27 and Jun 28, which were fill junctions, were utilized for the droplet flow leaving liquid film and the steam flow vaporizing from liquid film, respectively. Jun 27 was connected with the core volume and Jun 28 was connected with the upper plenum.

The bypass-lower plenum leakage model was also applied at the core bypass inlet junction (Jun 18).

6.2.3 Calculated Results

In the calculation RELAP4/MOD6/U4/J3 ran without any troubles. The physical time from the break initiation until the core recovery was calculated to be 600 sec. This required 100 minutes of CPU time on the FACOM M200 at the JAERI Computing Center.

The major events which occurred during the transient are given in Table 6.4. The output data traces are shown in Figure 6.7 through 6.10 at the end of this section. A summary discussion of the transient follows.

The transient began when the break junction (Jun 20) opened and the power to the recirculation pump was tripped. The trips for the scram, and the feedwater valve were initiated shortly after the break occurred.

As shown in Fig. 6.7 the vessel pressure began to drop when the break opened. After steamline valve was fully closed at 49 sec, the vessel pressure began to increase slowly.

The break flow reached a maximum shortly after the break and then

decreased following the vessel depressurization as shown Figure 6.8. Generally, it followed vessel pressure change.

The vessel pressure reached a relief valve set point of 1,084 psia, so that the valve opened. Then the pressure remained steady until ADS valve opened at 256 sec. After ADS valve opened, the vessel pressure decreased rapidly until it reached about 100 psia.

The mixture level in the shroud began to decrease at 60 sec, and the core uncovering started at about 180 sec as shown in Figure 6.9. When ADS valve opened, the lower plenum saturated and its liquid flowed into the core and the core bypass. Then the mixture level in the core increased, but, after about 20 sec, it decreased again, and the active core was uncovered completely at 323 sec. The lower plenum mixture level began to decrease at 300 sec. A bubble velocity in the lower plenum was changed to 1.0×10^6 ft/sec upon restart at 430 sec for stabilization of calculation.

LPCS and LPCI started at 387 sec and 458 sec, respectively. CCFL phenomena occurred at the core outlet, so the most of LPCS water fell into core bypass region. Therefore, after the LPCS initiation, core bypass mixture level increased slowly. But when LPCI started, core mixture level dropped sharply because of subcooled water mixing. Soon after that, it increased rapidly, and the core bypass region was filled up. After 495 sec, core bypass water level was controlled to remain constant. ECC water began to refill the lower plenum after the control rod guide tube was filled up. The bottom reflooding of the core start at 527 sec, and the core mixture level was balanced with the hydraulic head of coolant in the jet pump.

Clad surface temperatures are shown in Figure 6.10. The clad temperatures followed the fluid saturation temperature while the heat slabs were covered by the two phase mixture. But when they were uncovered because of the core mixture level decrease, the convective heat transfer coefficients were set equal to zero, so that the clad surface temperature increased rapidly. Soon after LPCS initiation, the top heat slab was rewetted by top quench at 387 sec, and its surface temperature dropped sharply. The middle heat slab was also rewetted by top quench at 461 sec. The bottom heat slab temperature turned around at 528 sec because of bottom reflooding. The difference in the rates of temperature decrease between top quench and bottom reflooding were due to the difference in the convective heat transfer coefficients.

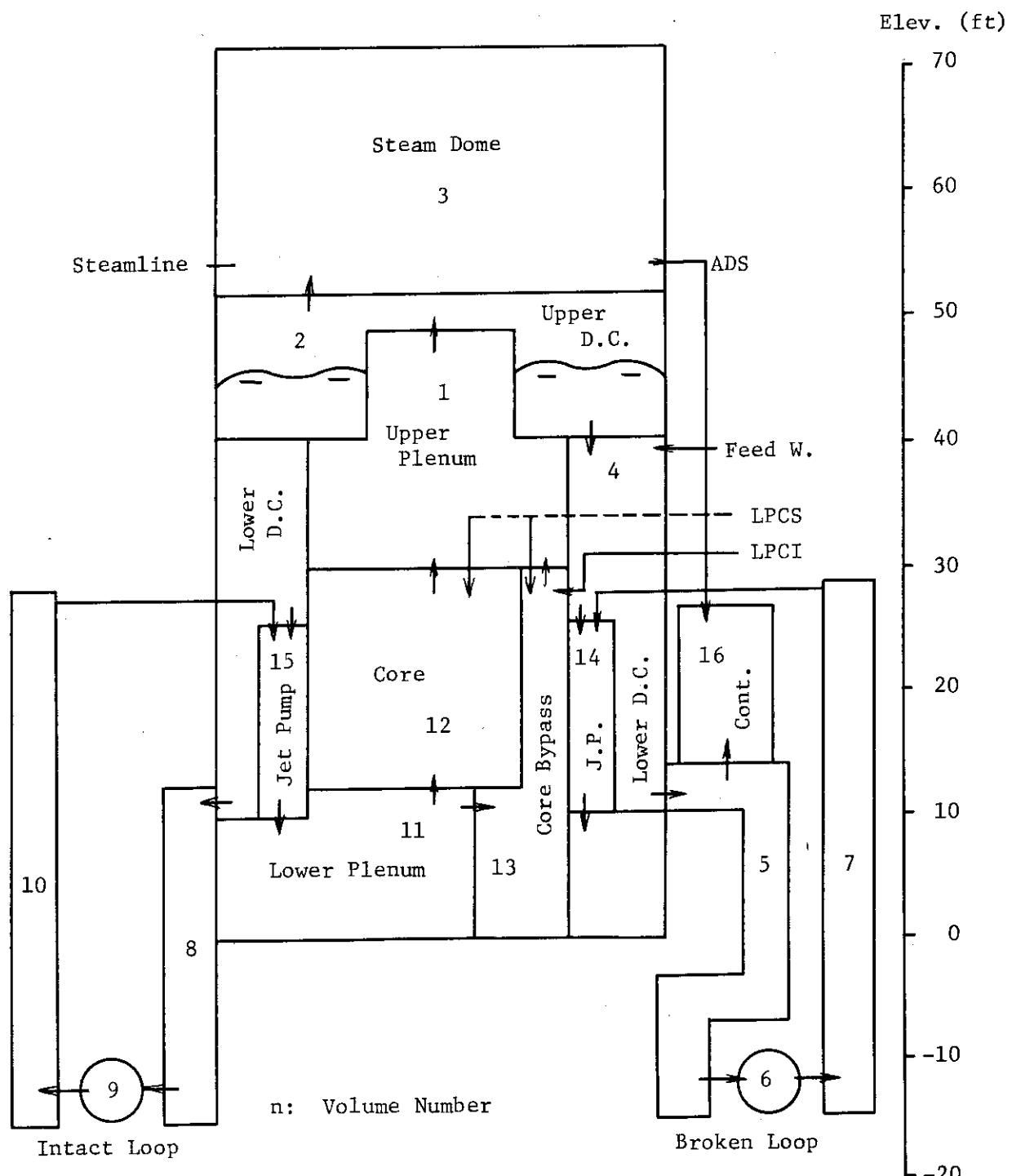


Fig. 6.6 Nodalization for BWR Small Break

Table 6.4 Volume and Junction Identification for BWR Small Break

Volume No.	Description
1	Upper Plenum and Steam Separator
2	Upper Downcomer
3	Steam Dome
4	Lower Downcomer
5	Broken Loop Recirculation Suction Line
6	Broken Loop Recirculation Pump
7	Broken Loop Recirculation Discharge Line
8	Intact Loop Recirculation Suction Line
9	Intact Loop Recirculation Pump
10	Intact Loop Recirculation Discharge Line
11	Lower Plenum
12	Average Core
13	Core Bypass and Guide Tubes
14	Broken Loop Jet Pump
15	Intact Loop Jet Pump
Fill Junction No.	
22	Feedwater Inlet
23	Steam Outlet
24	LPCS Water Injection into Average Core
25	LPCS Water Injection into Core Bypass
26	Low Pressure Coolant Injection
27	Liquid Flow Injection Simulating Liquid Droplet Flow Leaving from Quench Front
28	Steam Flow Injection Simulating Steam Flow Vaporizing from Liquid Film

Table 6.5 Major Events Summary for BWR Small Break

Time (sec)	Events
0.001 to 0.002	Break opened, pump power off, scram tripped
1 to 4	Feedwater stopped
49	Steamline closed fully
125	Relief valves opened
256	ADS started
323	Active core was uncovered completely
387	LPCS started
458	LPCI started
527	Bottom reflooding started
528	Middle heat slab was quenched

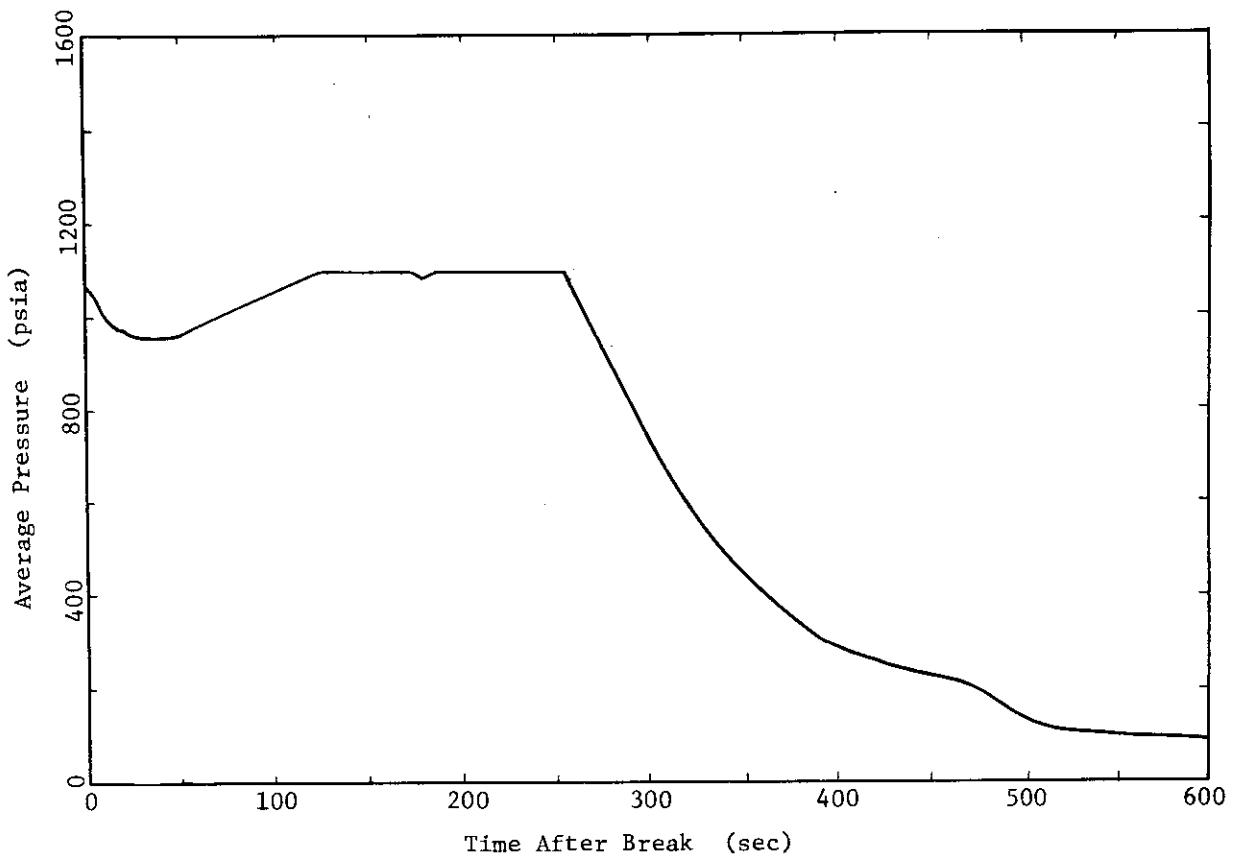


Fig. 6.7 Lower Plenum Pressure - BWR Small Break

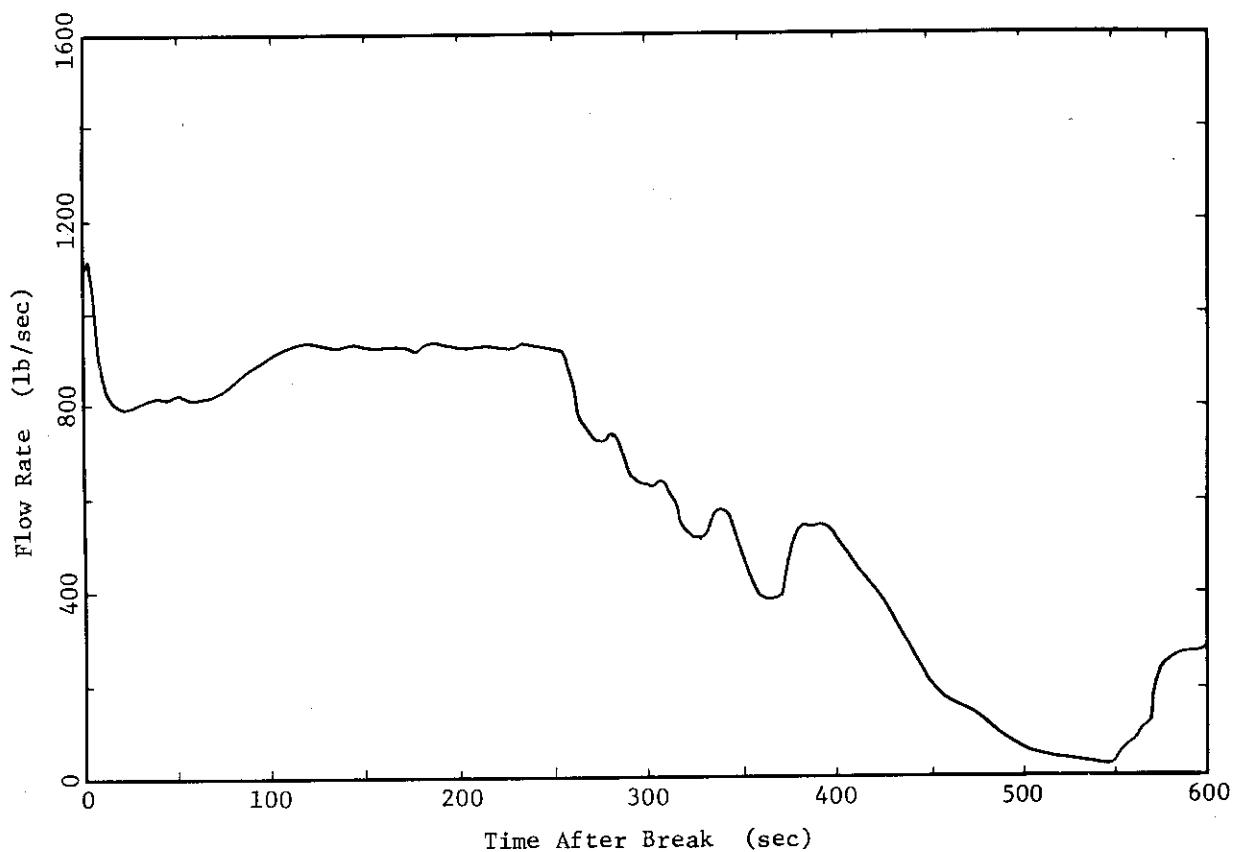


Fig. 6.8 Break Flow Rate - BWR Small Break

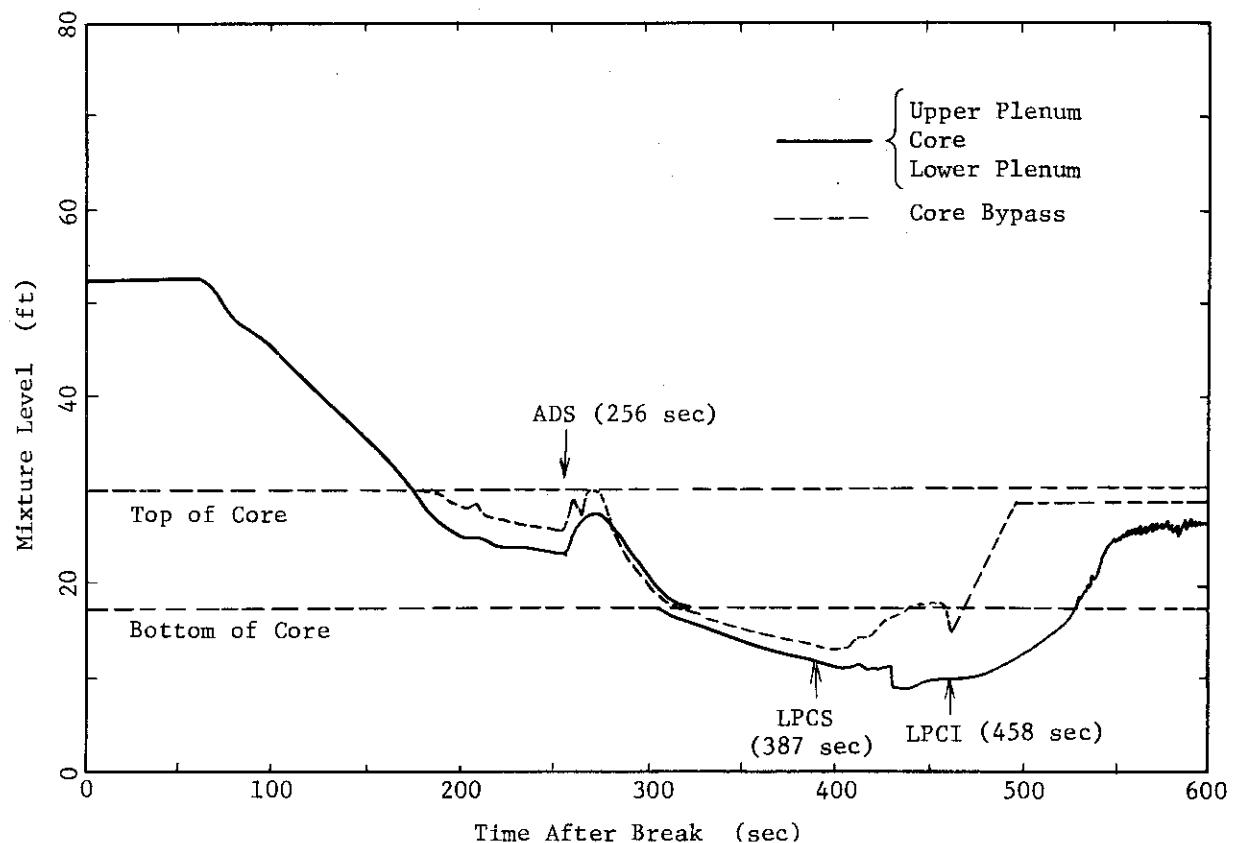


Fig. 6.9 Mixture Level in Shroud - BWR Small Break

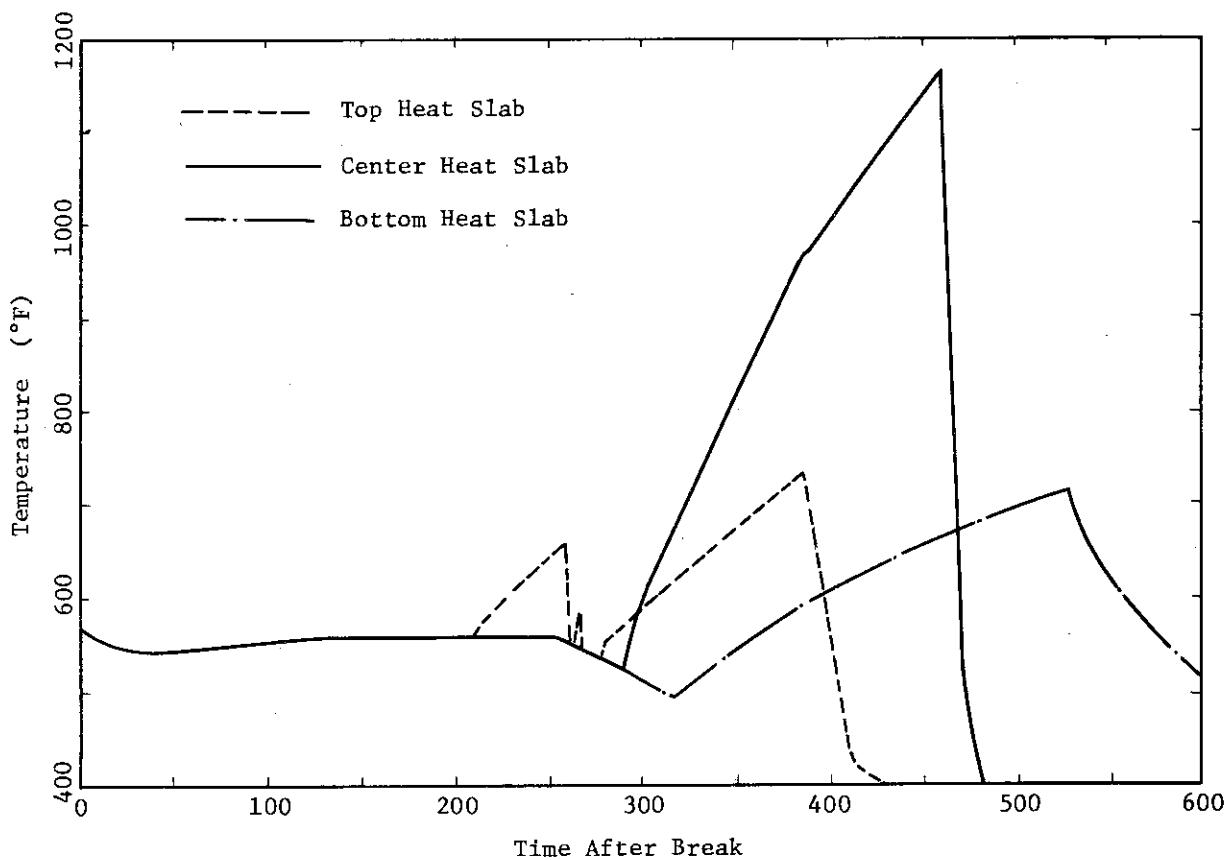


Fig. 6.10 Clad Surface Temperature - BWR Small Break

Table 6.6 Input List for BWR Small Break

```

= RELAP4/MOD6/U4/J3    BWR SMALL BREAK ANALYSIS          *00000100
*                                         *00000200
*      PROBLEM DIMENSION          *00000300
*                                         *00000400
010C01 -2 9 3 13 16 4 0 30 2 8 5 6 46 10 5 32 0 0  *00000500
*                                         *00000600
*      POWER OMEGA              *00000700
*                                         *00000800
010C02 3388. 1.0               *00000900
*                                         *00001000
*      EDIT VARIABLES           *00001100
*                                         *00001200
020000 AP 11 ML 1 ML 12 ML 11 ML 13 JW 24 JW 25 JW 17 JW 20 *00001300
*                                         *00001400
*      TIME STEP CONTROL CARD  *00001500
*                                         *00001600
030010 2 100 1 0 .1 .00001 180. 7140. *00001700
030020 20 100 1 0 .01 .00001 190. *00001800
030030 2 100 1 0 .1 .00001 1.0E6 *00001900
*                                         *00002000
*      TRIP CONTROL CARD       *00002100
*                                         *00002200
040010 1 1 0 0 1.0E6 0. *00002300
040020 2 1 0 0 0. 0. *00002400
040030 3 1 0 0 .001 0. *00002500
040040 4 1 0 0 .002 0. *00002600
040050 5 1 0 0 1.0 0. *00002700
040060 6 1 0 0 1000. 0. *00002800
040070 7 -5 4 0 21.48 40. *00002900
040080 8 1 0 0 .001 1000. *00003000
040090 9 -5 4 0 21.48 120. *00003100
040100 10 9 25 0 0.001 0. 12.85 0. 5 12 0 *00003200
040110 11 9 25 0 0.001 0. *00003300
040120 12 1 0 0 100. 0. *00003400
040130 13 -5 4 0 30.78 0. *MSIV CLOSE *00003500
*                                         *00003600
*      VOLUME DATA             *00003700
*                                         *00003800
050011 2 0 1039. -1. .091632 1548. *00003900
050021 2 0 1028.28 -1. .002448 6703. *00004000
050031 1 0 1024.98 -1. .999 3777. *00004100
050041 3 0 1031.93 532.3 -1. 3177. *00004200
050051 0 0 1024. 532.3 -1. 136.0 *00004300
050061 0 0 1126.17 533.25 -1. 63. *00004400
050071 0 0 1226.17 533.25 -1. 366. *00004500
050081 0 0 1024. 532.30 -1. 136. *00004600
050091 0 0 1126.17 533.25 -1. 63. *00004700
050101 0 0 1226.17 533.25 -1. 366. *00004800
050111 2 0 1062.16 532.53 -1. 2131.5 *00004900
050121 2 0 1051.52 -1. .13855 973.09 *00005000
050131 2 0 1050.07 532.6 -1. 1477. *00005100
050141 2 0 1059.2 532.53 -1. 115. *00005200
050151 2 0 1059.2 532.53 -1. 115. *00005300
050161 4 0 14.7 100. .6 3.43E8 *00005400
*                                         *00005500
*                                         *00005600
050012 22.20 22.20 0 224. 0. 29.97 0 *00005700
050022 12.25 5.27 0 497. 0. 41.75 0 *00005800
050032 21.25 21.25 0 497. 0. 51.25 0 *00005900
050042 32.23 32.23 0 165. 0. 10.02 0 *00006000
050052 26. 26. 0 3.67 0. -14. 4 .98 *00006100
050062 3. 3. 0 4.0 0. -14. 0 0 *00006200
050072 40.53 40.53 0 3.2 0. -14. 4 14.98 *00006300
050082 26. 26. 0 3.67 0. -14. 4 .98 *00006400
050092 3. 3. 0 4.0 0. -14. 0 0 *00006500
050102 40.53 40.53 0 3.2 0. -14. 4 14.98 *00006600
050112 17.05 17.05 0 120. 0. 0. 0 *00006700
050122 12.92 12.92 0 81.091 .0473 17.05 0 *00006800

```

Table 6.6 (continued)

050132	29.97	29.97	0	43.635	0.	0.	1		*00006900
050142	15.7	15.7	0	19.69	0.	10.02	4	14.93	*00007000
050152	15.7	15.7	0	19.69	0.	10.02	4	14.93	*00007100
050162	250.	0.0	1	1000.	100.	-10.	0		*00007200
*									*00007300
*	CCFL CORRELATION COEF.								*00007400
*									*00007500
060002	1.0	.46							*00007600
060012	0.7	.47							*00007700
*									*00007800
*	BUBBLE DATA								*00007900
*									*00008000
060011	1.3	0.0							*00008100
060021	0.0	-1.0							*00008200
060031	0.8	-1.0							*00008300
060041	0.0	1.26							*00008400
*									*00008500
*	JUNCTION DATA								*00008600
*									*00008700
080011	1	2	0	0	29583.	191.1	52.17	0.	*00008800
080021	2	3	0	0	4074.3135	312.	52.25	0.	*00008900
080031	2	4	0	0	25444.	155.	42.0	0.	*00009000
080041	4	15	0	0	10041.5	3.112	25.	30.	*00009100
080051	4	5	0	0	4750.	3.67	11.0	0.	*00009200
080061	5	6	-1	0	4750.	3.67	-13.	0.	*00009300
080071	6	7	1	0	4750.	3.2	-13.	0.	*00009400
080081	7	15	0	0	4750.	0.538	25.	47.	*00009500
080091	4	8	0	0	4750.	3.67	11.	0.	*00009600
080101	8	9	-2	0	4750.	3.67	-13.	0.	*00009700
080111	9	10	2	0	4750.	3.2	-13.	0.	*00009800
080121	10	14	0	0	4750.	0.538	25.	47.	*00009900
080131	4	14	0	0	10041.5	3.112	25.	30.	*00010000
080141	14	11	0	0	14791.5	19.69	10.12	0.	*00010100
080151	15	11	0	0	14791.5	19.69	10.12	0.	*00010200
080161	11	12	0	0	26639.	20.32	17.05	0.	*00010300
080171	12	1	0	0	26639.	37.13	29.97	0.	*00010400
080181	13	11	0	5	-2944.	2.246	17.	0.	*00010500
080191	1	13	0	0	-2944.	43.635	29.97	0.	*00010600
080201	5	16	0	4	0.	.15	11.	0.	*00010700
080211	3	16	0	3	0.	.484	55.	1.	*00010800
080221	0	4	1	0	4074.3135	4.712	40.	0.	*00010900
080231	0	3	2	2	-4074.3135	14.75	72.	0.	*00011000
080241	0	12	3	0	0.	.46	29.96	0.	*00011100
080251	0	13	3	6	0.	.54	29.96	0.	*00011200
080261	0	13	4	6	0.	1.	29.	1.	*00011300
080271	0	12	105	0	0.	1.	29.	0.	*00011400
080281	0	1	106	0	0.	37.13	30.	0.	*00011500
080291	3	16	0	7	0.	.1993	72.	1.	*00011600
080301	3	16	0	8	0.	.1993	72.	1.	*00011700
*									*00011800
*									*00011900
080012	0.	0.	1	4	3	0	0.	0.	*00012000
080022	0.	0.	1	4	3	0	0.	0.	*00012100
080032	0.	0.	1	4	3	0	0.	0.	*00012200
080042	.2084	1.17	2	4	0	2	0.	0.	*00012300
080052	0.	0.	1	4	3	0	0.	0.	*00012400
080062	0.	0.	0	4	3	0	0.	0.	*00012500
080072	0.	0.	0	4	3	0	0.	0.	*00012600
080082	.2373	6.8	0	4	0	2	0.	0.	*00012700
080092	0.	0.	1	4	3	0	0.	0.	*00012800
080102	0.	0.	0	4	3	0	0.	0.	*00012900
080112	0.	0.	0	4	3	0	0.	0.	*00013000
080122	.2373	6.8	0	4	0	2	0.	0.	*00013100
080132	.2084	1.17	2	4	0	2	0.	0.	*00013200
080142	0.	0.	1	4	3	0	.05	0.	*00013300
080152	0.	0.	1	4	3	0	.35	0.	*00013400
080162	0.	0.	1	4	3	0	0.	0.	*00013500
080172	0.	0.	1	4	3	0	0.	0.	*00013600
080182	0.	0.	1	4	3	0	0.	0.	*00013700
080192	0.	0.	1	4	3	0	0.	0.	*00013800
080202	1.	.5	0	4	2	0	0.	0.	*00013900
080212	1.	1.	0	4	0	0	0.	0.	*00014000

Table 6.6 (continued)

080222	0.	0.	0	4	3	0	0.	0.	4	0	0.	0	*00014100		
080232	0.	0.	0	4	3	0	0.	0.	4	0	0.	0	*00014200		
080242	0.	0.	0	4	3	0	0.	0.	4	0	0.	281	*00014300		
080252	0.	0.	0	4	3	0	0.	0.	4	0	0.	-192	*00014400		
080252	0.	0.	0	4	0	0	0.	0.	4	0	0.	0	*00014500		
080272	0.	0.	0	4	0	0	0.	0.	4	0	0.	0	*00014600		
080282	0.	0.	0	4	0	0	0.	0.	4	0	0.	0	*00014700		
080292	1.	1.	0	4	0	0	0.	0.	4	0	0.	0	*00014800		
080302	1.	1.	0	4	0	0	0.	0.	4	0	0.	0	*00014900		
*													*00015000		
*	PUMP DESCRIPTION DATA												*00015100		
*													*00015200		
090011	3	4	0	1	0	1668.	1.0	44943.	710.3	22200.	20000.	47.17	0.	0	*00015300
090021	3	4	0	1	0	1668.	1.0	44943.	710.3	22200.	20000.	47.17	0.	0	*00015400
*														*00015500	
*	PUMP HEAD MULTIPLIER DATA												*00015600		
*														*00015700	
091001	-11	0.	0.	.1	0.	.15	.05	.24	.8					*00015800	
091002	.3	.96	.4	.98	.6	.97	.8	.9						*00015900	
091003	.9	.8	.96	.5	1.	0.								*00016000	
*														*00016100	
*	PUMP TORQUE MULTIPLIER DATA												*00016200		
*														*00016300	
092001	-2	0.	0.	1.	0.									*00016400	
*														*00016500	
*	PUMP STOP DATA												*00016600		
*														*00016700	
095011	0.	0.	0.											*00016800	
095021	0.	0.	0.											*00016900	
*														*00017000	
*	PUMP CURVE INPUT INDICATOR DATA												*00017100		
*														*00017200	
100000	0	0	16	0										*00017300	
*														*00017400	
*	PUMP HEAD AND TORQUE DATA												*00017500		
*														*00017600	
103011	1	1	5	0.	1.31	.25	1.25	.5	1.20	.75	1.12	1.	1.0	*00017700	
103021	1	2	5	0.	-0.9	.25	-.5	.5	-0.05	.75	.4	1.	1.0	*00017800	
103031	1	3	5	-1.	2.1	-.75	1.775	-.5	1.54	-.25	1.4	0.	1.31	*00017900	
103041	1	4	5	-1.	2.1	-.75	1.50	-.5	1.13	-.25	.92	0.	.825	*00018000	
103051	1	5	5	0.	.4	.25	.53	.5	.625	.75	.8	1.	1.0	*00018100	
103061	1	6	5	0.	.825	.25	.79	.5	.815	.75	.9	1.	1.0	*00018200	
103071	1	7	5	-1.	-1.6	-.75	-1.	-.5	-0.4	-.25	.1	0.	0.4	*00018300	
103081	1	8	5	-1.	-1.8	-.75	-1.72	-.5	-1.54	-.25	-1.27	0.	-0.9	*00018400	
103091	2	1	5	0.	.55	.25	.63	.5	.71	.75	.86	1.	1.0	*00018500	
103101	2	2	5	0.	-.55	.2	-0.175	.4	.0	.75	.58	1.	1.0	*00018600	
103111	2	3	5	-1.	1.77	-.75	1.23	-.5	.83	-.25	.62	0.	.55	*00018700	
103121	2	4	5	-1.	1.77	-.75	1.52	-.5	1.32	-.25	1.13	0.	1.0	*00018800	
103131	2	5	5	0.	-0.8	.2	-.375	.5	-0.1	.75	.15	1.	.43	*00018900	
103141	2	6	5	0.	1.0	.25	0.88	.5	0.75	.75	0.61	1.	.43	*00019000	
103151	2	7	5	-1.	-3.45	-.75	-2.75	-.50	-2.0	-.25	-1.375	0.	-.6	*00019100	
103161	2	8	5	-1.	-3.45	-.75	-2.62	-.50	-1.583	-.25	-1.15	0.	-.55	*00019200	
*														*00019300	
*	VALVE DATA												*00019400		
*														*00019500	
110010	6	0	0	0.	0.	0.	0.	0.						*00019600	
110020	13	2	0	0.	0.	0.	0.	0.						*00019700	
110030	-9	0	0	0.	0.	0.	0.	0.						*00019800	
110040	-3	0	0	0.	0.	0.	0.	0.						*00019900	
110050	1100	13	0	0.	685.389	-0.4816	.096206							*00020000	
110060	10	3	0	0.	0.	0.	0.	0.						*00020100	
110070	4	4	0	0.	0.	0.	0.	0.						*00020200	
110080	4	5	0	0.	0.	0.	0.	0.						*00020300	
*														*00020400	
*	LEAK TABLE DATA												*00020500		
*														*00020600	
120101	-2	9	0	30.	0.	1.	1000.	1.						*00020700	
120201	6	13	0	14.7	0.	1.	2.25	1.	2.5	.667				*00020800	
120202					2.75	.333	3.	0.	10000.	0.				*00020900	
120301	4	10	-2	14.7	0.	1.	28.5	1.	26.6	0.				*00021000	
120302					30.	0.								*00021100	
120401	12	4	1	14.7	1.	0.	1084.29	0.						*00021200	

Table 6.6 (continued)

120402	1084.3	1.	1094.19	1.	1094.2	3.	1104.19	3.	*00021300										
120403	1104.2	5.	1114.09	5.	1114.1	7.	1124.09	7.	*00021400										
120404	1124.1	9.	2000.	9.					*00021500										
120501	12	4	1	14.7	1.	0.	1139.69	0.	* 1E SAFETY VALVES *00021600										
120502					1139.7	1.	1169.49	1.	*00021700										
120503					1199.5	5.	1209.39	5.	*00021800										
120504					1219.4	9.	2000.	9.	*00021900										
*									*00022000										
*									*00022100										
*									*00022200										
130103	2	1	4	1	0	'LBS/SEC'	1050.	401.11324	*00022300										
130101	0.					864.6676	1.	864.6676	4.	0.	*00022400								
130102	3000.					0.				*00022500									
*									*00022600										
*									*00022700										
130200	2	2	4	3	0	'LBS/SEC'	548.	.999	*00022800										
130201	0.					940.	0.	1025.	-276.2246	*00022900									
130202	3000.					-276.2246				*00023000									
*									*00023100										
*									*00023200										
130300	7	2	10	-101	0	'LBS/SEC'	14.696	0.	*00023300										
130301	14.7			970.86		137.	882.6	224.7	573.69	*00023400									
130302	252.2			441.3		264.7	353.04	272.2	264.78	*00023500									
130303	277.2			176.52		304.7	88.26	304.8	0.	*00023600									
130304	3000.			0.						*00023700									
*									*00023800										
*									*00023900										
*									*00024000										
130400	7	2	3	4	0	'LBS/SEC'	14.7	200.	*00024100										
130401	14.7			2194.66		149.7	1242.16	164.7	1097.24	*00024200									
130402	194.7			703.88		204.7	517.56	214.7	103.51	*00024300									
130403	214.8			0.0		2000.	0.			*00024400									
*									*00024500										
*									*00024600										
130500	2	1	2	-112	0	'GAL/MIN'	14.7	.016719	*00024700										
130501	0.			0.		1000.	0.			*00024800									
*									*00024900										
*									*00025000										
130600	2	1	2	-212	0	'GAL/MIN'	14.7	.016719	*00025100										
130601	0.			0.		1000.	0.			*00025200									
*									*00025300										
*									*00025400										
140000	3	0	116.	0.	1.	0.	0.		*00025500										
*									*00025600										
*									*00025700										
*									*00025800										
141001	-8	4	0.	0.	0.9	0.	1.075	-.4	1.6	-.4	2.7	-10.	5.7	-28.1	8.	-30.	*00025900		
141002							10.	-30.										*00026000	
*																		*00026100	
*																		*00026200	
*																		*00026300	
*																		*00026400	
142001	-10	.2	-11.55	.3	-8.830	.4	-6.690	.5	-5.01	.6	-3.64	.7	-2.51						*00026500
142002	.8		-1.55	.9	-0.73	1.	0.	1.1	0.										*00026600
*																		*00026700	
*																		*00026800	
143001	-6	0.	1.85	1.E3	0.	2.E3	-1.71	3.E3	-3.	4.E3	-4.28	5.E3	-5.43	*00026900					
*																		*00027000	
*																		*00027100	
*																		*00027200	
140010	.08369				.08369		0.	0.											*00027300
140020	.17071				.17071		0.	0.											*00027400
140030	.17561				.17561		0.	0.											*00027500
140040	.12391				.12391		0.	0.											*00027600
140050	.11655				.11655		0.	0.											*00027700
140060	.10292				.10292		0.	0.											*00027800
140070	.12944				.12944		0.	0.											*00027900
140080	.09717				.09717		0.	0.											*00028000
140090	4(0.)																		*00028100
140100	4(0.)																		*00028200
140110	4(0.)																		*00028300
140120	4(0.)																		*00028400

Table 6.6 (continued)

140130	4(0.)																		*00028500
140140	4(0.)																		*00028600
140150	4(0.)																		*00028700
140160	4(0.)																		*00028800
140170	4(0.)																		*00028900
140180	4(0.)																		*00029000
140190	4(0.)																		*00029100
140200	4(0.)																		*00029200
140210	4(0.)																		*00029300
140220	4(0.)																		*00029400
140230	4(0.)																		*00029500
140240	4(0.)																		*00029600
140250	4(0.)																		*00029700
140260	4(0.)																		*00029800
140270	4(0.)																		*00029900
140280	4(0.)																		*00030000
140290	4(0.)																		*00030100
140300	4(0.)																		*00030200
140310	4(0.)																		*00030300
140320	4(0.)																		*00030400
*																			*00030500
*																			*00030600
*																			*00030700
150000	-1	0	0	0															*00030800
*																			*00030900
*																			*00031000
150011	0	3	2	0	0	0	0	0.		687.	422.	0.	0.	0.	0.	0.	0.	0.	*00031100
150021	0	2	2	0	0	0	0	0.		1368.	698.	0.	0.	0.	0.	0.	0.	0.	*00031200
150031	0	4	2	0	0	0	0	0.		1916.	977.	0.	0.	0.	0.	0.	0.	0.	*00031300
150041	0	11	2	0	0	0	0	0.		687.	385.	0.	0.	0.	0.	0.	0.	0.	*00031400
150051	4	13	3	0	0	0	0	0.		1355.	1355.	239.	0.	0.	0.	0.	0.	0.	*00031500
150061	1	2	4	0	0	0	0	0.		2288.	2288.	286.	0.	0.	0.	0.	0.	0.	10.42*00031600
150071	11	12	5	0	0	0	0	0.		197.	197.	65.	0.	0.	0.	0.	0.	0.	*00031700
*50081	12	1	5	0	0	0	0	0.		94.	94.	31.	0.	0.	0.	0.	0.	0.	*00031800
150081	11	13	6	0	0	0	0	0.		6884.	6884.	95.	0.	0.	0.	0.	0.	0.	17.1*00031900
150091	0	11	7	0	0	0	0	0.		736.	46.	0.	0.	0.	0.	0.	0.	0.	*00032000
150101	2	3	8	0	0	0	0	0.		4380.	4380.	184.	0.	0.	0.	0.	0.	0.	*00032100
150111	0	5	9	0	0	0	0	0.		450.	36.	0.	0.	0.	0.	0.	0.	0.	*00032200
150121	0	8	9	0	0	0	0	0.		450.	36.	0.	0.	0.	0.	0.	0.	0.	*00032300
150131	0	7	9	0	0	0	0	0.		838.	67.	0.	0.	0.	0.	0.	0.	0.	*00032400
150141	0	10	9	0	0	0	0	0.		838.	67.	0.	0.	0.	0.	0.	0.	0.	*00032500
**** S17---S24 : GROUP 1 RODS: SPRAY HTC = 3 BTU /F.H.FT2																			*00032600
150151	0	12	1	0	122	1	10	0		919.73	10.7902								*00032700
150161	0	12	1	1	122	1	10	0		919.73	10.7902								*00032800
150171	0	12	1	1	122	1	10	0		689.80	8.0927								*00032900
150181	0	12	1	1	122	1	10	0		459.86	5.3951								*00033000
150191	0	12	1	1	122	1	10	0		459.86	5.3951								*00033100
150201	0	12	1	1	122	1	10	0		459.86	5.3951								*00033200
150211	0	12	1	1	122	1	10	0		689.80	8.0927								*00033300
150221	0	12	1	1	122	1	10	0		919.73	10.7902								*00033400
**** S25---S32 : GROUP 2 RODS: SPRAY HTC = 3.5 BTU /F.H.FT2																			*00033500
150231	0	12	1	0	122	1	10	0		4598.65	53.951								*00033600
150241	0	12	1	1	122	1	10	0		4598.65	53.951								*00033700
150251	0	12	1	1	122	1	10	0		3448.99	40.443								*00033800
150261	0	12	1	1	122	1	10	0		2299.32	25.976								*00033900
150271	0	12	1	1	122	1	10	0		2299.32	26.976								*00034000
150281	0	12	1	1	122	1	10	0		2299.32	26.976								*00034100
150291	0	12	1	1	122	1	10	0		3448.99	40.443								*00034200
150301	0	12	1	1	122	1	10	0		4598.65	53.951								*00034300
**** S23---S40 : GROUP 3,4 RODS: SPRAY HTC = 1.5 BTU /F.H.FT2																			*00034400
150311	0	12	1	0	122	1	10	0		5518.37	64.741								*00034500
150321	0	12	1	1	122	1	10	0		5518.37	64.741								*00034600
150331	0	12	1	1	122	1	10	0		4138.78	48.556								*00034700
150341	0	12	1	1	122	1	10	0		2759.18	32.371								*00034800
150351	0	12	1	1	122	1	10	0		2759.18	32.371								*00034900
150361	0	12	1	1	122	1	10	0		2759.18	32.371								*00035000
150371	0	12	1	1	122	1	10	0		4128.78	48.556								*00035100
150381	0	12	1	1	122	1	10	0		5518.37	64.741								*00035200
**** S29---S46 : HOT CHANNEL HEAT SLAB																			*00035300
150391	0	12	1	0	122	1	10	0		14.446.	.16948								*00035400
150401	0	12	1	1	122	1	10	0		14.446	.16948								*00035500
150411	0	12	1	1	122	1	10	0		10.8345	.12711								*00035600

Table 6.6 (continued)

150421	0	12	1	1	122	1	10	0	7.223	.08474	*00035700
150431	0	12	1	1	122	1	10	0	7.223	.08474	*00035800
150441	0	12	1	1	122	1	10	0	7.223	.08474	*00035900
150451	0	12	1	1	122	1	10	0	10.8345	.12711	*00036000
150461	0	12	1	1	122	1	10	0	14.446	.16948	*00036100
**** S15--S22 : GROUP 1 RODS: SPRAY HTC = 3.0 BTU/F.H.FT2											
150152	0	.048	0	.0588	0	12.	.5	2.5			*00036300
150162	0	.048	0	.0588	0	12.	2.5	4.5			*00036400
150172	0	.048	0	.0588	0	12.	4.5	6.0			*00036500
150182	0	.048	0	.0588	0	12.	6.0	7.0			*00036600
150192	0	.048	0	.0588	0	12.	7.0	8.0			*00036700
150202	0	.048	0	.0588	0	12.	8.0	9.0			*00036800
150212	0	.048	0	.0588	0	12.	9.0	10.5			*00036900
150222	0	.048	0	.0588	0	12.	10.5	12.5			*00037000
**** S25--S32 : GROUP 2 RODS: SPRAY HTC = 3.5 BTU /F.H.FT2											
150232	0	.048	0	.0588	0	12.	.5	2.5			*00037200
150242	0	.048	0	.0588	0	12.	2.5	4.5			*00037300
150252	0	.048	0	.0588	0	12.	4.5	6.0			*00037400
150262	0	.048	0	.0588	0	12.	6.0	7.0			*00037500
150272	0	.048	0	.0588	0	12.	7.0	8.0			*00037600
150282	0	.048	0	.0588	0	12.	8.0	9.0			*00037700
150292	0	.048	0	.0588	0	12.	9.0	10.5			*00037800
150302	0	.048	0	.0588	0	12.	10.5	12.5			*00037900
**** S25--S40 : GROUP 3,4 RODS: SPRAY HTC = 1.5 BTU /F.H.FT2											
150312	0	.048	0	.0588	0	12.	.5	2.5			*00038100
150322	0	.048	0	.0588	0	12.	2.5	4.5			*00038200
150332	0	.048	0	.0588	0	12.	4.5	6.0			*00038300
150342	0	.048	0	.0588	0	12.	6.0	7.0			*00038400
150352	0	.048	0	.0588	0	12.	7.0	8.0			*00038500
150362	0	.048	0	.0588	0	12.	8.0	9.0			*00038600
150372	0	.048	0	.0588	0	12.	9.0	10.5			*00038700
150382	0	.048	0	.0588	0	12.	10.5	12.5			*00038800
**** S39--S46 : HOT CHANNEL HEAT SLA3											
150392	0	.048	0	.0588	0	12.	.5	2.5			*00039000
150402	0	.048	0	.0588	0	12.	2.5	4.5			*00039100
150412	0	.048	0	.0588	0	12.	4.5	6.0			*00039200
150422	0	.048	0	.0588	0	12.	6.0	7.0			*00039300
150432	0	.048	0	.0588	0	12.	7.0	8.0			*00039400
150442	0	.048	0	.0588	0	12.	8.0	9.0			*00039500
150452	0	.048	0	.0588	0	12.	9.0	10.5			*00039600
150462	0	.048	0	.0588	0	12.	10.5	12.5			*00039700
* CORE SLAB DATA FOR EM											
**** C.S 1--C.S 8: GROUP 1 RODS											
160010	15	7	9	15	.002667		.00696079				*00040000
160020	16	7	9	15	.002667		.01420260				*00040100
160030	17	7	9	15	.002667		.01461026				*00040200
160040	18	7	9	15	.002667		.01030809				*00040300
160050	19	7	9	15	.002667		.00969541				*00040400
160060	20	7	9	15	.002667		.00856084				*00040500
160070	21	7	9	15	.002667		.01076784				*00040600
160080	22	7	9	15	.002667		.00808245				*00040700
**** C.S 9--C.S 16: GROUP 2 RODS											
160090	23	7	9	15	.002667		.03480396				*00040800
160100	24	7	9	15	.002667		.07101299				*00040900
160110	25	7	9	15	.002667		.07305128				*00041100
160120	26	7	9	15	.002667		.05154045				*00041200
160130	27	7	9	15	.002667		.04847703				*00041300
160140	28	7	9	15	.002667		.04280421				*00041400
160150	29	7	9	15	.002667		.05383921				*00041500
160160	30	7	9	15	.002667		.04041226				*00041600
**** C.S 17--C.S 24: GROUP 3,4 RODS											
160170	31	7	9	15	.002667		.04176475				*00041800
160180	32	7	9	15	.002667		.08521558				*00041900
160190	33	7	9	15	.002667		.08766154				*00042000
160200	34	7	9	15	.002667		.06184854				*00042100
160210	35	7	9	15	.002667		.05817244				*00042200
160220	36	7	9	15	.002667		.05136506				*00042300
160230	37	7	9	15	.002667		.06460705				*00042400
160240	38	7	9	15	.002667		.04849471				*00042500
**** C.S 25--C.S 32: HOT CHANNEL											
160250	39	7	9	15	.002667		.00014565				*00042600
160260	40	7	9	15	.002667		.00029718				*00042700
											*00042800

Table 6.6 (continued)

160270	41	7	9	15	.002667	.00030571	*C0042900						
160280	42	7	9	15	.002667	.00021569	*C0043000						
160290	43	7	9	15	.002667	.00020287	*C0043100						
160300	44	7	9	15	.002667	.00017913	*C0043200						
160310	45	7	9	15	.002667	.00022531	*C0043300						
160320	46	7	9	15	.002667	.00016912	*C0043400						
*							*C0043500						
*	SLAB GEOMETRY DATA						*C0043600						
*							*C0043700						
170101	2	3	1	6 0.0	.020071	1.	*C0043800						
170102	1		2		.000721	0.	*C0043900						
170103	0		3	8	.00267	0.	*C0044000						
170201	1	2	4	3 0.0	.4	0.	*C0044100						
170202	0		5	1	.0208	0.	*C0044200						
170301	1	1	5	1 0.	.17	0.	*C0044300						
170401	1	1	5	1 0.	.125	0.	*C0044400						
170501	1	1	5	1 0.	.33	0.	*C0044500						
170601	1	1	5	1 0.	.0138	0.	*C0044600						
170701	1	1	5	1 0.	.0625	0.	*C0044700						
170801	1	1	5	1 0.	.042	0.	*C0044800						
170901	1	1	5	1 0.	.08	0.	*C0044900						
171001	1	1	5	1 0.	.0234	0.	*C0045000						
*							*C0045100						
*	THERMAL CONDUCTIVITY DATA						*C0045200						
*							*C0045300						
180100	-20	500.	3.341	650.	2.971	800.	2.677	950.	2.439	1100.	2.242	*C0045400	
180101	1250.	2.078	1400.	1.940	1550.	1.823	1700.	1.724	1850.	1.639		*C0045500	
180102	2000.	1.568	2150.	1.507	2300.	1.457	2450.	1.415	2600.	1.382		*C0045600	
180103	3100.	1.323	3600.	1.333	4100.	1.406	4600.	1.538	5100.	1.730		*C0045700	
180200		2		32.	.41562	5400.		.41562					*C0045800
180300	18	32.	7.812	212.	7.992	392.	8.208						*C0045900
180301	572.	3.784	752.	9.540	932.	10.404							*C0046000
180302	1112.	11.268	1292.	12.492	1472.	13.176							*C0046100
180303	1652.	15.958	1832.	14.796	2012.	16.128							*C0046200
180304	2192.	17.784	2372.	19.656	2552.	21.780							*C0046300
180305	2732.	24.048	3092.	28.908	3360.	33.120							*C0046400
180401	-5	32.	30.	212.	29.5	392.	28.3	572.	26.6	752.	24.7		*C0046500
180501	-2	200.	8.33	1200.									*C0046600
*													*C0046700
*	VOLUMETRIC HEAT CAPACITY DATA						*C0046800						
*													*C0046900
190100	16	32.	34.45	122.	38.35	212.	40.95						*C0047000
190101		392.	43.55	752.	46.8	2012.	51.35						*C0047100
190102		2732.	52.55	3092.	56.55	3452.	63.05						*C0047200
190103		3812.	72.8	4352.	89.7	4532.	94.25						*C0047300
190104		4712.	98.15	4892.	100.1	5144.	101.4						*C0047400
190105		8000.	101.4										*C0047500
*													*C0047600
*													*C0047700
*													*C0047800
190200	2	32.		.000075	5400.		.000075						*C0047900
*													*C0048000
*													*C0048100
*													*C0048200
190300	5	0.0	28.392	1480.3	34.476	1675.	35.176						*C0048300
190301		1787.5	34.476	3500.	34.476								*C0048400
*													*C0048500
*													*C0048600
*													*C0048700
190401	-7	130.	56.9	350.	60.3	450..	62.3						*C0048800
190402		530.	65.2	620.	67.2	710..	70.2						*C0048900
190403		800.	77.5										*C0049000
*													*C0049100
*													*C0049200
*													*C0049300
190501	-10	63.	52.8	200.	56.7	400..	61.6						*C0049400
190502		600.	54.	300.	66.	1000..	67.						*C0049500
190503		1200.	68.4	1400.	71.8	1600..	75.8						*C0049600
190504		1800.	80.6										*C0049700
*													*C0049800
*	LINEAR EXPANSION COEFFICIENT DATA						*C0049900						
*													*C0050000

Table 6.6 (continued)

200101	-2	0.	3.718E-6	5000.	1.2653E-5	*00050100				
200201	-2	0.	0.	5000.	0.	*00050200				
200301	-4	0.	3.094E-6	1652.	4.706E-6	1653.	5.389E-6	5000.	5.389E-6	*00050300
200401	-2	0.	0.	5000.	0.	*00050400				
200501	-2	0.	0.	5000.	0.	*00050500				
*						*00050600				
*	CORE SPRAY MODEL DATA					*00050700				
*						*00050800				
205000	15	16	17	9(0)			*00050900			
205010	24272817	0.		12.	1.0E6		*00051000			
205100	1000.						*00051100			
205110	200.	.5		.003	.5		*00051200			
205120	1000.		1000.	0.	25.	.05	*00051300			
205210	3.	3.5		1.5			*00051400			
205310	.002667	.002667		.002667			*00051500			
205410	.08334	.41663		.50003			*00051600			
							*00051700			

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Appendix A

Plotter Program; "PLT4CAL"

"PLT4CAL" program, which is a modified program of PLOTR4M, is a more useful plotter program for RELAP4/MOD5 and MOD6. The most useful feature of this program is a capability to do various arithmetic operations among plot-variables, and then to plot its computed results. For example, a void fraction of two phase mixture in a control volume may not be available as plot-variable, but it can be obtained from bubble mass, liquid mass, liquid specific volume, and vapor specific volume which are available to PLOTR4M program. PLT4CAL can plot void fraction by processing these variables.

The normal usage of PLT4CAL is as same as of PLOTR4M. If user wants to produce graphs of computed results which will be obtained from some plot variables, user needs to make a subroutine "PLTCAL", which executes arithmetic operations among plot variables, and link it to PLT4CAL program, and then executes a plotter job. In Table A.1 and A.2, input cards deck and the "PLTCAL"'s source list to produce a graph of the void fraction in a two phase mixture are shown.

In the PLT4CAL execution, the plot data, which are created by a previous RELAP4 run, are read from FORTRAN Unit 1, and the requested plot variable's records are stored temporarily in Unit 11 ~ Unit 30. In this example, the requested plot variables are bubble mass (BM), liquid mass (WM), saturated vapor specific volume (VG), and saturated liquid specific volume (VL). After that, subroutine "PLTCAL" reads these records from Unit 11 ~ Unit 14, and computes mixture void fraction (AMIX) according to following equation;

$$AMIX = \frac{BM \cdot VG}{BM \cdot VG + WM \cdot VL} \quad (A.1)$$

And then the values of AMIX are written to FORTRAN Unit 31. After computing these procedure about all plot points are completed, PLT4CAL moves computed results from Unit 31 to Unit 11. The argument "N" in of subroutine "PLTCAL" is the number of variables which are computed from the plot variables available from RELAP4's plot tape.

Table A.1 Source List of Subroutine PLTCAL

```

SUBROUTINE PLTCAL(N)
10 READ(11,END=999) XX,WM
    READ(12)      XX,BM
    READ(13)      XX,VF
    READ(14)      XX,VG
    AMIX = BM*VG/(BM*VG + WM*VF)
    WRITE(31) XX,AMIX
    GO TO 10
999 REWIND 11
    REWIND 12
    REWIND 13
    REWIND 14
    REWIND 31
    N=1
    RETURN
    END

```

Table A.2 Input List of PLT4CAL for Void Fraction Plot

```

RELAP4/MOD6/U4/J3   BWR LARGE BREAK ANALYSIS
TI     100.00E02.00E2      TIME AFTER BREAK (SEC)
WM    13    8      VOID FRAC. OF MIXTURE IN BYPASS REGION
BM    13    8
VF    13    8
VG    13    8

```

Table A.3 JCL for PLT4CAL Program at JAERI

```

//FORT EXEC POKTHE,SD='J3197.PLTCAL',A='ELM(PLTCAL)'
//LINK EXEC LKEDIT,LM='J3197.PLT4CAL',GRLIB=PLT
//PLCT EXEC RLP4PLOT,PNM=TEMPNAME,PN='88LM',REGION.PLOTR4=750K
//SYSIN DD DSN=J3197.PLTDATA,DATA(AMIX),DISP=SHR
//      EXPAND PLCT
//      EXPAND TAPE,DDN=FT01F001,DSN='J3197.RELAP4',MTV=002947,
//      MTU=TAPE,DISP=OLD,SEN=3
//      EXPAND TPSISK,DDN=FT31F001,RSIZE=12,BSIZE=6220,RECFM=VBS,DSN=F31

```