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ABSTRACT

The modular computational system known as the Water Reactor Analysis Package (WRAP) has been extended to provide the computational tools required to perform a complete analysis of LOCAs in BWRs. The new system is known as the WRAP-EM (Evaluation Model) system and will be used by NRC in interpreting and evaluating reactor vendor EM methods and computed results.

The system for BWR-EM analysis is comprised of several computer codes which have been developed to analyze a particular phase of a LOCA. These codes include GAPCON for calculation of initial fuel conditions, WRAP (the previously developed SRL analog of RELAP4/MOD5) for analysis of the system blowdown, NORCOOL for analysis of the reflood phase, and MOXY for the calculation of the fuel assembly hot plane temperature. In addition, a BWR steady-state initialization procedure has been developed to provide the initial operating state of the reactor system. The BWR-EM system is operational and is currently being evaluated to determine the adequacy and consistency of the physical models employed for EM analysis. A similar effort to develop a PWR-EM system is also in progress.

CONTENTS

I. INTRODUCTION

WRAP-EM is a modular system of computer codes which provides the computational tools required to perform a complete analysis of postulated loss-of-coolant accidents (LOCAs) in light water nuclear power reactors. The system is being developed at the Savannah River Laboratory (SRL) for use primarily by the Nuclear Regulatory Commission (NRC) in interpreting and evaluating reactor vendor evaluation model (EM)[1] methods and computed results. The initial version of the WRAP-EM system for analysis of boiling water reactors (BWRs) is described in this report. A similar analysis capability for pressurized water reactors (PWRs) is also being developed. A second phase in the development of each of these capabilities will involve an evaluation of the adequacy and consistency of the physical models employed in each computational step for EM analyses. Modifications and improvements will be incorporated into the system as a result of this study so as to provide a system capable of analyzing a broad range of LOCAs, i.e., large and small breaks in a variety of locations in the reactor system.

The WRAP-EM system is a major extension of the WRAP[2,3] (Water Reactor Analysis Package) system developed at SRL during 1977.[a] WRAP is a modified version of the RELAP4 code[b] with an extensively restructured input format, a dynamic dimensioning capability, and additional computational capabilities such as an automatic steady-state option for pressurized water reactors and an automatic restart capability with provision for renodalization. The initial objective in the development of WRAP was to provide a user-oriented system for routine production use that is more efficient and amenable to modification than the then-existing RELAP4 code. In accomplishing this objective, the following tasks were completed:

- Development of an improved format for user input,
- Development of an automatic steady-state initialization procedure for pressurized water reactors ,
- Development of an automatic spatial renodalization procedure,
- Implementation of a dynamic dimensioning capability,
- FORTRAN cleanup, FORTRAN commenting and generation of comprehensive programming documentation, and
- Implementation of WRAP under the JOSHUA[5] Operating System in a modular form.

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a) In the preparation of this document, a basic familiarity of the reader with the concepts presented in references 2 and 3 was assumed.

b) RELAP4/MOD5/UPDATE2[4] - latest released version when WRAP project began in 1976.

The modular structure of the WRAP system has been extended to provide all the computational capabilities required to audit EM analyses of LOCAs in boiling water reactors. These capabilities include:

- Calculation of the initial fuel condition,
- Calculation of the initial thermal-hydraulic state of the reactor system,
- Calculation of the blowdown phase of the LOCA,
- Calculation of the reflood phase of the LOCA, and
- Calculation of the temperature of the fuel at the hottest plane of the core.

In the remainder of this report, an overview of the BWR capability of the WRAP-EM system will be presented. Principally, the report will describe the modular structure of the WRAP-EM system and the data interfaces for transfer between the various computational steps. Appropriate references for the documentation of the physical models employed in the computer codes incorporated in the WRAP-EM system are included in the references. Companion reports[6,7] describe the BWR steady-state procedure developed at SRL and the additional input required for the new computational capabilities of the WRAP-EM system.

II. SUMMARY

The WRAP-EM system provides the computational tools required to analyze all phases of a LOCA in a boiling water reactor. WRAP-EM provides an EM description of the reactor system and will be used by NRC in the evaluation of current licensing concerns and in the development of reference calculations and sensitivity studies for use in evaluating vendor EM methods and computed results. The system for BWR-EM analysis is comprised of several computer codes, each of which has been developed to analyze a particular phase of a LOCA. These codes include GAPCON[8] for calculation of initial fuel conditions, WRAP (the previously developed SRL analog of RELAP4/MOD5) for analysis of the system blowdown, NORCOOL[9] for analysis of the reflood phase, and MOXY[10] for the calculation of the fuel assembly hot plane temperature. In addition, a BWR steady-state initialization procedure[6] has been developed to provide the initial operating state of the reactor system.

WRAP-EM is designed to operate under the JOSHUA operating system[5] which was developed at SRL in 1968 and 1969 and has been in production use since 1970. JOSHUA provides extensive data management facilities and user conveniences for problem setup and execution through the JOSHUA CRT terminal system. For computers without terminal facilities, a JOSHUA Terminal Simulator[3] (JTS) has been developed to simulate JOSHUA operations in the batch mode using card input.

The data management facilities of the JOSHUA system are utilized to provide automatic transfer of data between these computational steps. The use of a modular structure and standardized data base minimizes the amount of human intervention required in a complete LOCA analysis and provides for simplified maintenance and incorporation of new modules in the system.

III. SYSTEM OVERVIEW

The overall structure of the WRAP-EM system is shown in Figure 1. Initial fuel conditions are calculated as a function of burnup by the GAPCON[8] module. These conditions are passed to MOXY[10] and WRAPIT, the generalized input processor, for initialization of the transient fuel models. GAPCON results are also stored on magnetic tape or disk for use in subsequent calculations. The steady-state initialization procedure (both BWR[6] and PWR[11]) are contained in the WRIN module. The blowdown phase of the LOCA is calculated by the TWRAM module (most of the RELAP4/MOD5 code is contained in this module) with transient results stored on magnetic tape for plotting via the WROP module and to provide fuel thermal conditions for the hot plane analysis by the MOXY module.

At the end of blowdown (EOB), system renodalization is performed by the WRAP-NORCOOL interface routine and the reflood phase of the accident is calculated by the NORCOOL[9] module. The time to hot plane quench is passed to MOXY for use in determining the end time for the hot plane analysis. Other capabilities within the system include the transient restart capability provided by WRROT and by MWRROT with the added capabilities of system renodalization and problem re-specification. The overall execution of the various modules is controlled by the executive module, WRAPEX.

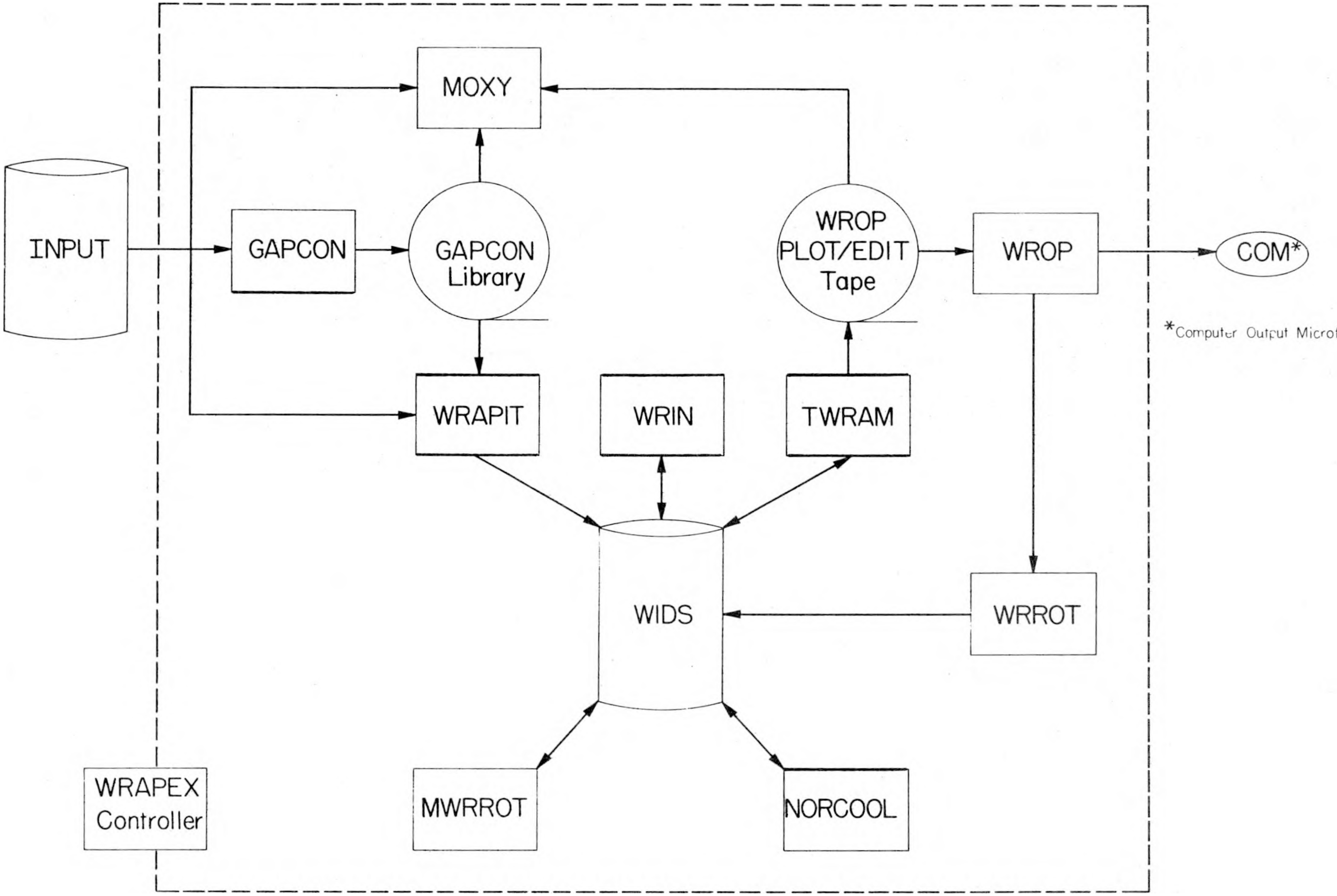
IV. NEW WRAP-EM COMPUTATIONAL CAPABILITIES

The development of the WRAP-EM system for BWR analysis has required EM modifications to WRAP, the implementation of three new codes (GAPCON, MOXY and NORCOOL) in the system and the development of a BWR steady-state procedure. GAPCON, NORCOOL, and MOXY were implemented by converting the codes to JOSHUA modules, converting the card input to templated input JOSHUA records,[7] and defining and programming data interfaces to automate data transfer between the new and existing modules. A brief description of each of these new computational capabilities is provided below. A complete description of the input required for each of these new capabilities is provided in a companion document.[7]

A. EM Modifications to WRAP Blowdown Capability

The initial WRAP system was based on RELAP4/MOD5/Version 65. The initial step in the EM development required updating WRAP to RELAP4/MOD5/Version 74 and then implementing several modifications to provide an EM treatment of the BWR blowdown calculation. The latter included:

FIGURE 1



CONCEPTUAL VIEW OF WRAP-EM SYSTEM

- Vertical slip modeling modifications[12] necessary to properly model gravity induced velocity differences between liquid and gas phases,

- Jet pump modeling modifications[12] required to eliminate the discontinuity in the jet pump momentum equations that develops as either drive or suction flow becomes zero,

- Addition of the GEXL correlation[13] for determination of the boiling transition location, and

- Corrections to the fuel rod plenum temperature calculations.[12]

Recently, several other corrections[14] were made which included the proper calculation of potential energy contributions to the junction enthalpy when flow reverses as well as other minor coding modifications.

B. Initial Fuel Condition Calculation

The GAPCON module calculates pre-accident thermal conditions of the fuel rods. For a given fuel rod GAPCON determines the gap conductance, temperatures, pressures, and stored energy as a function of the power history of the rod. These data are then used as initial conditions for the transient fuel models.

The GAPCON module implemented at SRL is essentially the GAPCON-THERMAL-2 code developed at Battelle Pacific Northwest Laboratories,[8] including BPNL revision updates current to February, 1978.[15] The code has been modified to permit rod power histories to be calculated from reactor power history and rod peaking factors. Also the fuel and clad emissivities are no longer fixed by the code but are defined by inputs. Because the GAPCON module is to be used primarily for EM calculations, the user must assure that the input options given in Table I are selected. These options may be changed for stand-alone GAPCON calculational studies.

GAPCON calculations can be performed as part of WRAP-EM modular path or separately from the other calculations. In either procedure, GAPCON results may be stored in a data library. The stored GAPCON data are then used as input to WRAP and MOXY calculations. The GAPCON data transferred to WRAP require only two fuel rod descriptions - an average rod for the hottest fuel bundle and an average rod for the other fuel bundles.

TABLE I

GAPCON Input Options for WRAP-EM Studies*

GAPCON Input Options	COMMENT
IPEAK = 1	Provides average rod power from input reactor power and peaking.
IGAS+ = 0	Realistic EM option for gas release model.
IRELOC+ = 1	Realistic EM option for fuel relocation model.
S = 0.0	Sorbed gas model not provided in MOXY and WRAP.
CO = 0.0	CO gas not considered in MOXY and WRAP.
DVOIDZ = 0.0 LVOIDZ = 0.0	Central fuel void model not in MOXY.
CRUDTH = 0.0	Clad crud model not in MOXY.
DBO = 0.0 NB = 0.0 HBC = 0.0	Secondary clad model not in MOXY.

*These options are not required for stand-alone GAPCON calculational studies.

+These EM options are not most conservative (see reference 7).

The GAPCON data transferred to MOXY can require up to 36 rod descriptions for a hot 8x8 bundle - 36 individual rods at different powers. Further description of the data transferred from GAPCON to WRAP and MOXY is given in Sections V.A. and V.B.

C. Fuel Hot Plane Analysis

The MOXY module is used to perform thermal analysis of a planar section of a BWR fuel assembly during a LOCA. The MOXY module is essentially the MOXY/MOD033 code[10] developed at the Idaho National Engineering Laboratory (INEL). The module calculates the temperature distribution of each fuel rod in a BWR fuel assembly at a single axial level of the assembly, usually the level with the hottest axial temperature. The code models describe heat transfer by conduction, convection, and radiation and heat generation by fission product decay and the metal-water reaction. Fuel rod swelling and rupture are considered along with energy transfer across the fuel-cladding gap. Heat transfer in BWR fuel assemblies is calculated during the three stages of a LOCA; blowdown, core heatup, and emergency cooling. Only during blowdown are the time-dependent data for power, heat transfer coefficient and coolant temperature required. For the remainder of the transient, built-in data as required by 10 CFR 50, Appendix K[1] guidelines for EM analysis are used.

Input options that are recommended for EM analysis are presented in Table II.

D. Reflood Analysis

The NORCOOL[9] code was developed at Riso National Laboratory (Denmark) for the evaluation of emergency core cooling systems in BWRs. It is applicable to the regime following the termination of reactor blowdown where there is near pressure equilibrium between the reactor vessel and the containment. The code is used to analyze operation of the spray and reflood systems through the refill and reflood phases.

NORCOOL consists of two basic models; a fuel rod model and a model for two-phase flow. One dimensional heat conduction equations are solved by the fuel rod model. The two-phase flow model is based on a solution of the conservation equations for mass, momentum, and energy as well as the equation of state. The flow regimes covered are single-phase liquid, bubbly flow, inverse annular flow, film flow, and dispersed flow. Thermodynamic equilibrium is not assumed; i.e., steam is allowed to be superheated and water subcooled. The fuel rod model and the two-phase flow models are coupled through a number of physical models and heat transfer correlations which include conduction, convection, and thermal radiation effects. Two dimensional axial conduction is treated in the rewetting front.

TABLE II - MOXY Recommended Input Options for EM Analysis

OPTION	EVALUATION MODEL SELECTION	NON-EM ALTERNATIVES
Decay-heating source term	Time-dependent	Can be constant
Metal-water reaction	Calculated	Can neglect
Convection heat transfer	Calculated	Can neglect
Initial surface temperature distribution	Computed from surface heat transfer coefficient	Can input initial surface temperature distribution
Fluid temperature	Time-dependent	Can be constant
Convection heat transfer coefficient	Time-dependent	Can be constant
Normalized power, heat transfer coefficient, fluid temperature	Input from direct-access files that are derived from a WRAP plot tape	Can be input
Transient gap conductance	Internally computed	Can be input
Metal-water reaction multiplier	1.0	Any positive number
Spray cooling model	GE model (ε = .7)	Can be input, can select GE model for ε=0.9, can select ANC-3 model, or can provide own model as FORTRAN subroutine
Canister quenching time	Internally computed by Yamanouchi correlation	Can be input
Inactive rod quenching time	Internally computed by Yamanouchi correlation	Can be input
Temperature Jump Distance	Value calculated by GAPCON	Can be computed internally
Time lag to be added to Yamanouchi-calculated quenching time	60 sec	Any finite number
Heat of reaction for zirconium-water reaction	2800 btu/lb_m	Can select one of two different temperature-dependent functions or provide own function as FORTRAN subroutine

To incorporate NORCOOL into the WRAP-EM system, several operational changes were carried out. The code was originally developed for Burroughs and CDC computers on which single-precision arithmetic operations are approximately equivalent to IBM double-precision arithmetic. Thus the entire code was converted to double-precision for the IBM system at SRL. All output operations to tape (e.g., the generation of restart and plot files) were replaced with JOSHUA writes to disk. The existing WROP module was expanded to handle plotting of NORCOOL output on microfiche. A new output convention was added to NORCOOL: when the quench front position reaches the hottest plane in the core, the code automatically creates a MOXY input record, prints a detailed edit, and then continues the calculation.

E. BWR Steady-State Procedure

The RELAP4/MOD5 code provides no explicit procedure for initializing the transient thermal-hydraulic calculation. Instead, the user is required to generate the initial system state by a series of hand calculations to produce estimates of the state variables and then short transient runs to evaluate the reasonableness of the estimates. In the initial development of the WRAP system, an automatic PWR steady-state procedure was developed to eliminate this time-consuming process.

In the extension of the system for BWR-EM analysis, an automatic steady-state procedure has been developed for boiling water reactors. The BWR steady-state procedure employs a time-dependent solution of the thermal-hydraulic equations without perturbation. Instead of specifying the volume variables and junction flows required by RELAP, the WRAP user specifies the following quantities:

- Core power,
- Total water mass in the system,
- Steam dome specific volume, and
- Feedwater junction specific enthalpies.

The procedure then computes the:

- Thermodynamic state of all control volumes, and
- Flow rates for all junctions including the feedwater and steam line.

The uniqueness of the solution obtained by the BWR steady-state procedure has been demonstrated. The procedure requires approximately 15 to 20 minutes cpu time on an IBM 360 Model 195 for a typical BWR nodalization. A detailed description of the procedure is provided in reference 6.

V. MODULAR INTERFACES FOR DATA TRANSFER

The integration of the GAPCON, WRAP (WRAPIT, WRIN, and TWRAM), MOXY, and NORCOOL modules to form the WRAP-EM system required the defining and programming of the following interfaces (See Figure 2):

- o GAPCON/WRAP,
- o GAPCON/MOXY,
- o WRAP/MOXY,
- o WRAP/NORCOOL, and
- o NORCOOL/MOXY.

These interfaces automate the computational steps required to perform a complete LOCA analysis from break through reflood.

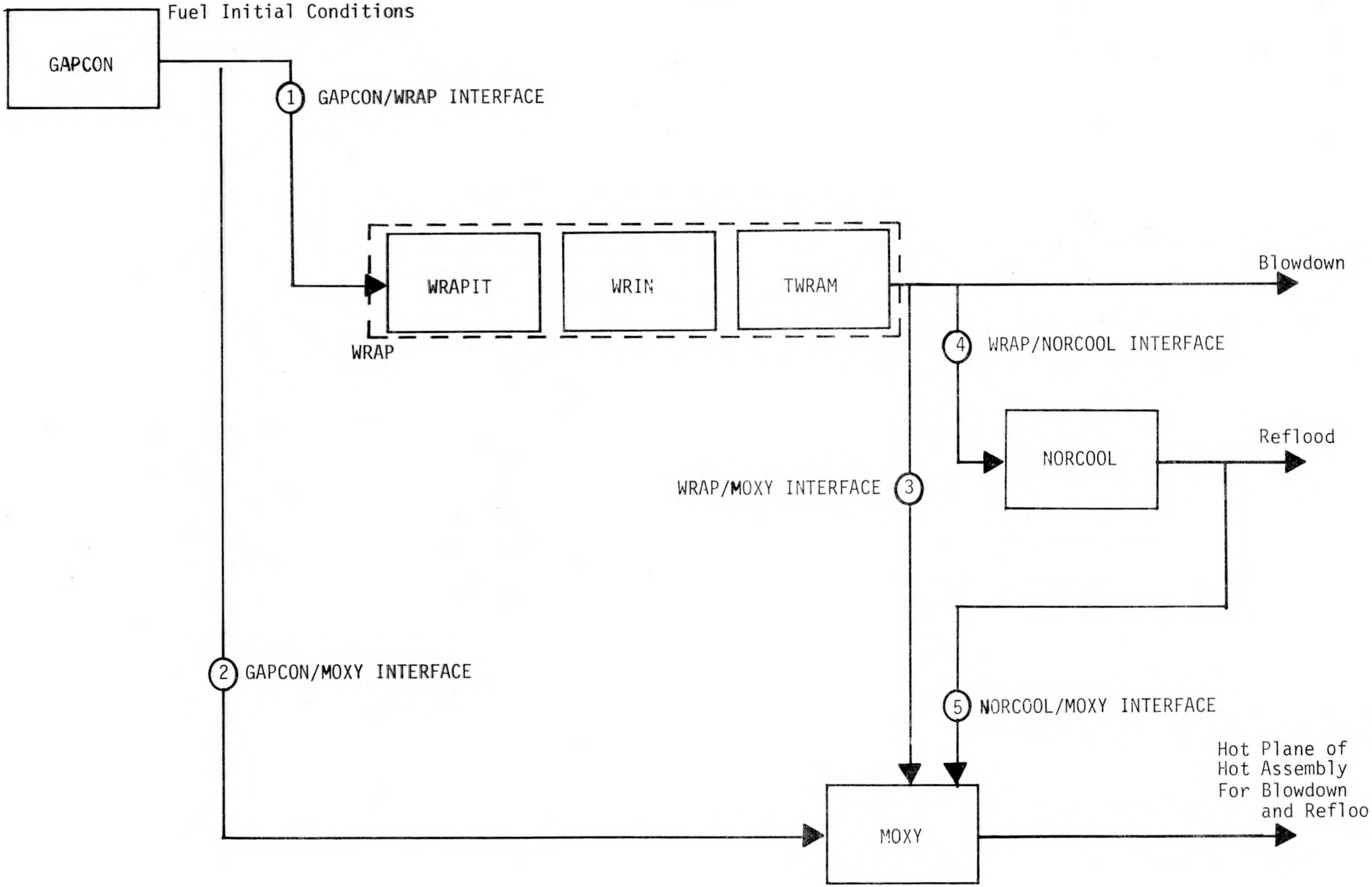
In general, hot assembly and average assembly fuel pin conditions as calculated by GAPCON are transferred to WRAP via the GAPCON/WRAP interface. The fuel pin conditions for the hot assembly are also transferred to MOXY via the GAPCON/MOXY interface. The WRAP/NORCOOL interface is a transfer of the data from WRAP at end of blowdown to NORCOOL for initialization of the reflood calculation. Transient hot assembly data during blowdown and reflood are passed to MOXY via the WRAP/MOXY and NORCOOL/MOXY interfaces, respectively. These interfaces will be described in the remainder of this section. A more detailed description of the data transferred by each interface is presented in reference 7.

A. GAPCON/WRAP

In the WRAP-EM computational system, GAPCON is used to determine fuel rod conditions at the beginning of the LOCA analysis. These initial conditions are functions of power level, burnup, fill gas pressure, etc. The data from the GAPCON calculation are transferred via the GAPCON/WRAP interface (see Figure 2) to WRAP (WRAPIT, WRIN, and TWRAM) which calculates the blowdown phase of the LOCA.

The data transfer between GAPCON and WRAP is not straightforward because the fuel models in the two codes differ. For example, GAPCON models a single fuel pin allowing up to 20 axial nodes for detail. WRAP, on the other hand, models the complete core as one or two (or possibly three) stacks of heat slabs. One stack may represent the hot bundle; while, the other models the remainder of the core. Thus, the data transferred from GAPCON to WRAP must be collected, sorted, and interpolated by the interface before being used in WRAP.

FIGURE 2



MODULAR INTERFACES

Data transferred between GAPCON and WRAP is specified for a given pin(s). For example, hot channel and average channel heat slab conditions may be determined by 'typical' hot rod and 'typical' average fuel rod calculations done with GAPCON. In the interface, the GAPCON 'typical' pin data may be scaled by the number of fuel rods per stack to obtain WRAP heat slab data. The data transferred by the interface includes the fuel rod geometry (before and after burnup), power, fuel density, and gap heat transfer factors including fission gas composition and gm-moles of fission gas. Where GAPCON data differs as a function of axial location, the WRAP heat slab data is linearly interpolated from the GAPCON data.

B. GAPCON/MOXY

Initial fuel conditions as calculated by GAPCON are passed automatically to MOXY by the GAPCON/MOXY interface (see Figure 2). As with the GAPCON/WRAP interface, the data transfer is not straightforward because of the model differences between GAPCON and MOXY.

GAPCON models in detail a single fuel pin as a function of power level, burnup, fill gas pressure, etc. GAPCON allows up to 20 axial nodes. On the other hand, a MOXY calculation is based on a horizontal plane in a fuel assembly where the assembly contains a 7x7 or 8x8 square fuel pin array. Diagonal symmetry is assumed in the fuel array, but each pin in the remaining half assembly may differ in power and thermal characteristics. A GAPCON calculation for each pin of the MOXY model is required to properly initialize the MOXY pin array. In the case of a 7x7 fuel assembly, this requires 28 GAPCON calculations, and for the 8x8 assembly, 36 calculations for a given operating condition.

Since MOXY models a planar section of the assembly, the data transferred from GAPCON to MOXY is data for the hottest axial level. The data transfer includes a check to insure that the hottest axial node for each GAPCON calculation is at the same elevation. The data transferred via the GAPCON/MOXY interface includes the fuel rod geometry (before and after burnup), power, fuel density, and gap heat transfer factors including fission gas composition, gm-moles of fission gas, and temperature jump distance.

C. WRAP/MOXY

Transient hot assembly data during blowdown is transferred from WRAP to MOXY via the WRAP/MOXY interface (see Figure 2). WRAP describes the transient response of the reactor through blowdown during a postulated LOCA. WRAP typically models the complete core as one or two stacks of heat slabs. One stack may represent the hot assembly; the other the remainder of the core. MOXY, on the other hand, is used to analyze a planar section of a fuel assembly during a LOCA. Normally, MOXY is used to analyze the hot plane in the hot assembly. Thus, data for the hottest core heat slab is passed to MOXY.

The WRAP/MOXY interface provides MOXY with input of time-dependent data for the normalized power, for the cladding-to-coolant heat transfer coefficient, and for the fluid temperature during the blowdown portion of the transient. Other quantities passed to MOXY include the times at which the following events occur in the blowdown calculation:

- o End of lower plenum flashing which is defined as the time at which dryout of the hot bundle occurs,
- o Core sprays at rated flow, and
- o End of critical flow at the break.

The above times are used in applying the 10 CFR 50, Appendix K[1] rule for specifying convective heat transfer coefficients for BWR fuel under spray cooling.

D. WRAP/NORCOOL

Most of the input data required for NORCOOL is available directly (or may be calculated) from the data base created by execution of WRAP. In Table III, the correspondence between WRAP and NORCOOL variables is provided.

The interface module INTNOR carries out the transfer of data from the WRAP data base into JOSHUA templated input records for NORCOOL. Various algorithms are built into module INTNOR. A renodalization algorithm allows the user to subdivide a WRAP volume into several identical NORCOOL nodes merely by identifying the same WRAP volume name for a series of NORCOOL nodes. Each of the nodes is assigned the same state variables characteristic of the original volume. Since the nodalization of the diffuser region in NORCOOL may not be dimensionally consistent with the WRAP nodalization, several correction operations are built into the code: an equal-mesh transition zone may be created between the upper downcomer and the top of the diffuser; the top of the steam separators is equalized with the bottom of the steam dome. Nodes in the core and bypass regions are paralleled, as are those in the lower plenum and the region below the diffuser. The height of the lower plenum below the water-locking point is calculated from the user's specification of the node comprising the bottom of the diffuser. The cross-sectional areas of the two regions of the lower plenum, below the core and below the diffuser, are calculated automatically by continuing with the flow area at the bottom of the diffuser for the latter, while the former is set to the value required to preserve the total lower plenum flow area. Continuity of void fractions between adjacent regions is guaranteed in the calculation of VOIDAP and VOIDBP, the moving mesh void fractions. Mass flow rates are transferred from the data base with the following sign conventions: for node 1 through the break node, all flow rates are positive: from below the break node to the bottom of the region, the flow rates are negative.

TABLE III

CORRESPONDENCE BETWEEN NORCOOL AND TWRAM VARIABLES

Variables which are transferred by the interface

VARIABLE DESCRIPTION	TO NORCOOL	FROM TWRAM OR (NORCOOL)	REMARKS
Cross-Sectional Area	A	FLOWA/(SCALE)	From user supplied volume to node mapping; scale=effective number of fuel assemblies specified by user.
Elevation of node	Z	ELEV,ZVOL	Elevation of 'top' of TWRAM volume.
Perimeter of node	S	(A)	Assumes $S=2\sqrt{\pi A}$
Void fraction	VOID	GASV/V	Gas volume/total volume
Water enthalpy	HS	LIQH	
Steam enthalpy	HG	GASH	
Mass flow	WMIX	WP/(SCALE)	Finds junction coupling two nodes, uses sign convention, scales magnitude.
Node number of water level	NWLEV		Pseudo-level in nodes 1 and MA (lower plenum bottom).
Height of water level	DDZ		Volume-average, collapse void fractions
Moving level void fraction	VOIDAM/AP/ /BM/BP	(VOID)	Selects void fraction on proper side of level
Moving level water enthalpy	HSAM/AP/BM/BP	(HS)	Selects water enthalpy on proper side of level.
Moving level steam enthalpy	HGAM/AP/BM/BP	(HG)	Selects steam enthalpy on proper side of level.
Lower plenum/core flow area	AAP(3)	AJUN/(SCALE)	User specifies junction to be scaled.
Bypass/upper plenum flow area	ABUP	AJUN/(SCALE)	User specifies junction to be scaled.
Core/upper plenum flow area	AFUP	AJUN/(SCALE)	User specifies junction to be scaled.
Loss coefficient	XK	FJUNF,AJUN	Finds junction leaving node, XK=2*32.174*FJUNF*AJUN**2
Relative axial fuel rod power	PL	QFRAC	From user supplied slab to axial fuel node table, normalized to heated length.
Total power of assembly	POWER	POWER/(SCALE)	
Wall temperature	TWAL	TP	User specifies heat slab; code selects correct surface.

TABLE III (Cont'd)

VARIABLE DESCRIPTION	TO NORCOOL	FROM TWRAM OR (NORCOOL)	REMARKS
Outer radius of fuel nodes	RS	XDCR	Divides fuel pellet outer radius in equal spacings.
Size of gas gap	DGAB	XDCR	Calculates width of region 2 in slab geometry.
Cladding thickness	DC	XDCR	Calculates width of region 3 in slab geometry.
Diam. of rods	DROD		DROD=2*(RS(out)+DC+DGAB)
Temperature for clad and channel	TC	TP	User assigns slab to group/axial level. For clad, calculates ave. temp. in slab region 3; for channel, takes left and right surface temp.
Drywell pressure	PPT	P	User identifies drywell vol.
Time at end of blowdown	TIO	TIMEX	
Height to bottom of diffuser	HLP	(Z)	User specifies node for bottom of diffuser.
Correlation parameters	PAR	'VHEATCAP', 'THERCOND'	User provides correspondence between *'WRAP.INPUT.MATLTABL'* tables of data; code performs least square fit to generate coefficients.
Clad emissivity	EPSI	EC	

In a typical LOCA calculation, NORCOOL is executed when end of critical flow at the break occurs in the blowdown. At that time, the void fractions are essentially unity everywhere in the system except in the nodes close to the spray injection point and in the lower plenum. To model this situation, the interface defines a pseudo-water level at the bottom of the lower plenum, by volume averaging and collapsing void fractions required for NORCOOL to function properly. The void fraction is defined as zero below the pseudo-level and unity above it. In all other nodes, the true void fraction is extracted from the data base.

E. NORCOOL/MOXY

The data interface between NORCOOL and MOXY consists of the following quantities: the hottest plane number, its elevation from the core bottom, and the time at which the quench front in the core reached the hottest plane. The latter time is used in MOXY to complete the specification of convective heat transfer coefficients according to Appendix K[1] rules.

VI. HOPE CREEK TEST PROBLEM

To demonstrate the complete capability of the WRAP-BWR-EM system, a LOCA analysis was performed for the Hope Creek Plant (a BWR/4 system). The accident model represents a 200% double-ended recirculation line break for an early-in-life power profile. The initial power was 3388 MW(th). The reactor core consists of 764 8x8 fuel rod bundles. Sixty-two fuel rods plus two water rods are modeled in each bundle.

A. WRAP Nodalization

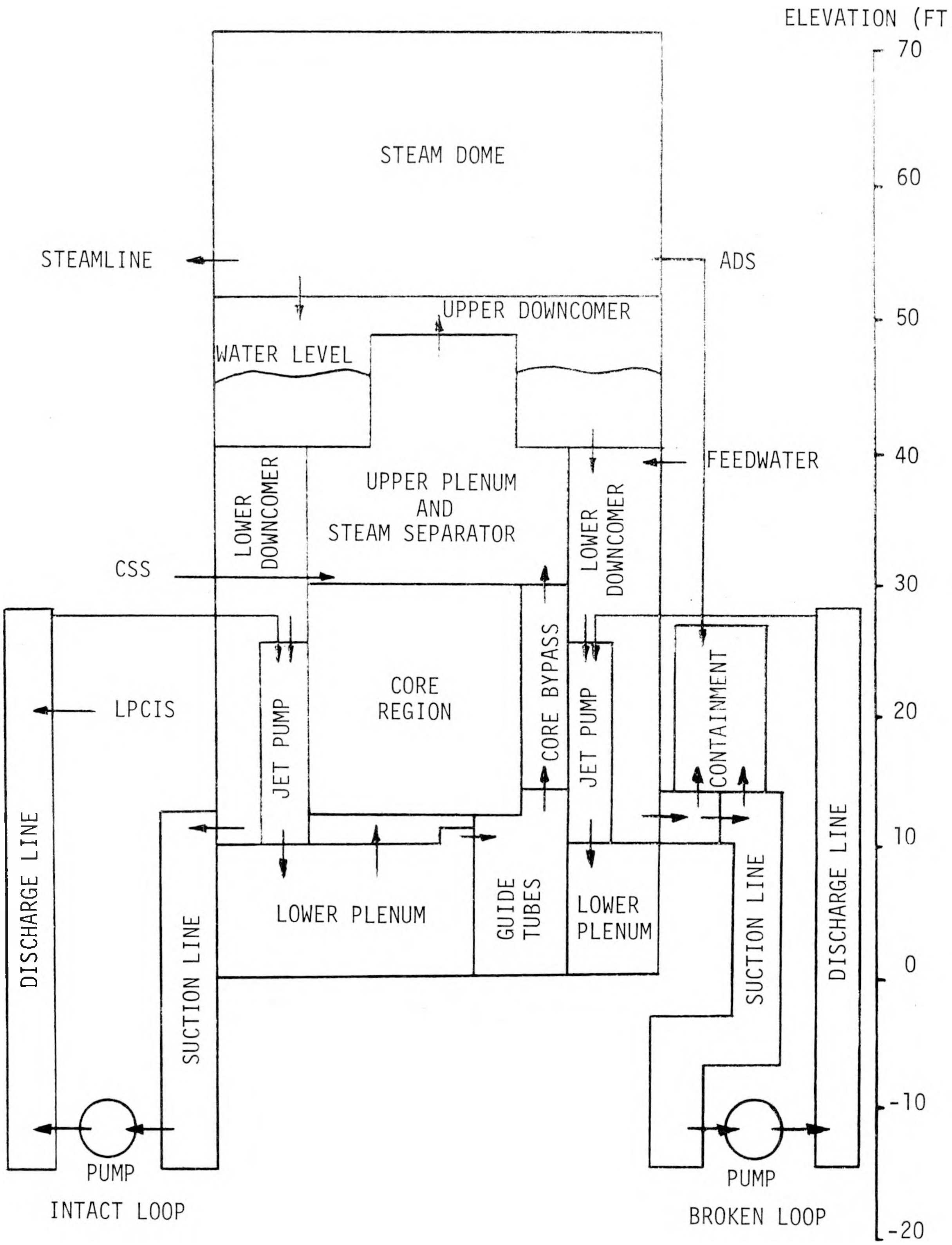
The nodalization used during blowdown to describe the Hope Creek BWR System is given in Figures 3 to 8. The model consists of 32 volumes, 43 junctions, and 34 heat slabs.

The system is divided into three parts as shown in Figure 4. The part "HINTLOOP", Figure 5, represents the intact loop which includes recirculation suction lines, recirculation pumps, and recirculation discharge lines. The part "HREACTOR", Figure 6, corresponds to the reactor primary. A more detailed description of the core region (i.e., the subpart "HCORE") is shown in Figure 7. The part "HBRKLOOP", the broken loop, shown in Figure 8, represents a recirculation suction line, a recirculation pump, a recirculation discharge line, a break volume, and the containment.

B. NORCOOL Nodalization

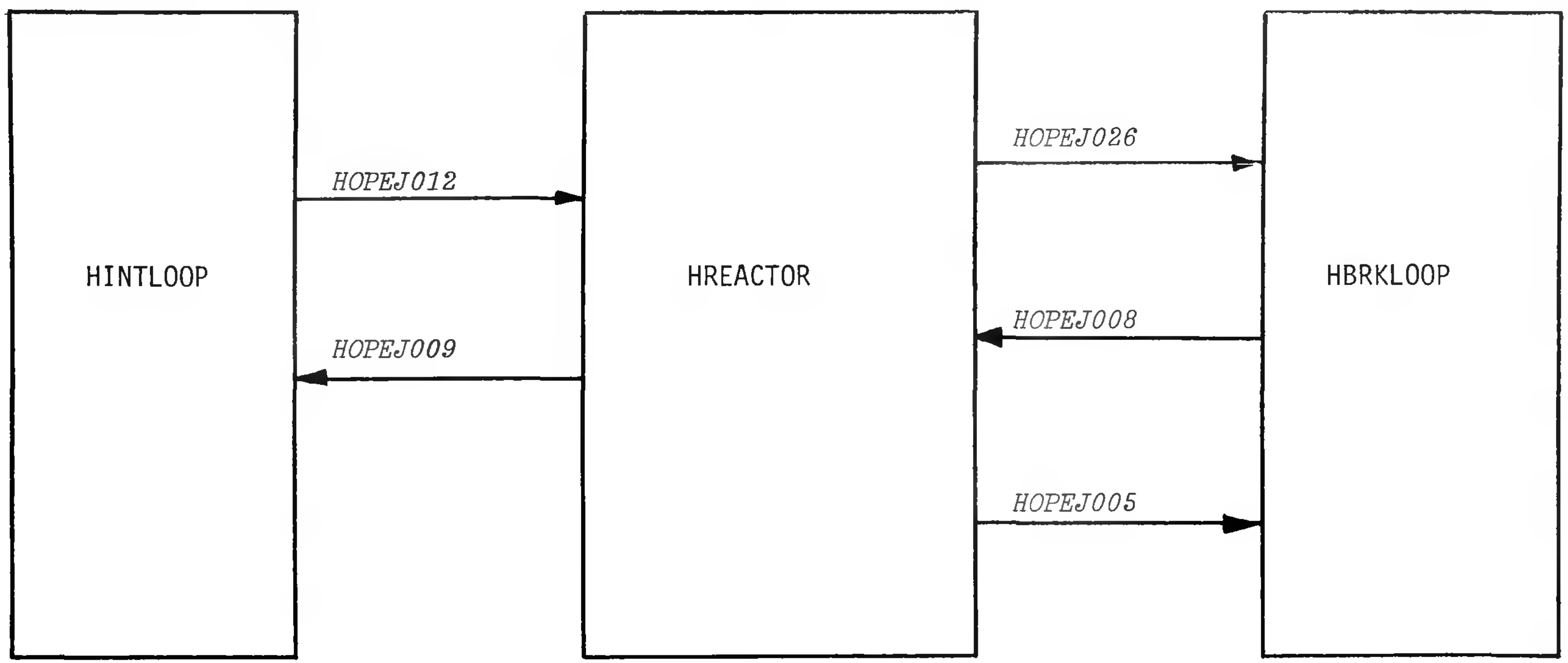
The nodalization used during reflood to specify the WRAP/NORCOOL transfer is shown in Figure 9. The nodalization is specified by assigning a WRAP element name to a NORCOOL node number (see Table IV). An automatic subdivision is carried out by the interface whenever multiple nodes are assigned the same name.

FIGURE 3



HOPE CREEK SYSTEM MODEL

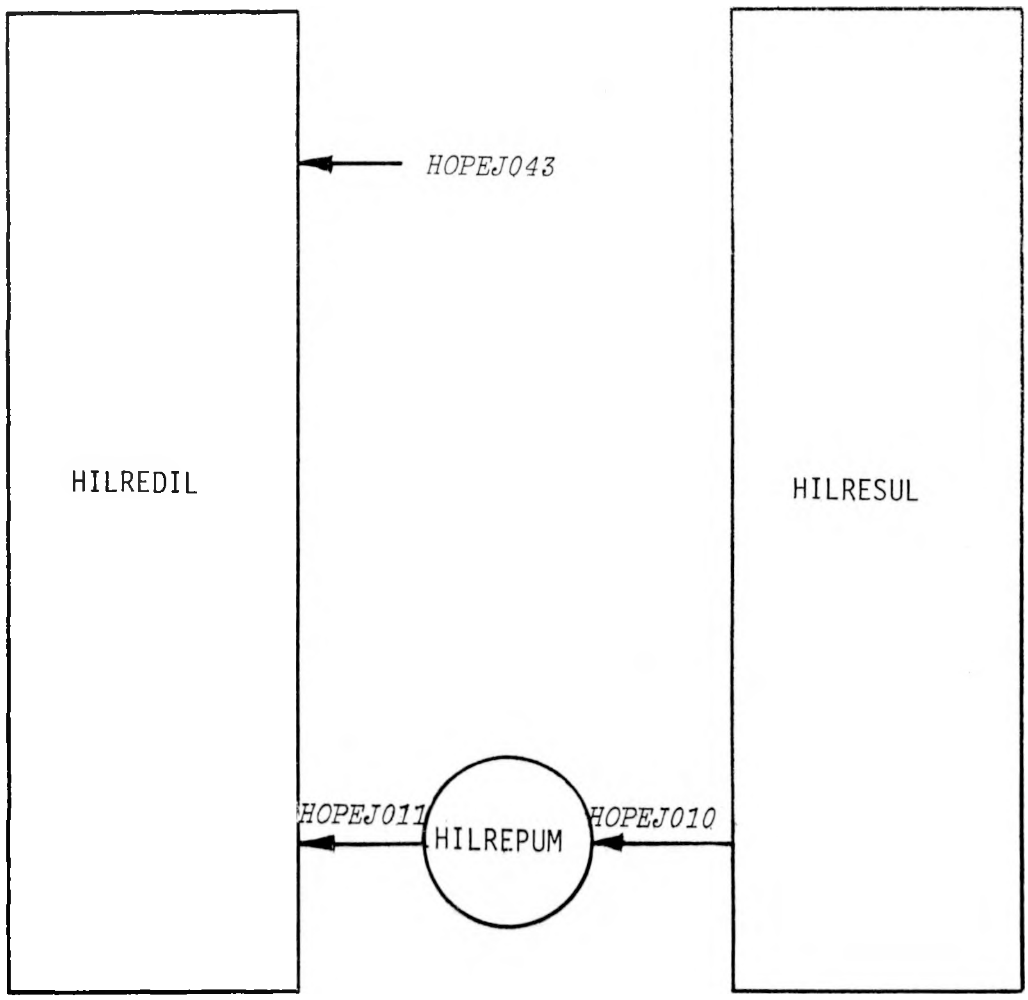
FIGURE 4



NOTE: PART
JUNCTION

SYSTEM PARTS STRUCTURE

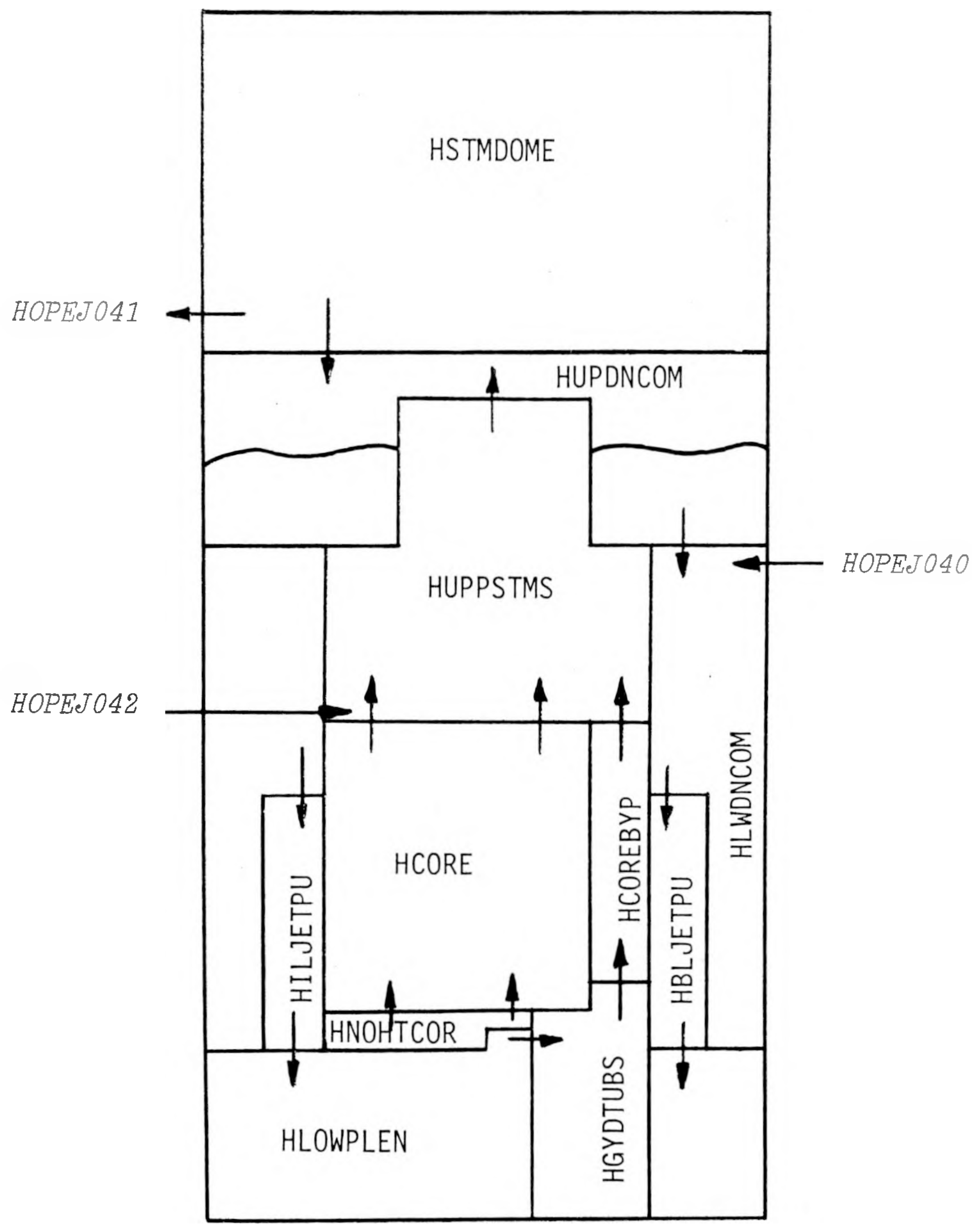
FIGURE 5



NOTE: VOLUME
JUNCTION

PART HINTLOOP

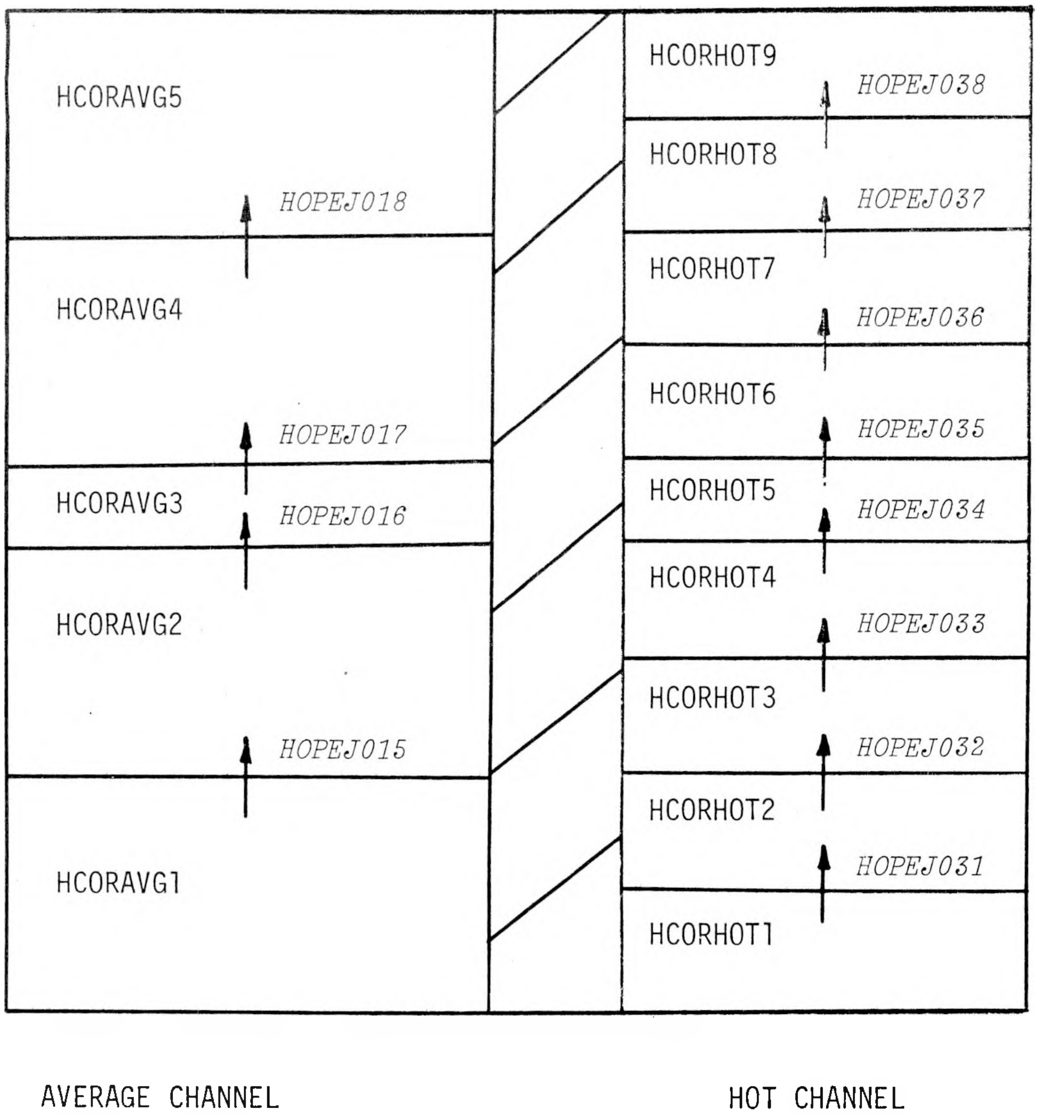
FIGURE 6



NOTE: VOLUME
JUNCTION

PART HREACTOR

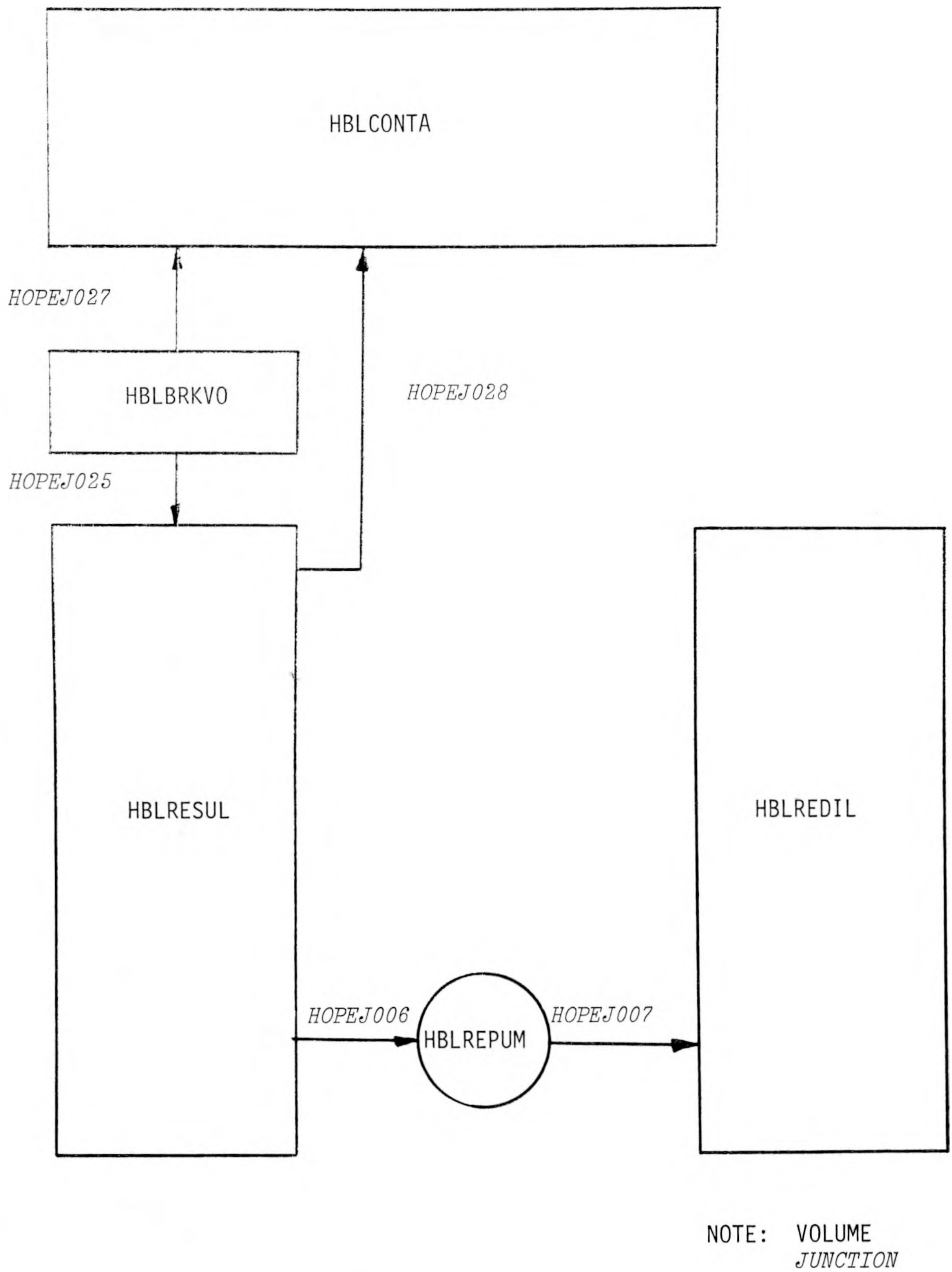
FIGURE 7



NOTE: VOLUME
JUNCTION

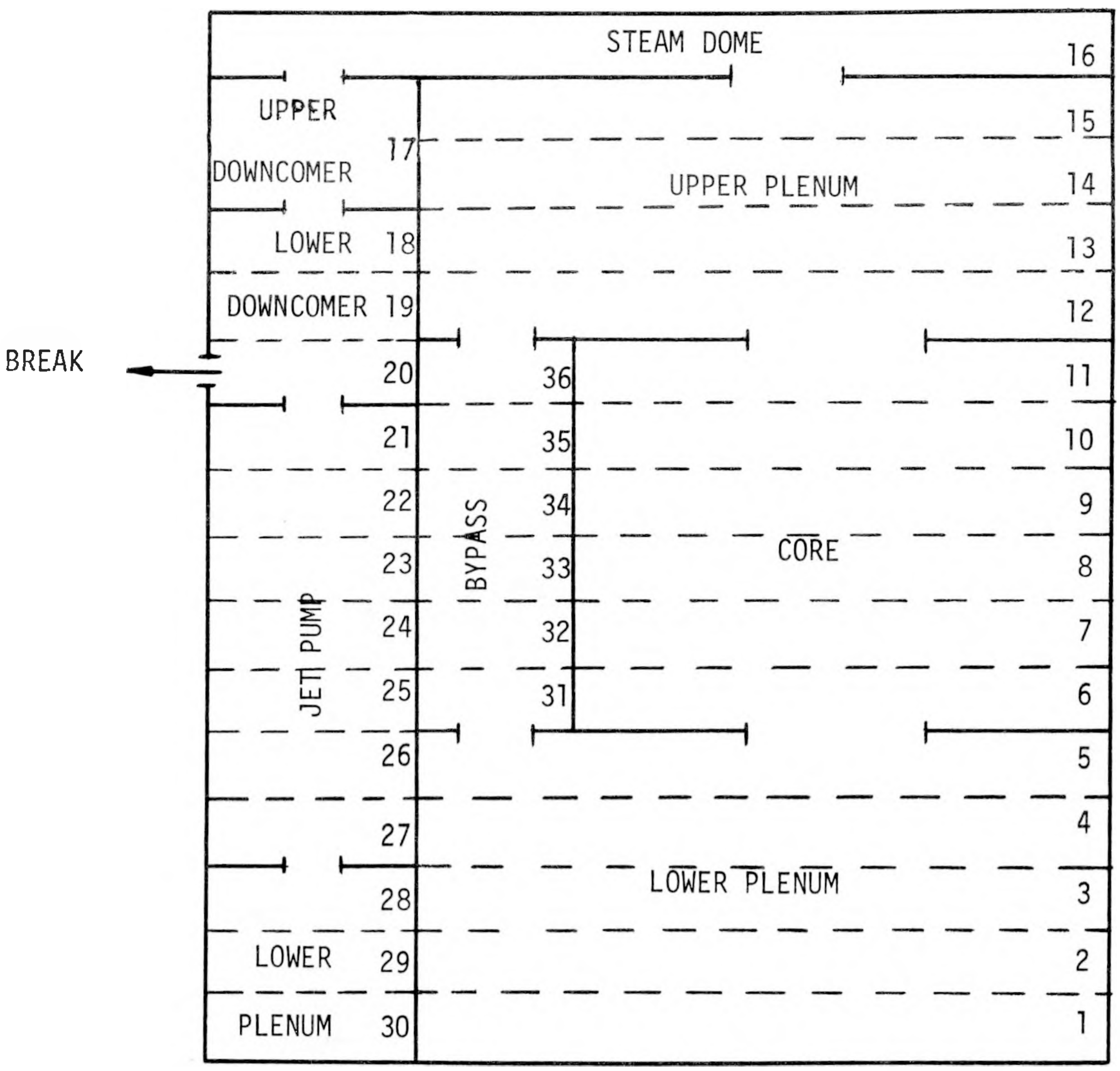
SUBPART HCORE

FIGURE 8



PART HBRKLOOP

FIGURE 9



SCHEMATIC OF NORCOOL NODALIZATION
(not to scale -- see Figure 1 for elevations)

TABLE IV

Correspondence between WRAP and NORCOOL Nodalization for Hope Creek Test Problem

NORCOOL Node Number	WRAP Volume Name
1	HLOWPLEN.HREACTOR
2	"
3	"
4	"
5	"
6	HNOHTCOR.HREACTOR
7	HCORAVG1.HCORE
8	HCORAVG2.HCORE
9	HCORAVG3.HCORE
10	HCORAVG4.HCORE
11	HCORAVG5.HCORE
12	HUPPSTMS.HREACTOR
13	"
14	"
15	"
16	HSTMDOME.HREACTOR
17	HUPDNCOM.HREACTOR
18	HLWDNCOM.HREACTOR
19	"
20	"
21	HBLJETPU.HREACTOR
22	"
23	"
24	"
25	"
26	"
27	"
28	HLOWPLEN.HREACTOR
29	"
30	"
31	HCOREBYP.HREACTOR
32	"
33	"
34	"
35	"
36	"

NORCOOL Node Number	WRAP Core Slab	WRAP Can Slab
6	HOPES007.HCORE	HOPES016.HREACTOR
7	HOPES021.HCORE	HOPES016.HREACTOR
8	HOPES022.HCORE	HOPES017.HREACTOR
9	HOPES023.HCORE	HOPES018.HREACTOR
10	HOPES024.HCORE	HOPES019.HREACTOR
11	HOPES025.HCORE	HOPES020.HREACTOR

NORCOOL fuel geometry from WRAP core slab HOPES021.HCORE
NORCOOL drywell pressure from WRAP volume HBLCONTA.HBRKLOOP
NORCOOL spray injection - node 13
NORCOOL flooding injection - node 30

C. Computational Steps

Utilization of the complete WRAP-BWR-EM system for a LOCA analysis for the Hope Creek Plant involved the following steps:

- GAPCON results were obtained for 36 cases representing the fuel pins in the hot bundle plus a 37th and a 38th case representing the "typical" pin in the hot bundle and a "typical" pin in the average bundle.
- WRAPIT was executed with GAPCON data for the hot channel and average channel heat slabs passed to WRAP via the GAPCON/WRAP interface.
- Accessing the WIDS data set generated by WRAPIT, WRIN was used to determine the thermal-hydraulic state of the reactor at the beginning of the LOCA.
- Beginning with the initial state as determined with WRIN, TWRAM was used to analyze the system during the blowdown phase of the transient.
- At the end of blowdown, the thermal-hydraulic state of the system was passed to NORCOOL via the WRAP/NORCOOL interface. The reflood analysis was performed with NORCOOL.
- MOXY was used to analyze the behavior of the hot plane in the hot assembly during blowdown and reflood. The initial pin conditions were obtained from GAPCON via the GAPCON/MOXY interface. Transient hot assembly data during blowdown and reflood were passed to MOXY via the WRAP/MOXY and NORCOOL/MOXY interface, respectively.
- And, plots of the blowdown and reflood phases of the LOCA were made using WROP.

It is important to note that the complete calculation was automated, i.e., no hand transfer or manipulation of data was performed between computational steps.

D. Results

Selected results for the complete WRAP-BWR-EM calculation for the postulated LOCA are presented here. End-of-blowdown was predicted to occur at 60 seconds. The NORCOOL calculation was terminated at 168 seconds.

1. TWRAM

- Steam Dome Pressure - The predicted steam dome pressure is shown in Figure 10. The pressure begins to slowly drop at the time of the break. At four seconds the steam line valves close causing the steam dome pressure to increase. The pressure begins to drop again at eight seconds when the jet pumps uncover. A small pressure rise occurs at nine seconds when the lower plenum flashes. At ten seconds the recirculation line uncovers, and the steam flow out the break becomes large causing a rapid depressurization.

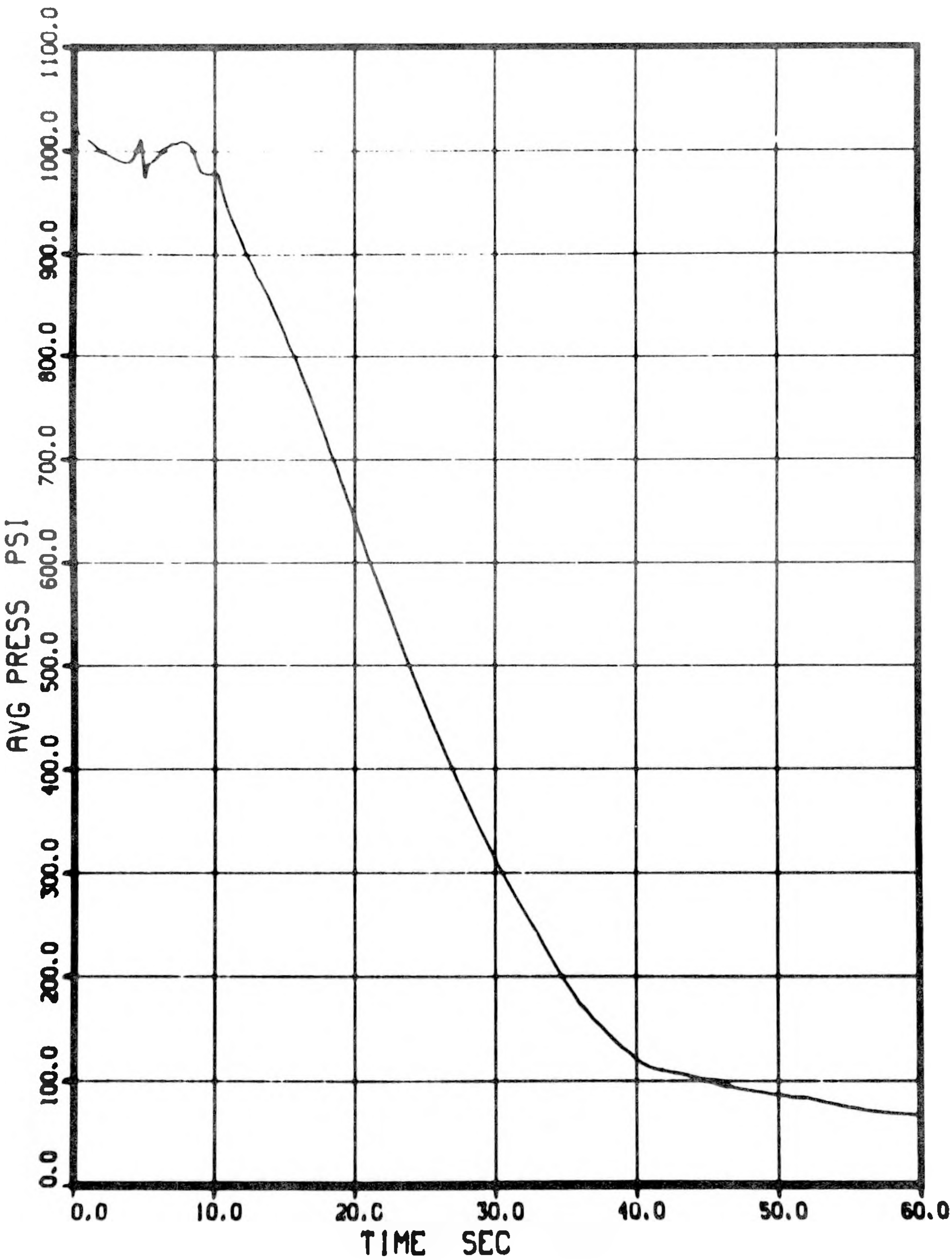
- Break Flow - The vessel side and pump side break flows are given in Figures 11 and 12, respectively. The vessel side break flow jumps to approximately 26,000 LBM/SEC at the time of the break. The flow slowly decreases until ten seconds at which time the recirculation line uncovers. When the recirculation line uncovers the flow at the break becomes high-quality two-phase fluid and the flow rate drops sharply.

  At the time of the break, the pump side break flow jumps to approximately 26,000 LBM/SEC but then rapidly drops because of the high flow resistance in the jet pump. The flow rate increases again when the recirculation pump stops. Beyond one second the flow gradually decreases as the system pressure falls.

- Core Inlet Flow - The inlet flow to the average channel in the core is given in Figure 13. Initially the flow rate decreases rapidly due to decreasing jet pump flow. Between one and eight seconds the core inlet flow increases and decreases as the unheated segment of the core flashes. The flow surge at eight seconds is due to flashing in the jet pump. The surge at ten seconds is caused by flashing in the lower plenum. The core flow then gradually decreases to zero.

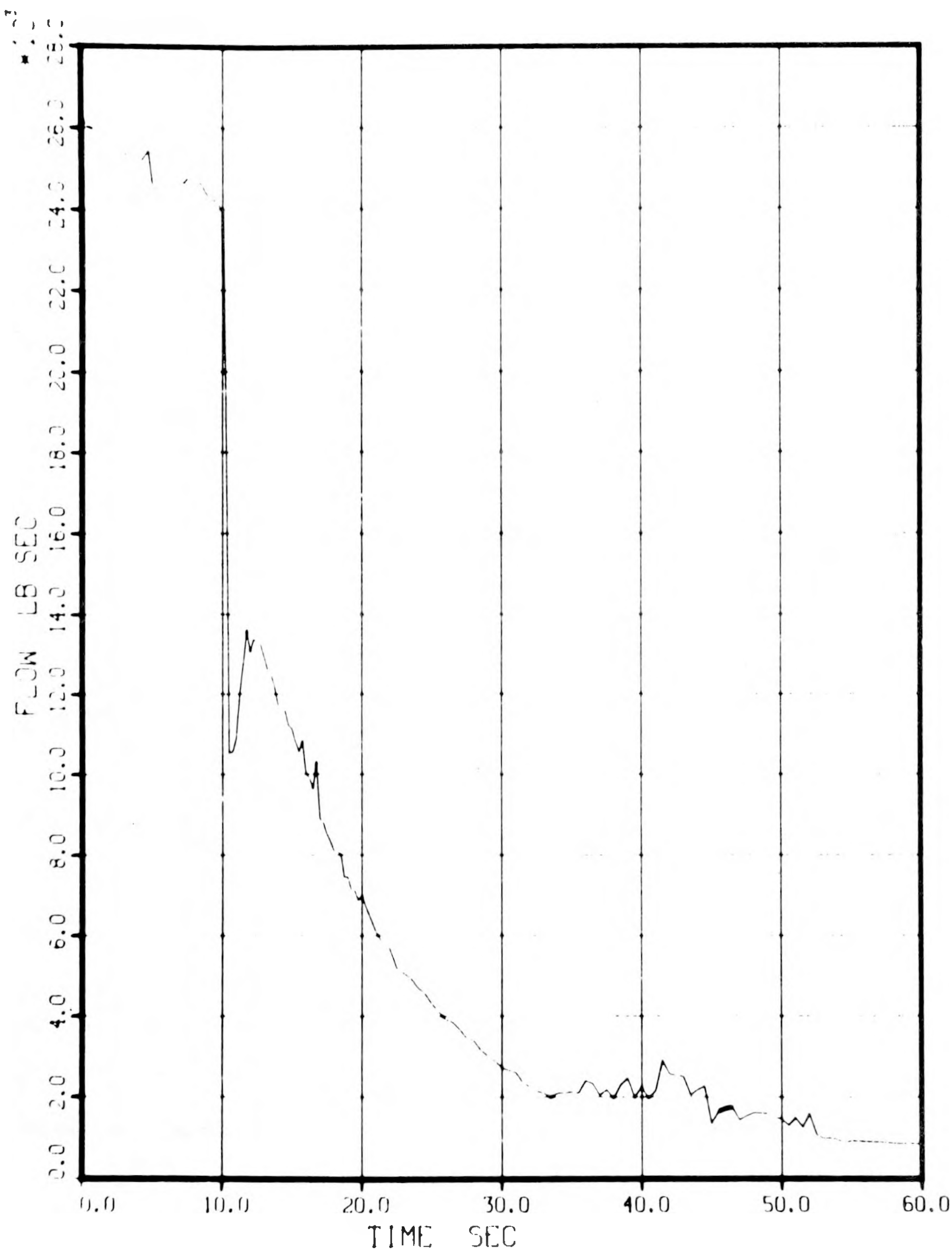
- Fuel Rod Temperature - The fuel rod surface temperature up to the end-of-blowdown for the hot level in the average channel and the hot level in the hot channel are given in Figures 14 and 15, respectively. (The hot level in the hot channel is at an elevation of 9.9 ft. from the bottom of the core.) In general, the core gradually cools for the first 20 seconds. The two surges in the heat slab surface temperatures at two and nine seconds are caused by decreased core flow. After 20 seconds the core coolant flow rate approaches zero and the core begins to heat up. The core spray reaches the hot level at 43 seconds and the core again cools off.

FIGURE 10



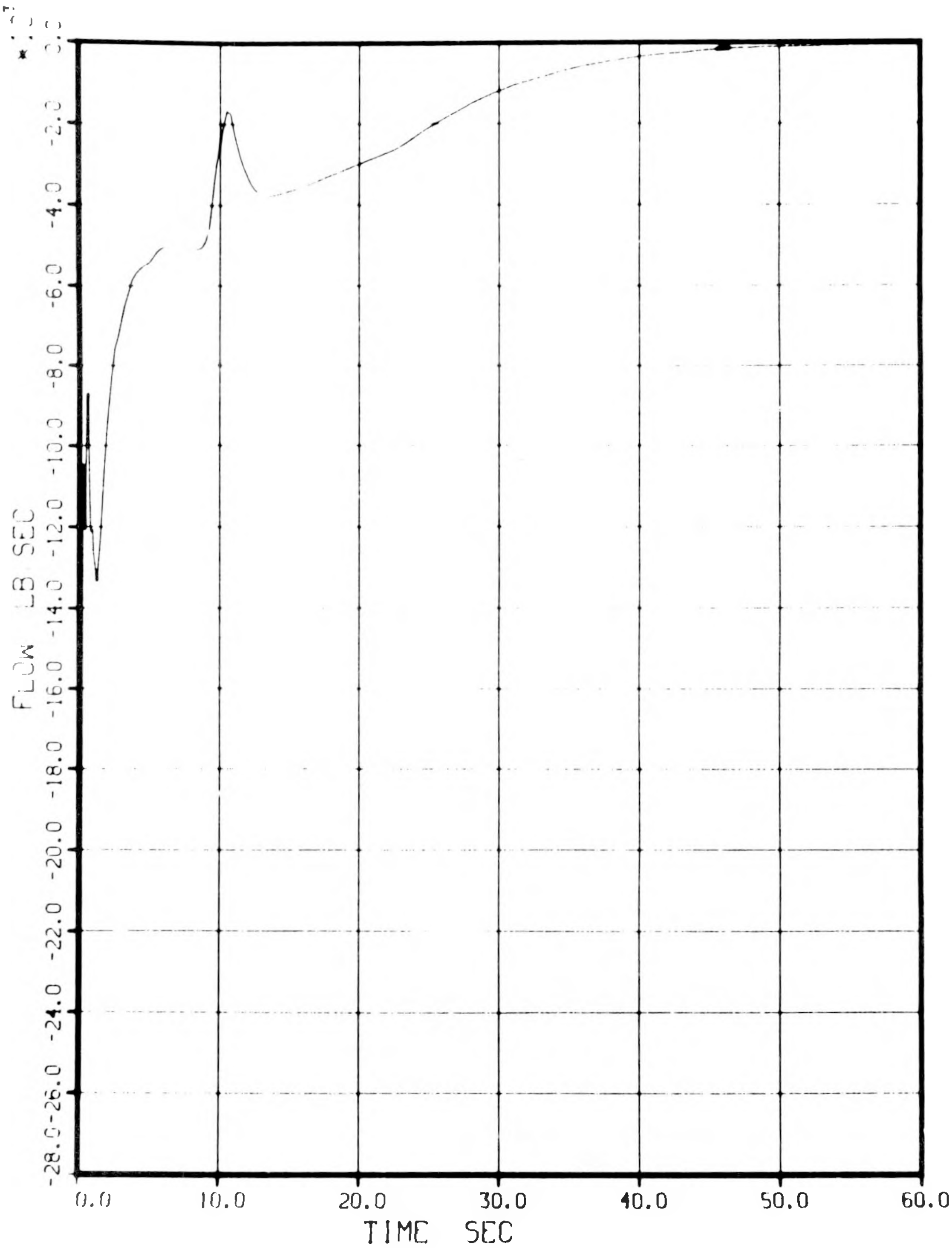
STEAM DOME PRESSURE

FIGURE 11



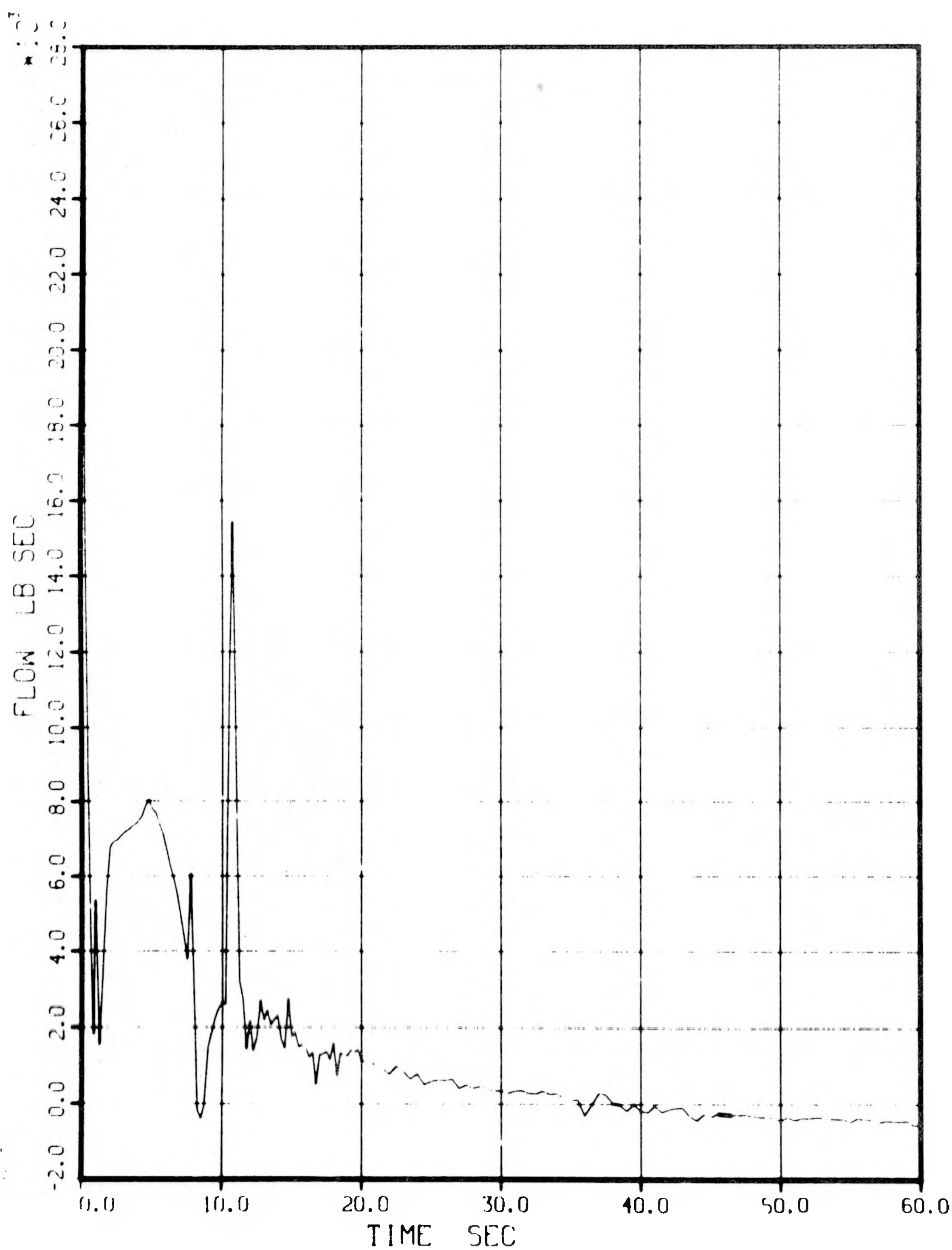
BREAK FLOW-VESSEL SIDE

FIGURE 12



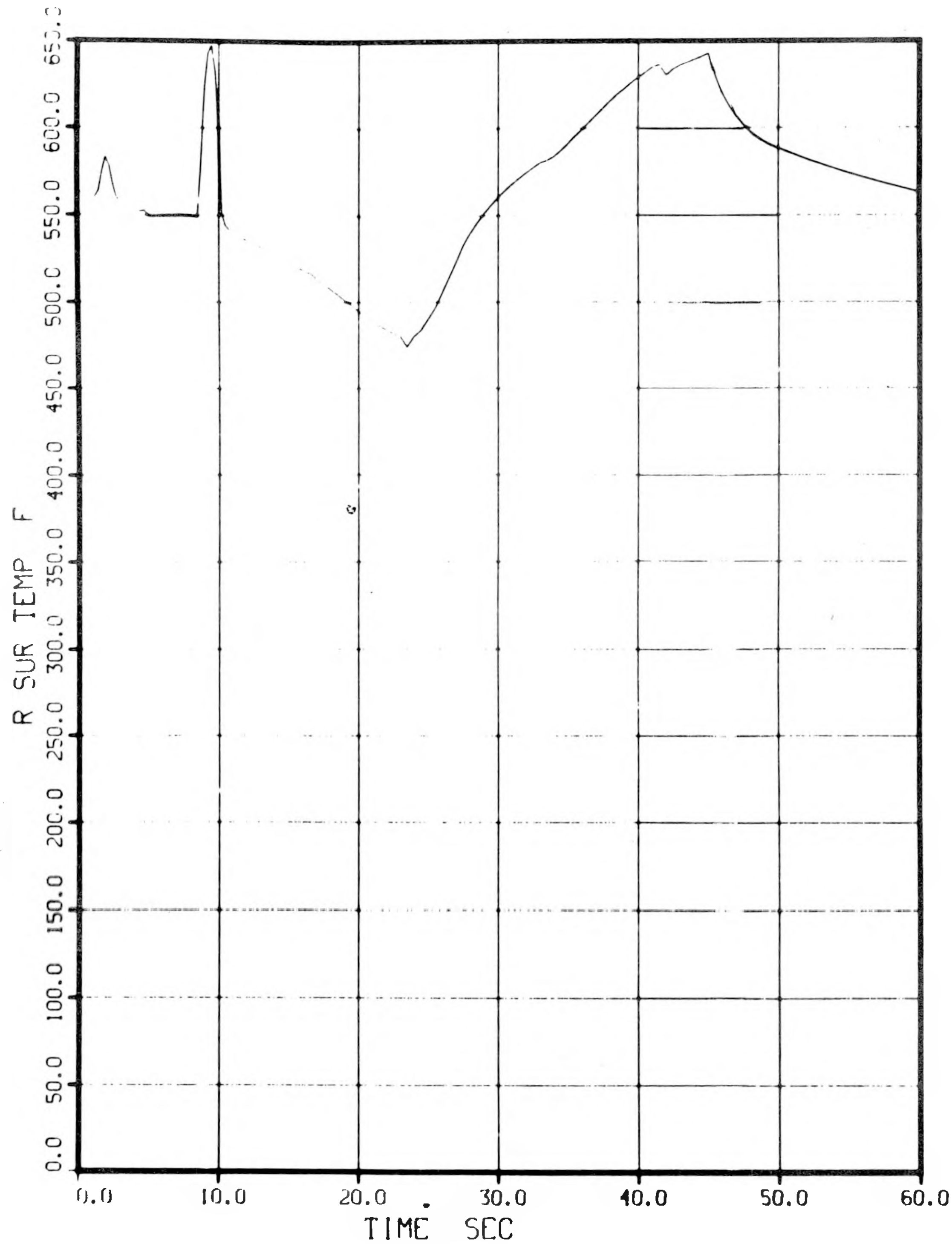
BREAK FLOW-PUMP SIDE

FIGURE 13



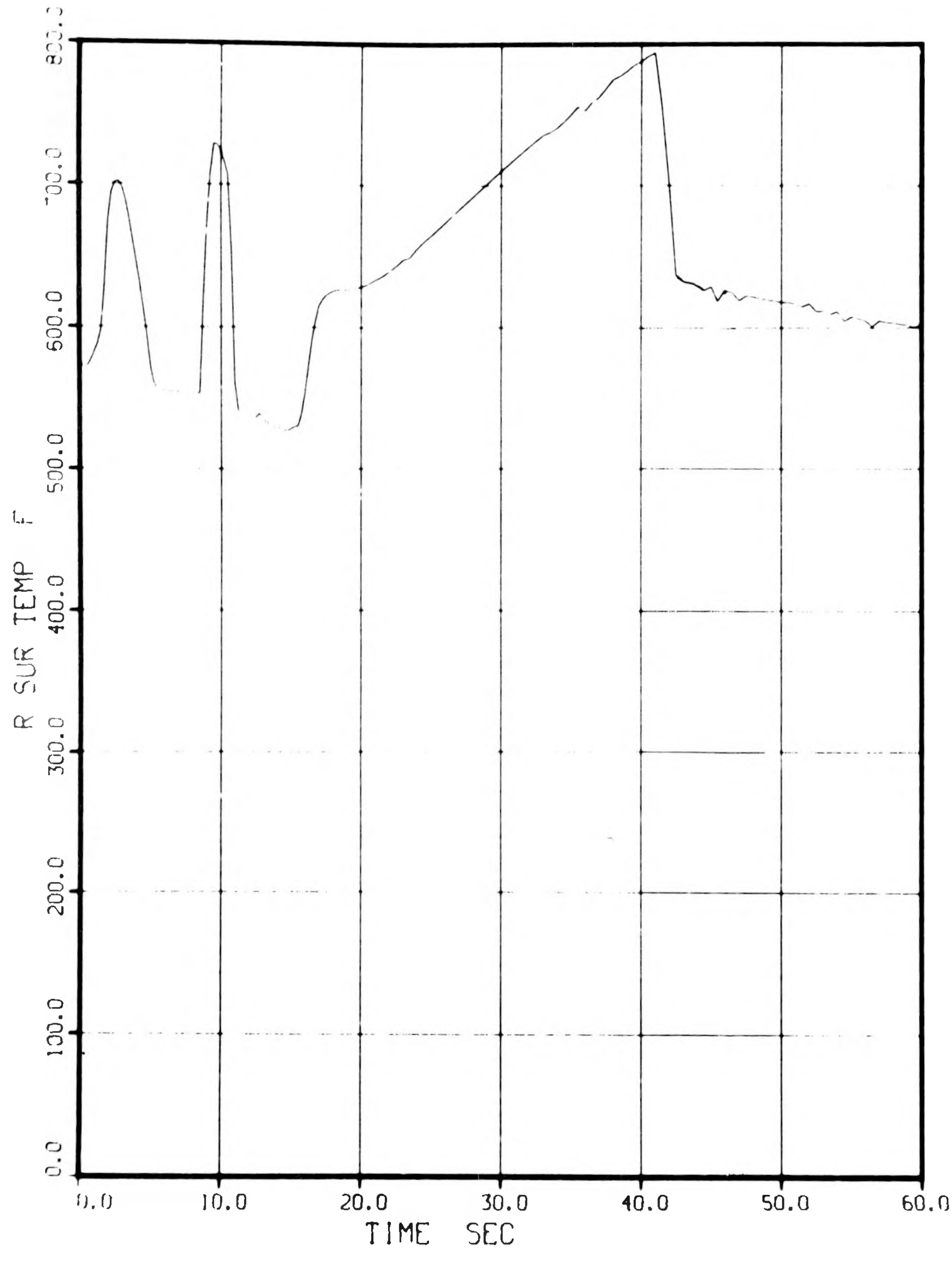
CORE INLET FLOW-AVERAGE CHANNEL

FIGURE 14



FUEL ROD SURFACE TEMPERATURE-AVERAGE CHANNEL-HOT SLAB

FIGURE 15



FUEL ROD SURFACE TEMPERATURE-HOT CHANNEL-HOT SLAB

2. NORCOOL

- Maximum Clad Temperature - The behavior of the maximum clad temperature is shown in Figure 6. At the start of the refill calculation, the temperature is at 293°C (559°F). It drops slowly until 117 seconds, at which time the water level has filled the lower plenum. Thereafter, the temperature drops sharply as the water level and quench front proceed up the core. At 152 seconds, the quench front reaches the position of maximum clad temperature causing a precipitous drop.

- Quench Front Position. The movement of the quench front position up through the core is shown in Figure 17. The core extends from 5.24 m to 9.12 m. Thus, the quench front enters the core at 117 seconds and is at the top of the core at 162 seconds.

- Water Level - The behavior of the water levels is shown in Figures 18, 19, and 20. The movement from the lower plenum to the upper plenum is shown in Figure 18. The lower plenum/core boundary is at 5.24 m while the core/upper plenum boundary is at 9.12 m with the top of the upper plenum at 15.90 m. Four district stages are visible. Up to 117 seconds, the lower plenum fills at a constant rate. From 117 seconds to 127 seconds the core floods at a more rapid rate. At 127 seconds, the water level is at the top of the core; however, the quench front is still only at 6.2 m. From 127 seconds to 144 seconds, the water level remains at the top of the core while the quench front advances. From 144 seconds, the water level moves into the upper plenum. The movement of the water level in the bypass region is shown in Figure 19. The bypass extends from 5.24 m to 9.12 m, thus, it is filled at 144 seconds. The behavior of the water level in the diffuser region is shown in Figure 20. The break is located at 7.84 m, thus, by 168 seconds, the water level is at the top of the diffuser and spilling out the break.

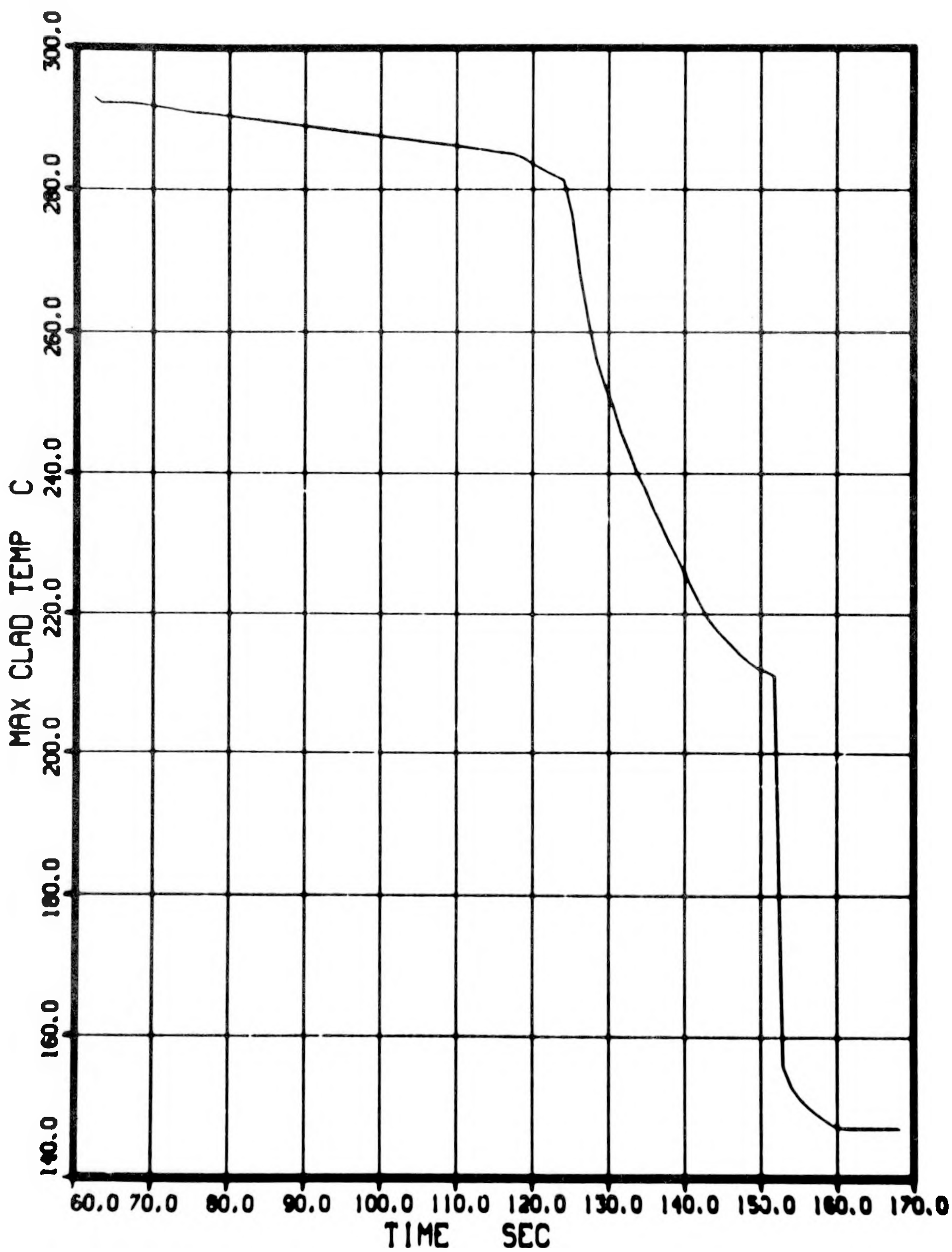
3. MOXY

The fuel rod surface temperature and centerline temperature for the hot pin in the hot channel are given in Figures 21 and 22, respectively. Beyond the end of lower plenum flashing (20 seconds), the rod temperature increases until the quench front reaches the hot plane at 140 seconds.

4. COMPUTER TIME AND STORAGE

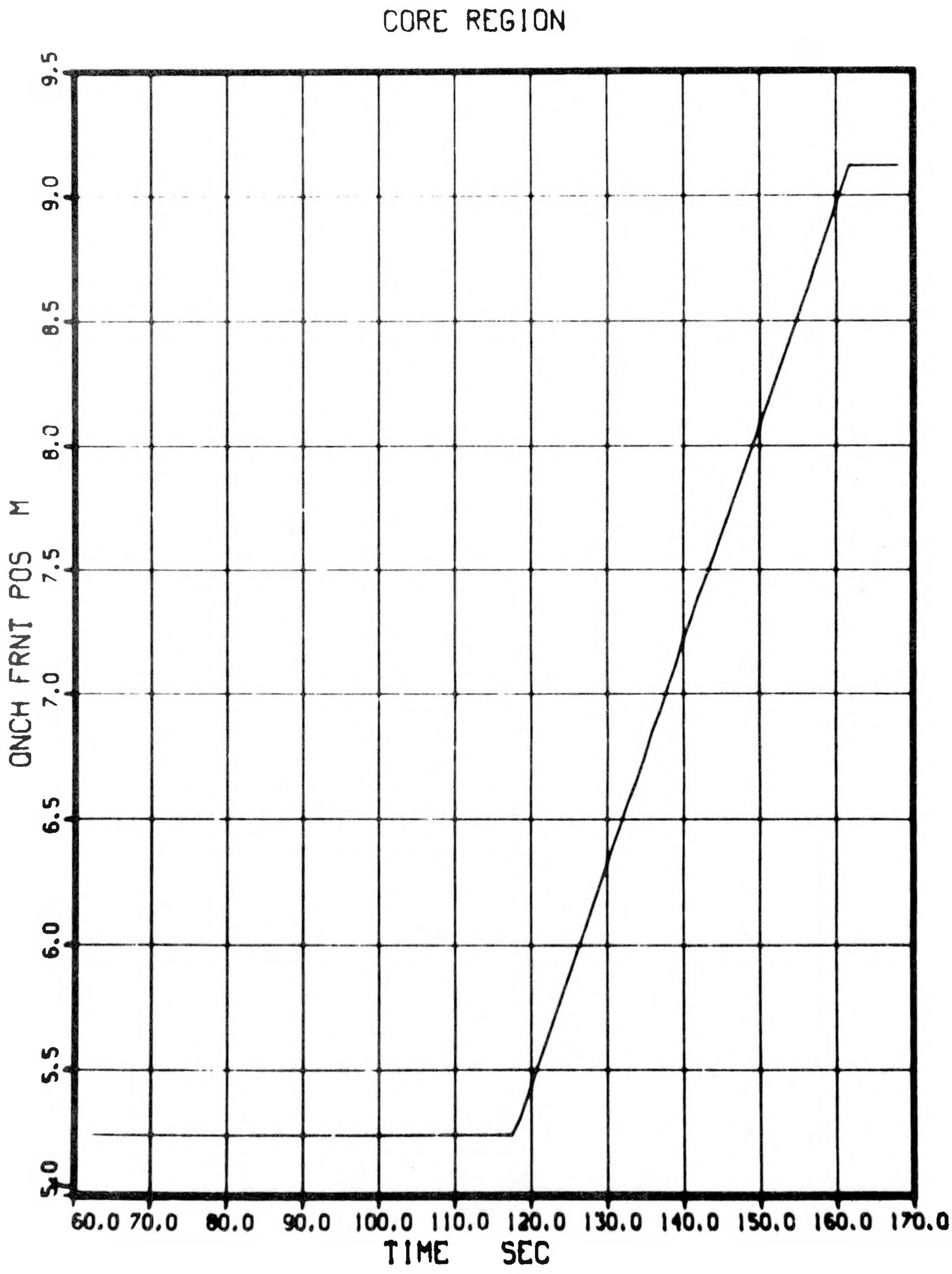
The CPU time and storage requirements for the various steps in the complete calculation are given in Table V. The calculations were performed on an IBM 360/195 computer.

FIGURE 16



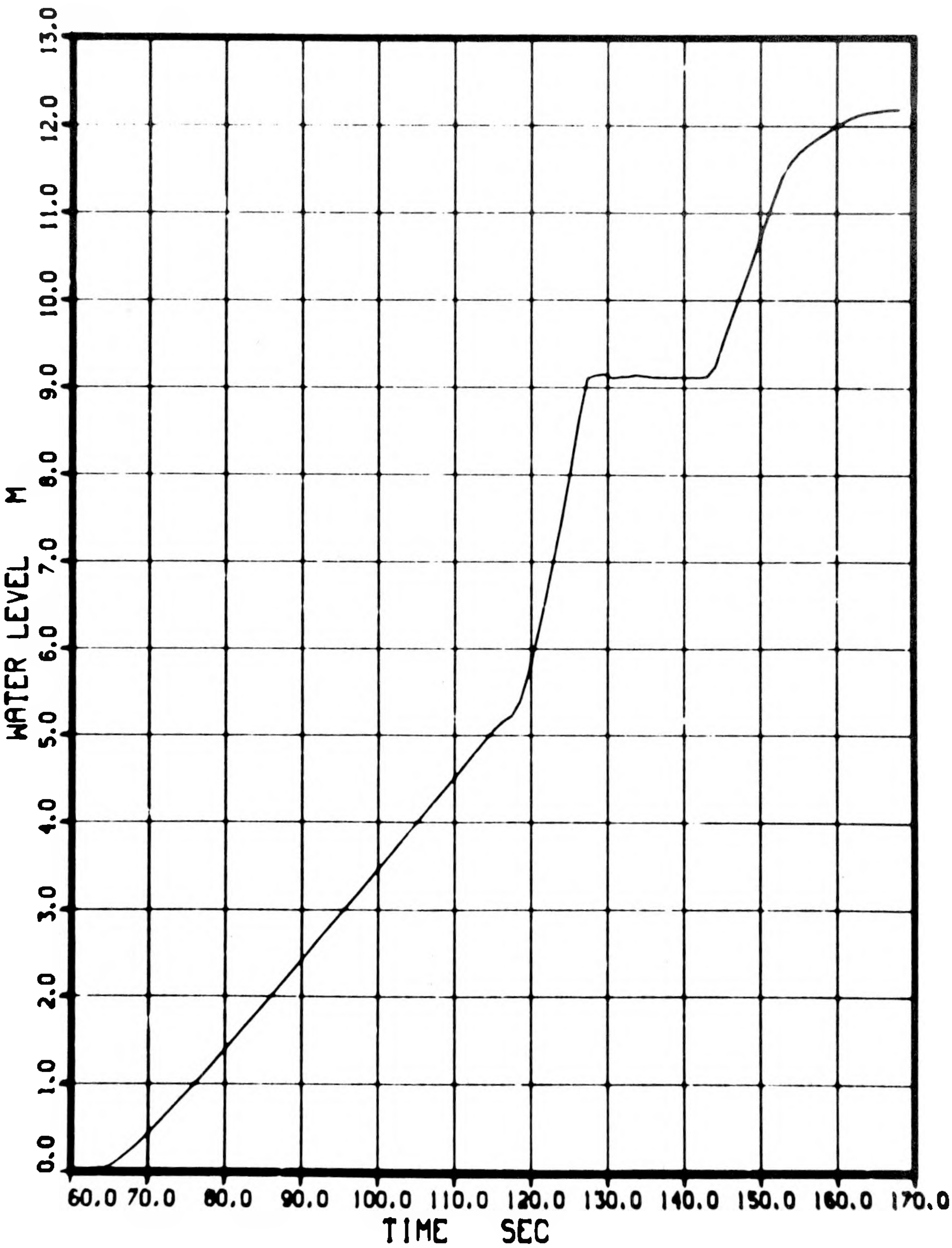
MAXIMUM CLAD TEMPERATURE

FIGURE 17



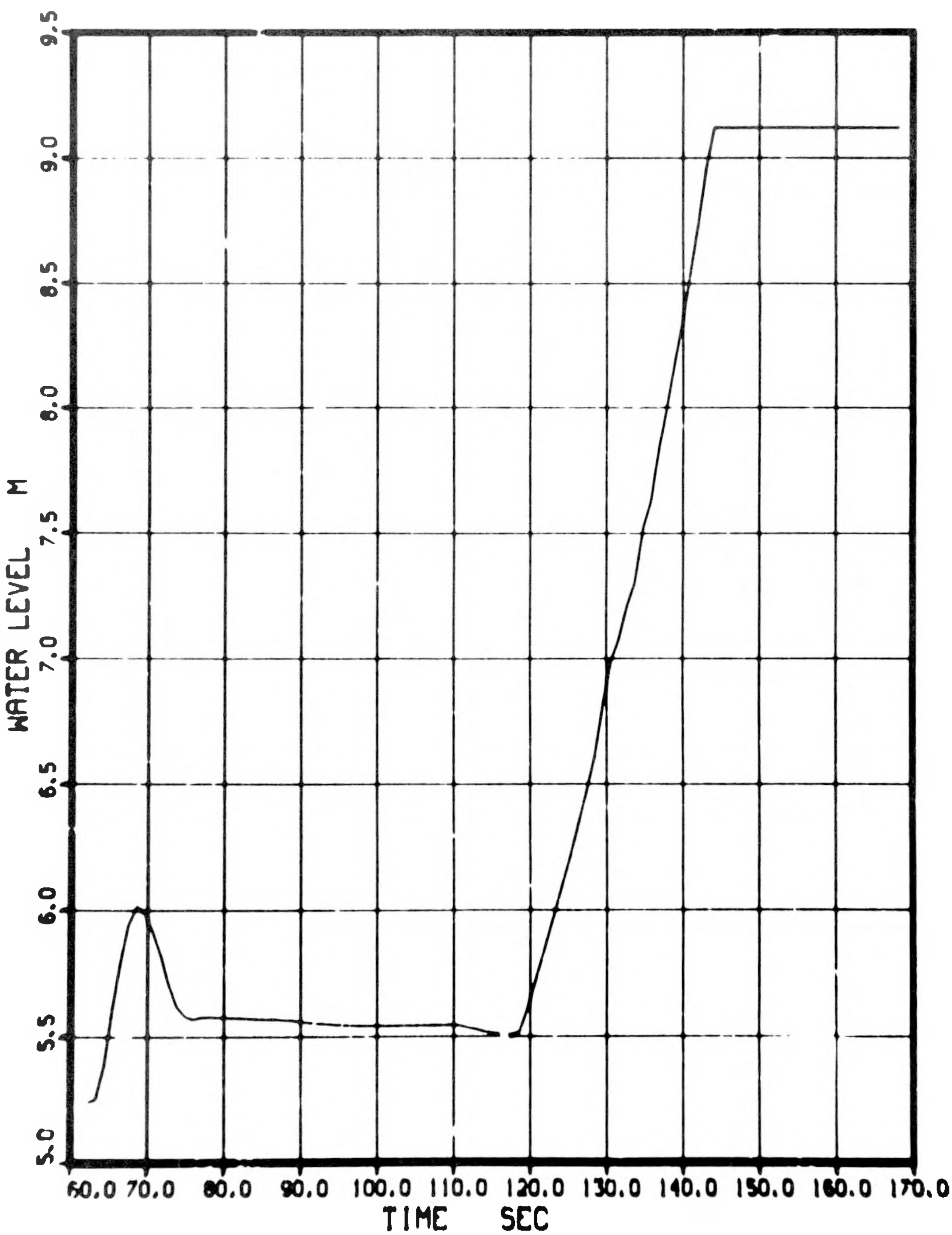
QUENCH FRONT POSITION

FIGURE 18



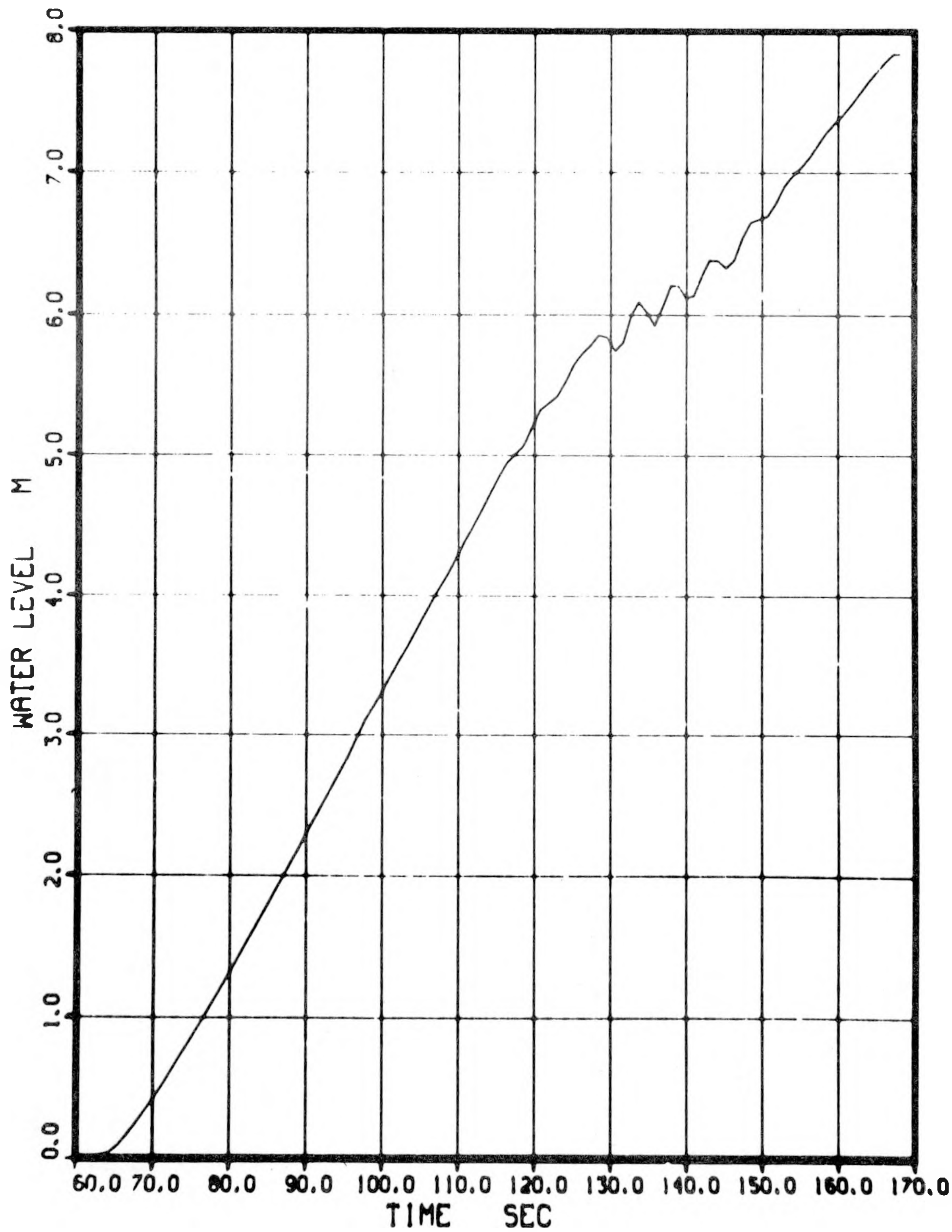
WATER LEVEL IN LOWER PLENUM, CORE, AND UPPER PLENUM

FIGURE 19



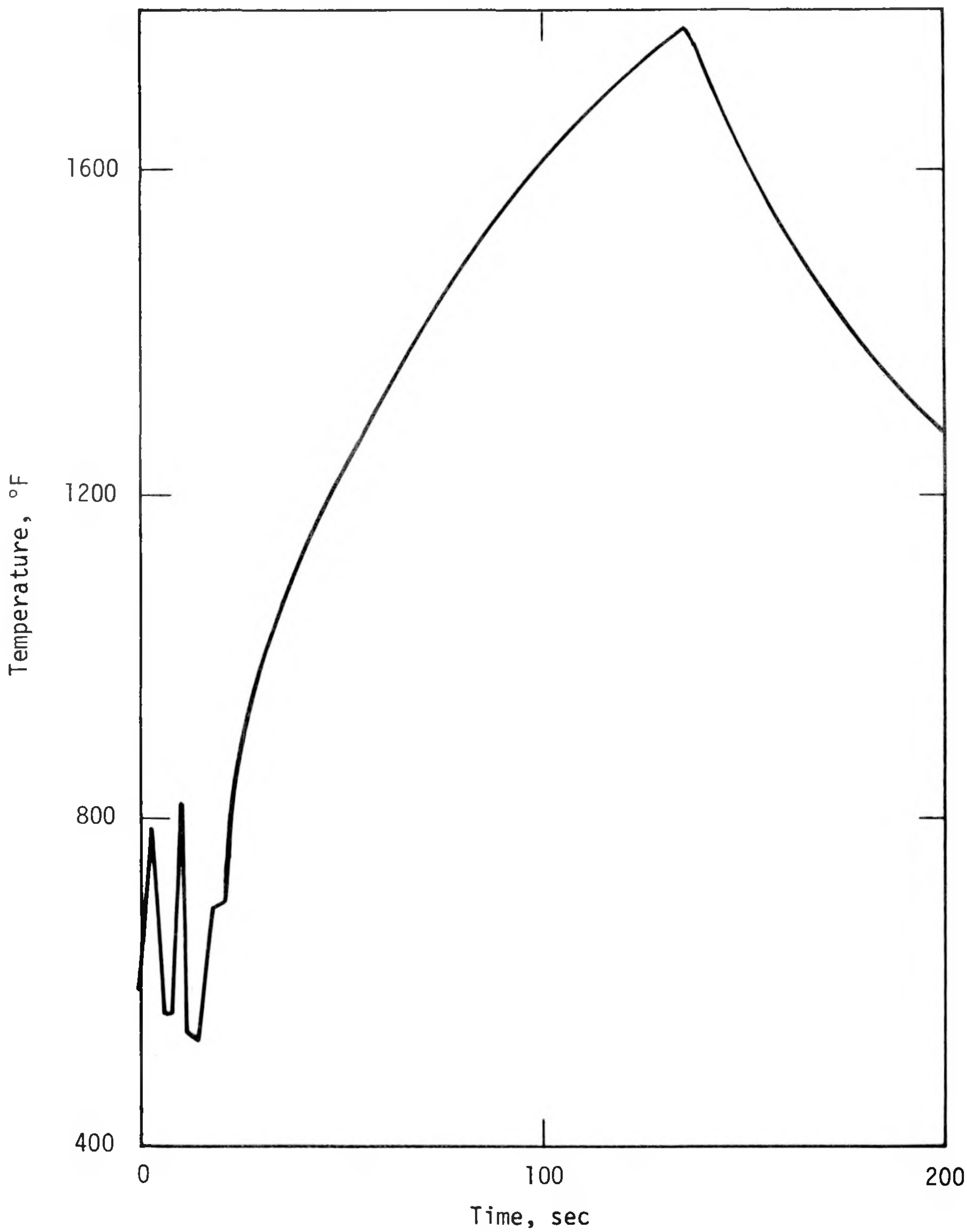
WATER LEVEL IN BYPASS

FIGURE 20



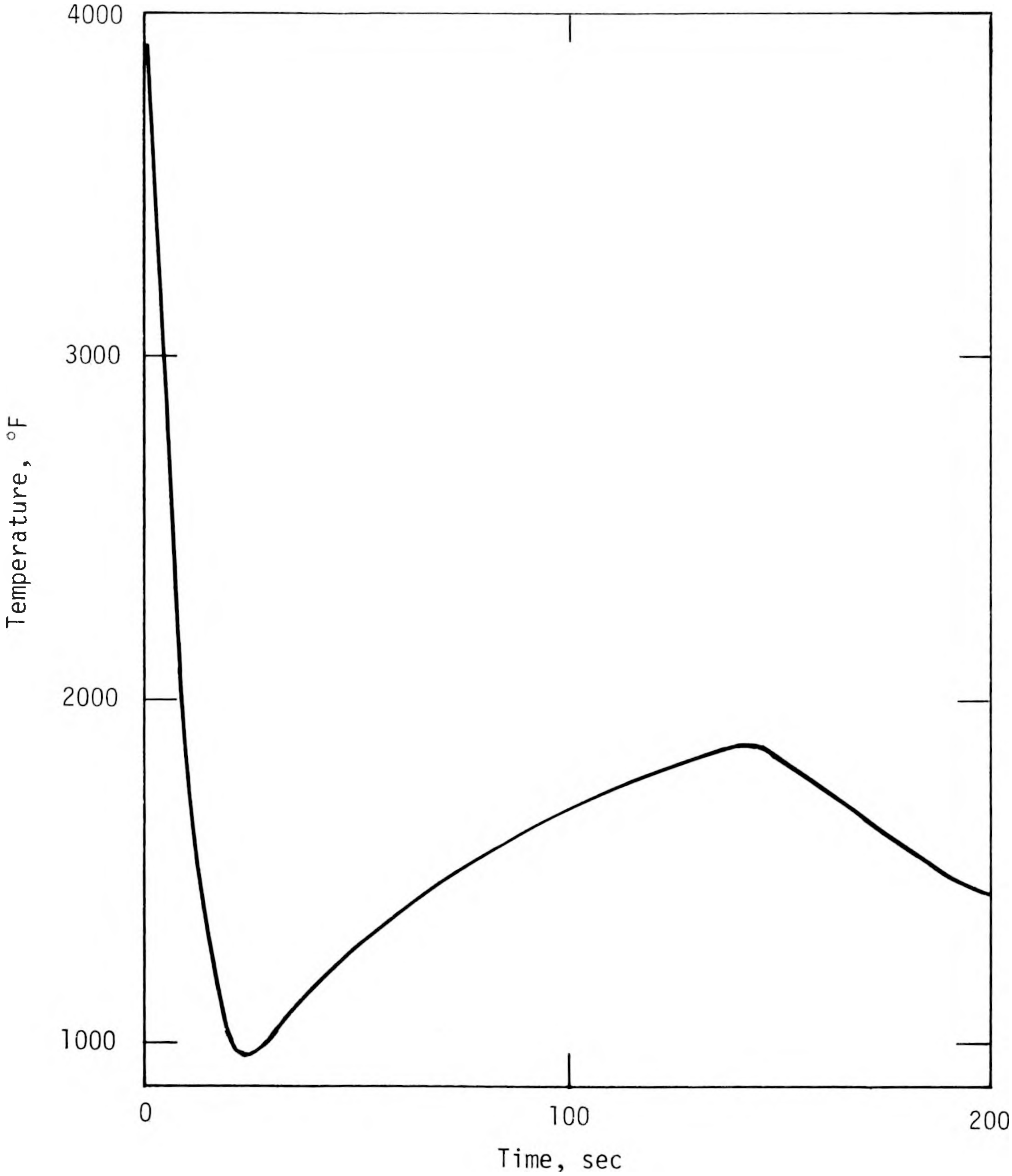
WATER LEVEL IN DOWNCOMER AND DIFFUSER

FIGURE 21



FUEL ROD SURFACE TEMPERATURE -
HOT CHANNEL - HOT PIN - HOT LEVEL

FIGURE 22



FUEL ROD CENTERLINE TEMPERATURE -
HOT CHANNEL - HOT PIN - HOT LEVEL

TABLE V

Computer Requirements

Step	CPU Time	Core Size
GAPCON (38 cases)	19.0 min	500 K bytes
WRAPIT (with GAPCON/WRAP interface)	0.7	700
WRIN	0.3	800
TWRAM	181.7	1000
NORCOOL (with WRAP/NORCOOL interface)	6.0	600
MOXY (with GAPCON/MOXY, WRAP/MOXY, and NOORCOOL/MOXY interfaces)	3.5	1200
WROP (for TWRAM)	6.5	1000
WROP (for NORCOOL)	2.0	600
Total CPU Time	219.7 min	

VII. WRAP-EM AVAILABILITY AND INSTALLATION REQUIREMENTS

The WRAP-EM System has been developed for operation under the JOSHUA Operating System[5]. JOSHUA was developed at SRL in 1968 and 1969 and has been in production use since 1970 on IBM computers. Associated with the JOSHUA system is a CRT terminal system which provides facilities for problem setup and modification as well as job execution. For IBM computers having no terminal facilities, a JOSHUA Terminal Simulator[3] has been developed to simulate JOSHUA operations via card input for execution in the batch mode. Currently, a CDC-compatible version of the JOSHUA system does not exist; however, an effort is in progress at SRL to develop JOSHUA-II. This new operating system is being designed to facilitate conversion to CDC computers.

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