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VOLUME I
UC-77

CASY - A DYNAMIC SIMULATION OF THE GAS COOLED FAST BREEDER REACTOR CORE AUXILIARY COOLING SYSTEM

VOLUME I: TECHNICAL DISCUSSION

by
JAYCOR
Del Mar, California

MASTER

Prepared under
Contract DE-AT03-76SF71023
for the San Francisco Operations Office
Department of Energy

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PREFACE

This report was prepared by JAYCOR of Del Mar, California in partial fulfillment of General Atomic Company Purchase Order No. 614990. It completely describes the model development and digital computer code for a dynamic simulation of a gas-cooled fast breeder reactor (GCFR) emergency core cooling system. This report is in two volumes:

Volume I - Technical Discussion
Volume II - Example Computer Run

The simulation described in this report represents the initial version of the development of an overall core auxiliary cooling system (CACS) dynamic simulation capability. The basic objective of this simulation development is to provide accurate predictions of overall system dynamic responses under anticipated operating conditions. Although this capability is primarily being developed to use in the design and analysis of CACS control systems, it will also be suitable for use in other system development areas (i.e., operating procedure definition, failure analysis, operating evaluation, system design studies, etc.).

The system's three independent cooling loops are modeled as a single equivalent loop on both the primary coolant (helium) side and the secondary coolant (water) side using lumped parameter modeling techniques. Since the purpose of this system is residual heat removal from the shutdown reactor, the core model does not include reactor kinetics. The emphasis in this modeling development was on the accurate prediction of component input/output relationships over a wide range of operating characteristics. This is an open loop plant simulation in the sense that the plant control systems, or control loops, are not incorporated. If these control systems are required, specific configurations must be supplied by the user.

The digital computer code for the CACS simulation is contained in the catalog file CACSSM*SEP77. The table of contents of this file is listed below.

Program Element Name

PROG

RUN

MAP

The program element name PROG contains the SYSL* code of the corresponding simulation. The program element names RUN and MAP contain the computer system control statements needed to execute the simulation on the UNIVAC 1110 digital computer. The RUN and MAP statements are listed below.

---

*Estrine, E. A., "System Simulation Language (SYSL) User's Guide," General Atomic Report GA-D14439, May 1978.

CACSSM*SEP77.RUN

```
@PRT,CS CACSSM*SEP77.PROG
@ASG,A  BIG*FOR.
@ASG,A SYSL*SIM.
@ASG,A SYSL*TRAN.
@ASG,T 3,F
@ASG,T 4,F2
@ASG,T 7,F2
@ASG,T 8,F2
@XQT SYSL*TRAN.SYSLTRAN
@ADD,P CACSSM*SEP77.PROG
@ADD,P 7.
```

CACSSM*SEP77.MAP

```
@ASG,X IC*CASY.
@ASG,A CALCOMP*BASIC.
@USE 12.,IC*CASY.
@MAP  ,SYSLSIM
   IN TPF$.
   IN SYSL*SIM.MAIN
   IN GCFR*SYSL.STEADY
  LIB SYSL*SIM
 LIB CALCOMP*BASIC.
   IN SSCOM
@XQT SYSLSIM
```

There are some differences between these RUN and MAP statements and those referenced in this report. These differences were produced by the different file identification used in CACSSM*SEP77 and by the elimination of unnecessary control statements in the report listings. The CACSSM*SEP77 file listings are correct and consistent with each other. The report listings of MAP and RUN statements should only be used for reference and for example when incorporating the features discussed in the User's Guide section (Appendix B).

The CACSSM*SEP77 file and the SYSL program have been entered into the General Atomic Company digital computer code archive library. The catalog numbers assigned to them are

CACSSM*SEP77 - SYSD 2923
SYSL TRANSLATOR - SYSD 2569
SYSL SIMULATOR - SYSD 2570

Herbert G. Greiner
General Atomic Company
August 1979

CASY - A Dynamic Simulation of the Gas-Cooled Fast Breeder Reactor Core Auxiliary Cooling System

Volume I: Technical Discussion

J77-6046-TR-01

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September 1977

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ABSTRACT

This report documents the development of the digital computer simulation code CASY. CASY is designed to evaluate alternative systems to perform emergency core cooling. It is modular in form such that modifications can be made easily. CASY was independently validated by comparing similar analysis results with existing core and core auxiliary cooling system transient codes. CASY is written in the preprocessor language available at General Atomic entitled SYSL.

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1. INTRODUCTION

This report documents the development of a simulation code, CASY, of the Core Auxiliary Cooling System (CACS) for the Gas Cooled Fast Breeder Reactor (GCFR). It is based upon an existing simulation and analysis (Ref. 1,2).

The main text outlines equation development and for completeness includes appropriately-referenced developments of models which were obtained from Ref. 1. Appendices provide data processing procedures and user instructions. The user instructions include use of SYSL, remote terminals, and the code itself.

The component models are developed in a modular form wherein versions of varying complexity may be interchanged freely. In addition, many of the individual models are comrpised of modules allowing the number of spatial divisions to be increased or decreased with a minimum of difficulty.

2. SYSTEM DESCRIPTION

The GCFR is equipped with three independent auxiliary core cooling loops, with each loop designed for 50% design residual heat removal capability. These three loops and their controls comprise the CACS system. Only two loops are required at any given time; hence, the third loop provides redundancy and allows the system to withstand a single active or passive failure.

The CACS cooling water circuit outside the PCRV is shown in Figure 2-1. The representation is schematical only and the pressurizer location may be design dependent, e.g., it could be in the hot line rather than in the cold line.

In the core cooling mode, each CACS loop circulates hot helium from the core lower plenum into the lower end of the core auxiliary heat exchanger cavity through a cross-duct. The hot helium flows upward through the counterflow auxiliary heat exchanger where it gives up its heat to the cooling water. Cold helium leaving the core auxiliary heat exchanger flows through the auxiliary shutoff valve into the auxiliary circulator, which pumps the cold helium through the upper cross-duct into the core top plenum for circulation through the core before beginning another auxiliary cooling loop cycle.

Each core auxiliary heat exchanger is supplied cooling water by an independent closed loop system. Cold water is pumped to the core auxiliary heat exchanger where it absorbs heat from the primary coolant and then returns to the air blast heat exchanger where the heat is rejected to the atmosphere. Flow is supplied by one of two pumps shown in parallel configuration, depending on the operating mode, e.g., the smaller operates in standby.

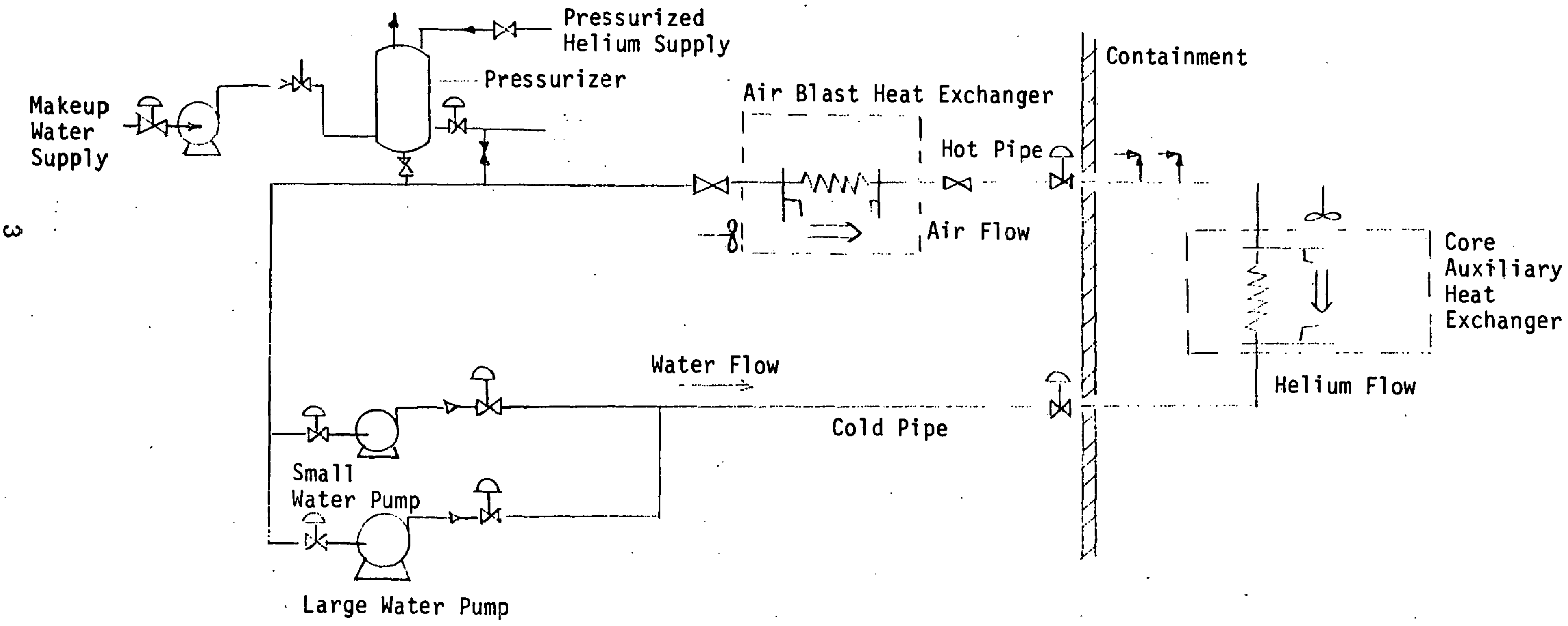

Figure 2-1. Core Auxiliary Cooling Water System

3. NOMENCLATURE

3.1 NOMENCLATURE GUIDELINES

Nomenclature guidelines are a virtual requirement in large-scale simulation where more than one individual may contribute component models that must ultimately be integrated together into the system simulation. The minimum requirements are:

1) The same letter designation should be used for a process or control variable, e.g., pressure, in all parts of the simulation.
2) The same variable name cannot be assigned in different sections of the simulation unless they represent the same quantity.

The first requirement does not preclude the possibility of two process variables, e.g., pressure and power, being designated by the same letter since frequently there are more unique variables than unique characters to represent them. As noted in Table 3.1-1, the first character is reserved for the purpose of indicating the type of variable represented. The letter K, as a first letter designator, is reserved for constants. The magnitude of each constant is assigned as input data in the program. The letters J and O, as first letter designators, are used as intermediate variables defined within the program. The remaining 23 letters are available to represent types of process and control variables. The second requirement is satisfied by reserving the second and third characters (alpha-numerical) for component designation.

Table 3.1-1. Character Definitions

```
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  NOMENCLATURE GUIDELINES FOR CASY-SEE SECTION 3 OF REPORT    *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

*  *  FIRST LETTER DESIGNATION - TYPE OF VARIABLE

*         A   NORMALIZED VALVE AREA                          (ND)
*         B   RATE OF THERMAL EXPANSION OR CONTRACTION       (FT**3/SEC)
*         D   RATE OF CHANGE WRT TIME                        (PER SEC)
*         E   EFFICIENCY (ND)
*         G   GAS FLOW RATE                                   (LBS/SEC)
*         I   INITIAL VALUE OF STATE
*         J   INTERMEDIATE VARIABLE
*         K   RESERVED FOR CONSTANTS
*         L   VALVE LIFT (ND) OR TANK LEVEL (FT)
*         N   ROTATIONAL SPEED (RPM) OR NUMBER (ND)
*         O   INTERMEDIATE VARIABLE
*         P   PRESSURE (PSIA) OR PRESSURE DIFFERENTIAL (PSID)
*         Q   RATE OF HEAT TRANSFER (BTU/SEC)
*         R   DENSITY (LB/FT**3)
*         T   TEMPERATURE (DEG F)
*         W   WATER FLOW RATE (LBS/SEC)
*         X   TORQUE (FT-LBS)

*  *  SECOND AND THIRD LETTER DESIGNATIONS - COMPONENT ID

*         A-   AIR BLAST HEAT EXCHANGER
*         AA   AIR SIDE
*         AM   TUBE AND FINS
*         AW   WATER SIDE
*         BP   CORE BYPASS
*         CA   CIRCULATOR AUXILIARY
*         CC   CIRCULATOR
*         CM   CIRCULATOR MOTOR
*         CG   CONTROL GUIDE
*         CS   CORE SUPPORT
*         H-   CAHE HEAT EXCHANGER
*         HH   HELIUM SIDE
*         HM   TUBE METAL
*         HW   WATER SIDE
*         LP   LOWER PLENUM
*         LR   LOWER REFLECTOR
*         PC   PIPE FROM AIR BLAST HX AND CAHE HX (COLD LEG)
*         PH   PIPE FROM CAHE HX TO AIR BLAST HX (HOT LEG)
*         PL   PUMP (LARGE)
*         PR   PRESSURIZER
*         PS   PUMP (SMALL)
*         RE   CORE (NUCLEAR REACTOR)
*         RF   REACTOR FUEL
*         RM   REACTOR MODERATOR
*         SR   SIDE REFLECTOR
*         SP   SUPPORT POSTS
*         UN   UNIVERSAL (CONVERSION FACTOR OR CONSTANT)
*         UP   UPPER PLENUM
*         UR   UPPER REFLECTOR
**********************************************************************
```

3.2 LIST OF NOMENCLATURE

Tables 3.2-1 to 3.2-4 present a summary of the constants, parameters, and variables as they appear in the digital program. Parameters and constants are distinct from variables in the sense that they are program inputs to be specified prior to a run, while variables are potential program outputs to be determined as a function of time. The program treats parameters and constants in the same manner, and the distinction between them is made by the programmer or user. The distinction as they appear in Tables 3.2-1 and 3.2-2 is drawn according to whether they

- are readily adjustable even after the plant is build, e.g., controller gains,
- might be determined as program variables rather than inputs in an expanded simulation, e.g., makeup flow into pressurizer,

in which case they are listed as parameters rather than constants.

Table 3.2-1. DEFINITION OF CONSTANTS USED IN CASY

CONSTANT	DEFINITION	UNITS
KAAA	Effective heat transfer area of tubes to air in air blast heat exchanger	ft^2
KAAG	Reference air flow in the air blast heat exchanger	lb/sec.
KAAR	Thermal resistance between metal and air in air blast heat exchanger	sec-ft-^{O}R/BTU
KAAW1,2	Air side weighting factor nodes 1,2 in the air blast heat exchanger	ND
KAMC	Thermal capacitance of metal in the air blast heat exchanger node	BTU/^{O}R
KAMCI	Thermal capacitance of metal in the air blast heat exchanger inlet node	BTU/^{O}R
KAMCO	Thermal capacitance of metal in the air blast heat exchanger outlet node	BTU/^{O}R
KAMCT	Total thermal capacitance of metal in the air blast heat exchanger	BTU/^{O}R
KAMR	Thermal resistance between metal and water on air blast heat exchanger (reference)	sec-ft-^{O}R/BTU
KAWA	Water side heat transfer surface area in air blast heat exchanger	ft^3
KAWISQ	Pressure loss coefficient squared for air blast heat exchanger inlet header	$\frac{\text{psid-(lbs/ft}^3)}{(\text{lbs/sec})^2}$
KAWN	Number of nodes in the air blast heat exchanger	ND
KAWSQ	Pressure loss coefficient squared for air blast heat exchanger	$\frac{\text{psid-(lbs/ft}^3)}{(\text{lbs/sec})^2}$
KAWV	Volume of water per node in the air blast heat exchanger	ft^3
KAWVI	Volume of water in inlet node of air blast heat exchanger	ft^3

Table 3.2-1 (Continued)

CONSTANT	DEFINITION	UNITS
KAWVO	Volume of water in outlet node of air blast heat exchanger	ft^3
KAWVT	Total volume of water in the air blast heat exchanger	ft^3
KAWW1,2	Water side weighting factor, nodes 1,2 in the air blast heat exchanger	ND
KCAN	Number of auxiliary circulators assumed in operation	ND
KCAPBN	Proportional band in auxiliary circulator speed controller	ND
KCAR	Auxiliary circulator speed to helium flow coefficient (assumed constant)	Ft^3/rpm/sec
KCARG	Helium flow through auxiliary circulator at design conditions	lb/sec
KCART	Reset time gain setting in auxiliary circulator speed controller	sec
KCATAU	Time constant of auxiliary circulator to change speed	sec
KCCN	Number of main coolant circulators assumed in operation	ND
KGPC	Thermal capacitance in core grid plate	BTU/^{o}R
KHHA	Effective heat transfer area metal to helium in CAHE	ft^2
KHHRX	Thermal resistance between helium and metal in CAHE	sec-ft-^{o}R/BTU
KHHVI6	Volume of helium between lower plenum and upper plenum	ft^3
KHHW1,2	Weighting factor for average temperature of CAHE helium node 1,2	ND
KHMC	Metal thermal capacitance for CAHE per node-heated zone	BTU/^{o}R

Table 3.2-1 (Continued)

CONSTANT	DEFINITION	UNITS
KHMCI	Metal thermal capacitance for CAHE inlet node	BTU/^{o}R
KHMCO	Metal thermal capacitance for CAHE outlet node	BTU/^{o}R
KHMCT	Total metal thermal capacitance for CAHE	BTU/^{o}R
KHMRX	CAHE metal heat transfer film resistance	(BTU/sec ft^{2o}R)
KHWA	Effective heat transfer area metal to water in CAHE	ft^2
KHWISQ	Pressure loss coefficient squared for CAHE inlet header	$\frac{\text{psid-(lbs/ft}^3)}{(\text{lbs/sec})^2}$
KHWMI	Coupling coefficient (thermal conductance) between metal and water in inlet node of CAHE	BTU/^{o}R/sec
KHWMO	Coupling coefficient (thermal conductance) between metal and water in outlet node of CAHE	BTU/^{o}R/sec
KHWN	Number of nodes in CAHE	ND
KHWSQ	Pressure loss coefficient squared for CAHE	$\frac{\text{psid-(lbs/ft}^3)}{(\text{lbs/sec})}$
KHWV	Volume of water in CAHE per node in heated zone	ft^3
KHWVI	Volume of water in inlet node of CAHE	ft^3
KHWVO	Volume of water in outlet node of CAHE	ft^3
KHWVT	Total volume in heated zone of CAHE	ft^3
KHWW1,2	Weighting factor for average water temperature in CAHE node 1,2	ND

Table 3.2-1 (Continued)

CONSTANT	DEFINITION	UNITS
KPCC	Heat capacitance of cold pipe per node	BTU/$^{\circ}$R
KPCCT	Heat capacitance of cold pipe, total	BTU/$^{\circ}$R
KPCN	Number of nodes in cold pipe	ND
KPCSQ	Pressure loss coefficient squared for cold pipe	$\frac{\text{psid-(lbs/ft}^3\text{)}}{\text{(lbs/sec)}^2}$
KPCV	Volume of water in cold pipe per node	ft^3
KPCVT	Volume of water in cold pipe total	ft^3
KPHC	Heat capacitance of hot pipe per node	BTU/$^{\circ}$R
KPHCT	Heat capacitance of hot pipe, total	BTU/$^{\circ}$R
KPHN	Number of nodes in hot pipe	ND
KPHSQ	Pressure loss coefficient squared for hot pipe	$\frac{\text{psid-(lbs/ft}^3\text{)}}{\text{(lbs/sec)}^2}$
KPHV	Volume of water in hot pipe per node	ft^3
KPHVT	Volume of water in hot pipe total	ft^3
KPL/KPS	Throttle valve coefficient (related to C_v max) of large pump/small pump	$\text{(lbs/sec)/((lb/ft}^3\text{)-psid)}^{\frac{1}{2}}$
KPLCR/KPSCR	Range of measurement of speed for large pump/small pump	rpm
KPLN/KPSN	Large pump reference speed/small pump reference speed	rpm
KPLPB/KPSPB	Proportional band setting in throttle valve controller of large pump/small pump	ND
KPLRT/KPSRT	Reset time setting on throttle valve of large pump/small pump	sec
KPRV	Volume of pressurizer	ft^3
KRCV1 thru KRCV6	Volume of cladding in reactor clad nodes 1 thru 6	ft^3

Table 3.2-1 (Continued)

CONSTANT	DEFINITION	UNITS
KREA1 thru KREA6	Heat transfer surface area in reactor nodes 1 thru 6	ft^2
KREGF	Reference helium flow thru reactor	lb/sec
KREL1 thru KREL6	Length of reactor nodes 1 thru 6	ft
KRENN	Number of fuel pins represented by equivalent fuel channel model	ND
KREPF	Fraction of total power generated in active core (normally .95)	ND
KREPF1 thru KREPF6	Fraction of power generated in active core in fuel nodes 1 thru 6	ND
KREQT	Total heat generated in reactor core	BTU
KRFV1 thru KRFV6	Volume of fuel in reactor fuel nodes 1 thru 6	ft^3
KTAU	Time constant of CAHE temperature measurement	sec
KUNACP	Heat capacity of air at constant pressure	BTU/lb^oR
KUNGR	Universal gas constant for helium	$psia/((lb/st^3)-^oR)$
KUNHCP	Heat capacity of helium at constant pressure	BTU/lb^oR
KUNHCV	Heat capacity of helium at constant volume	BTU/lb^oR
KUNWCP	Heat capacity of water at reference conditions	BTU/lb^oR

Table 3.2-2. DEFINITION OF PARAMETERS USED IN CASY

PARAMETER	DEFINITION	UNITS
GAA	Air flow in air blast heat exchanger	lb/sec
GPRI	Inlet gas flow to pressurizer	lb/sec
GPRO	Outlet gas flow from pressurizer	lb/sec
SPL/SPS	Switch to bypass large/small pump throttle valve; 0 for bypassing valve, 1 for using valve	ND
TAAI10	Input air temperature to air blast heat exchanger	^{o}R
WPLR/WPSR	Large pump/small pump recirculation flow	lb/sec
WPRI	Inlet makeup water flow to pressurizer	lb/sec
WPRO	Water drain flow from pressurizer	lb/sec

Table 3.2-3. DEFINITION OF VARIABLES USED IN CASY

VARIABLE	DEFINITION	UNITS
APL/APS	Area of throttle valve on large pump/ small pump normalized to 1.0 at fully open	ND
ICAN	Output of integrater in circulator speed controller	RPM
IPLIT/IPSIT	Output of integrator in large pump/small pump speed controller	RPM
NCAA	Speed of auxiliary circulator	RPM
NPL/NPS	Speed of large pump/small pump	RPM
PPRG	Pressure of gas in pressurizer	PSI
TAM1 to 10	Nodal metal temperatures in air blast heat exchanger node 1 to 10	°R
TAW1 to 10	Nodal water temperatures in air blast heat exchanger node 1 to 10	°R
TCAHOA	Outlet temperature of auxiliary circulator	°R
TGPM	Temperature of grid plates	°R
THHI6	Temperature of helium in volume node between auxiliary circulator and CAHE	°R
THM1 to 6	Nodal metal temperatures in CAHE node 1 to 6	°R
THW1 to 6	Nodal water temperatures in CAHE node 1 to 6	°R
THWI	Inlet water temperature to CAHE	°R
THWO	Outlet water temperature from CAHE	°R
TLPH	Temperature of helium in lower plenum of core	°R

Table 3.2-3 (Continued)

VARIABLE	DEFINITION	UNITS
TPC1 to 10	Nodal temperatures in cold leg pipe node 1 to 10	^{o}R
TPCOM	Outlet temperature of cold leg as measured with thermowell	^{o}R
TPH1 to 10	Nodal temperatures of hot leg pipe node 1 to 10	^{o}R
TPHM	Measured temperature of hot leg including thermowell	^{o}R
TPRW	Temperature of water in pressurizer	^{o}R
TRC1,6	Temperature of cladding in reactor node 1 thru 6	^{o}R
TRF1,6	Temperature of fuel in reactor node 1 thru 6	^{o}R
TUPH	Temperature of helium in upper plenum of reactor	^{o}R
VPRW	Volume of water in pressurizer	ft^3

Table 3.2-4. DEFINITION OF INTERMEDIATE VARIABLES

VARIABLE	DEFINITION	UNITS
APLD/APSD	Demand throttle valve area from large pump/small pump flow control	(ND)
BAWI	Thermal expansion/compression of water in CAHE inlet node	lb/sec
BAWO	Thermal expansion/compression of water in CAHE outlet node	lb/sec
BAW1 to 10	Thermal expansion/compression of water in air blast heat exchanger nodes 1 to 6	lb/sec
BAWT	Total thermal expansion/compression of water in air blast heat exchanger	lb/sec
BHW1 to 6	Thermal expansion/compression of water in CAHE nodes 1 to 6	lb/sec
BHWI	Thermal expansion/compression of water in CAHE inlet header	lb/sec
BHWO	Thermal expansion/compression of water in CAHE outlet header	lb/sec
BHWT	Total thermal expansion/compression of water in CAHE	lb/sec
BPC1 to 10	Thermal expansion/compression of water in cold leg pipe nodes 1 to 10	lb/sec
BPCT	Total thermal expansion/compression of water in cold leg pipe	lb/sec
BPH1 to 10	Thermal expansion/compression of water in hot leg pipe nodes 1 to 10	lb/sec
BPHT	Total thermal expansion/compression of water in hot leg pipe	lb/sec
CREFO	Initial fractional power level	ND
CREP1	Fractional power level	ND

Table 3.2-4 (Continued)

VARIABLE	DEFINITION	UNITS
CREPOO	Power level at beginning of reactor trip	ND
GBPH	Helium flow through core bypass paths	lb/sec
GCAA	Helium flow at auxiliary circulator	lb/sec
GCCA	Helium flow at main loop circulator	lb/sec
GREH	Helium flow through reactor core fuel pin	lb/sec
GRETOT	Total helium flow in reactor	lb/sec
JLPV	Volume of lower plenum	ft^3
JUPV	Volume of upper plenum	ft^3
MARGIN	Euthalpy margin in CAHE between water and generation of steam	BTU/lb
MLPH	Mass of helium in lower plenum	lb
MNSS	Total mass of helium	lb
MUPH	Mass of helium in upper plenum	lb
PNSS	Helium pressure	psi
POWER	Total power in the reactor	ND
QAAM1 to 10	Heat flow from air to metal in air blast heat exchanger node 1 to 10	BTU/sec
QAAMT	Total heat flow from air to metal in air blast heat exchanger	BTU/sec
QAAWM1 to 10	Heat flow from water to metal in air blast heat exchanger node 1 to 10	BTU/sec
QAWMT	Total heat flow from water to metal in air blast heat exchanger	BTU/sec
QBPH	Heat flow from heat source in the core bypass channel to helium	BTU/sec

Table 3.2-4 (Continued)

VARIABLE	DEFINITION	UNITS
QHHM1 to 6	Heat flow from helium to metal in CAHE node 1 to 6	BTU/sec
QHHMT	Total heat flow from helium to metal in CAHE	BTU/sec
QHWM1 to 6	Heat flow from water to metal in CAHE node 1 to 6	BTU/sec
QHWMT	Total heat flow from water to metal in CAHE	BTU/sec
QPR	Heat lost in pressurizer to water	BTU/sec
QRF1 to 6	Heat generated in fuel nodes 1 thru 6	BTU/sec
RAW1 to 10	Density of water in air blast heat exchanger nodes 1 to 10	lb/ft^3
RAWAV	Average density of water in air blast heat exchanger	lb/ft^3
RAWI	Density of water in inlet node of air blast heat exchanger	lb/ft^3
RAWO	Density of water in outlet node of air blast heat exchanger	lb/ft^3
RHW1 to 6	Density of water in CAHE heated zone nodes 1 to 6	lb/ft^3
RHWAV	Average density of water in CAHE	lb/ft^3
RHWI	Density of water in CAHE inlet node	lb/ft^3
RHWO	Density of water in CAHE outlet node	lb/ft^3
RPC1 to 10	Density of water in cold leg pipe nodes 1 to 10	lb/ft^3
RPCAV	Average density of water in cold leg pipe	lb/ft^3
RPH1 to 10	Density of water in hot leg pipe nodes 1 to 10	lb/ft^3
RPHAV	Average density of water in hot leg pipe	lb/ft^3

Table 3.2-4 (Continued)

VARIABLE	DEFINITION	UNITS
RPRW	Density of water in pressurizer	lb/ft^3
RPUMP	Density of water at the pumps	lb/ft^3
TAA1 to 10	Average temperature of air in air blast heat exchanger nodes	^oR
TAAO1 to 10	Outlet air temperature from air blast heat exchanger nodes 1 to 10	^oR
TAWI	Inlet water temperature to air blast heat exchanger	^oR
TAWO	Outlet water temperature from air blast heat exchanger	^oR
TAWO1 to 10	Temperature of water at node interfaces in air blast heat exchanger nodes 1 to 10	^oR
TBPH	Temperature of helium at outlet of bypass paths in reactor core	^oR
THH1 to 6	Average temperature of helium in each CAHE node	^oR
THHO1 to 6	Temperature of helium at node interfaces in CAHE node 1,2	^oR
THWO	Temperature of water at outlet of CAHE	^oR
THWO1 to 6	Temperature of water at node interfaces in CAHE nodes 1 to 6	^oR
THWOS	Temperature setpoint of outlet water from CAHE	^oR
THWOSS	Temperature setpoint of outlet water from CAHE when controller is off	^oR
TPCO	Temperature of water at outlet of cold leg pipe	^oR
TPHO	Temperature of water at outlet of hot leg pipe	^oR
TPRG	Temperature of gas in pressurizer	^oR

Table 3.2-4 (Continued)

VARIABLE	DEFINITION	UNITS
TPRI	Temperature of makeup water flowing into the pressurizer	^{o}R
TREH1,6	Temperature of helium in reactor nodes 1 thru 6	^{o}R
TREHO1, 6	Temperature of helium at outlet boundary of reactor nodes 1 thru 6	^{o}R
TSEC	Simulation time when reactor trip is initiated	sec
WFLQPD	Partial of flow through CAWS less pumps with respect to pressure drop across pumps	lb/sec
WFLOW	Water flow in CAWS	lb/sec
WFLOWS	Water flow setpoint in flow controller	lb/sec
WPL/WPS	Water flow through large pump/small pump	lb/sec
WPLPD	Partial of large pump flow with respect to pressure drop across the pump	lb/sec
WPR	Water flow into pressurizer from CAWS	lb/sec
WPSPD	Partial of small pump flow water pressure drop across the pump	lb/sec

4. CAWS PROCESS-FLOW MODEL DEVELOPMENT

The CAWS process-flow modeling schematic is shown in Figure 4-1, a listing is given in Figure 4-2. The CAWS process-flow model consists of two feedpumps, in parallel configuration, serving a line characterized by six lumped flow resistances in series. These two pumps consist of a large pump (PL) for pumping approximately 42 lbs/sec during cooldown operation, and a small pump (PS) for pumping approximately 5 lbs/sec during standby operation. The densities characterizing each of the resistances are provided by thermal models of the represented components, since density is dependent only upon the water temperature. The flow rates from each pump and through the line are determined as a function of the densities and the pressure differential PLOAD. Since water is assumed incompressible, the flow rates WPL, WPS, and WFLOW are related at all times by

$$\mathrm{WPL} + \mathrm{WPS} - \mathrm{WFLOW} = 0.$$

This constraint provides the defining expression for PLOAD which, due to the nonlinearities, cannot be solved for explicity and must be determined iteratively. Sections 4.1 and 4.2 develop model equations to determine the mass flow rates WPL, WPS, and WFLOW as functions of PLOAD. Section 4.3 develops the equations for the pressurizer model. The iterative scheme for determining PLOAD at each time step will be recognized below as a simple gradient approach utilizing the value at the last time step as an initial guess.

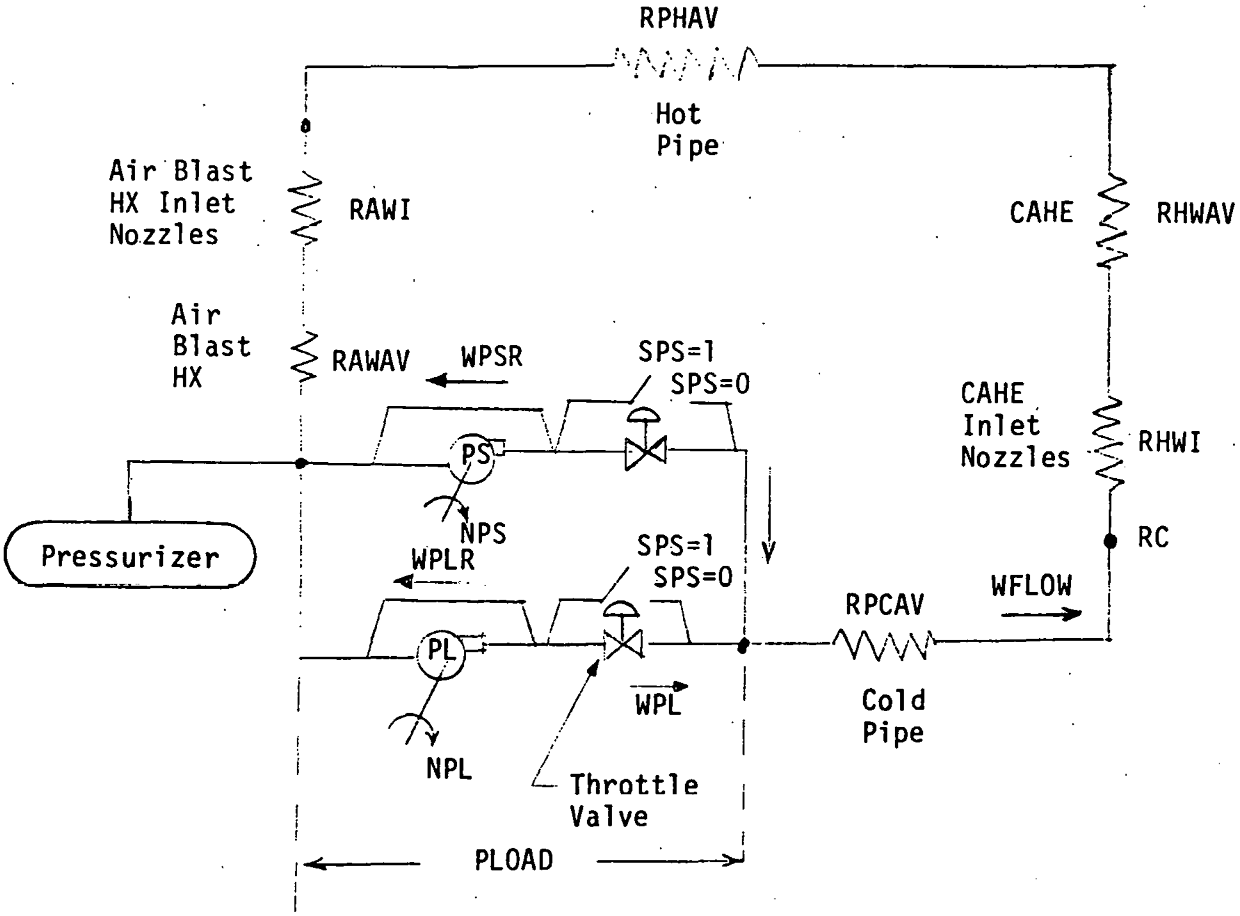

Figure 4-1. Process Flow Schematic - CAWS

```
*  *  *  *  *  *  *  CACWS PROCESS-FLOW MODEL  *  *  *  *  *  *
*  *  *  *  *  *  *        SECTION 4.           *  *  *  *  *  *

*     JPL0=KPLJ0*RPC1*(NPL/KPLN)**2
*     JPL1=KPLJ1*(NPL/KPLN)
*     JPL2=-KPLJ2/RPC1
*
*
*     JPS0=KPSJ0*RPC1*(NPS/KPSN)**2
*     JPS1=KPSJ1*(NPS/KPSN)
*     JPS2=-KPSJ2/RPC1
*
*     JAWPL=1./SQRT(KPHSQ/RPHAV+KPCSQ/RPCAV+KAWSQ/RAWAV+KHWSQ/RHWAV+...
*           KHWISQ/RHWI+KAWISQ/RAWI)
*     RPUMP=RPC1
*PROCED WFLOW,WPL,WPS,FLOAD=PRFLO(JAWPL,RPUMP,APL,SPL,WPLR,JPL0,JPL1,...
*      JPL2,NPL,APS,SPS,WPSR,JPS0,JPS1,JPS2,NPS)
*   4 IF(FLOAD)1,1,2
*   1 WFLOW=0.
*     WFLOPD=0.
*     GO TO 3
*   2 WFLOW=JAWPL*SQRT(FLOAD)
*     WFLOPD=0.5*WFLOW/FLOAD
*   3 CONTINUE
*     JPL=KPL*SQRT(RPUMP)
*     JPS=KPS*SQRT(RPUMP)
*     WPL,WPLPD=MOPTV(JPL,APL,SPL,JPL0,JPL1,JPL2,WPLR,FLOAD)
*     WPS,WPSPD=MOPTV(JPS,APS,SPS,JPS0,JPS1,JPS2,WPSR,FLOAD)
*     ERR=WPL+WPS-WFLOW
*     FLOAD=FLOAD-ERR/(WPLPD+WPSPD-WFLOPD)
*     IF(ERR*ERR.GT.0.01)GO TO 4
*ENDPRO
```

Note: The * in column 1 of the model indicates that the process-flow model is "commented out" of the current program.

Figure 4-2. Listing of Process Flow Model

4.1 FEEDPUMP MODEL

The feedpump model shown schematically in Figure 4.1-1

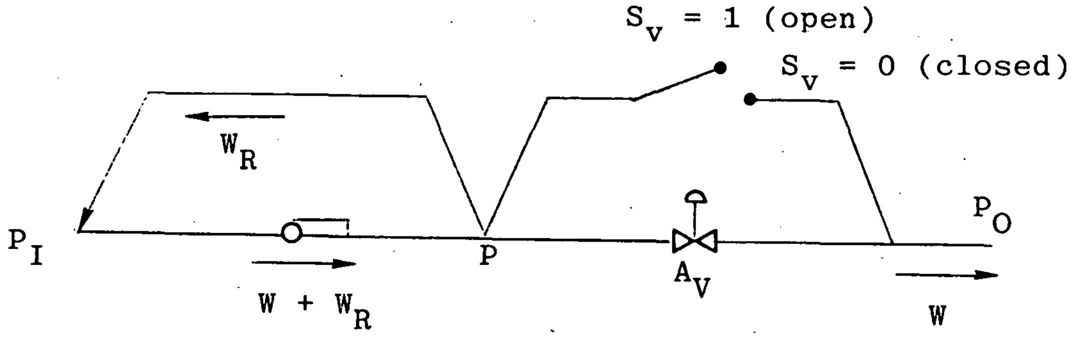

Figure 4.1-1. Feedpump Model Schematic.

is suitable for modeling

- a free-running constant speed pump (no flow control)
- a constant speed pump with throttle control
- a pump with variable speed control

and is quite flexible in this respect. The major assumptions are

- the pump characteristics (head and efficiency) can be expressed in terms of second order polynomials in the ratio of flow to speed.
- the isolation valve offers no resistance to flow when closed.
- the density of the water passing through the pump is well characterized by the density at the inlet.

Recirculation flow W_R (usually zero, except during startup and shutdown) must be specified by the user.

The flow through the pump ($W + W_R$) and the pressure rise across the pump ($P - P_I$) can be related in terms of

$$P - P_I = J_o + J_1(W + W_R) + J_2(W + W_R)^2 \qquad (4.1\text{-}1)$$

The pressure drop across the parallel isolation and throttle valves is given as a function of flow by

$$P - P_o = \frac{S_v W^2}{(K_v A_v)^2} \tag{4.1-2}$$

where $S_v = 0$ for an open isolation valve results in $P - P_o = 0$ as desired, and $S_v = 1$ for a closed isolation valve results in the standard flow squared law involving the throttle valve. Subtracting (4.1-2) from (4.1-1) yields

$$P_o - P_I = (J_o + J_1 W_R + J_2 W_R^2) + (J_1 + 2W_R J_2)W - \frac{S_v - J_2 K_v^2 A_v^2}{K_v^2 A_v^2} W^2 \tag{4.1-3}$$

which is a standard second order algebraic equation of the form

$$aW^2 + bW + C = 0 \tag{4.1-4}$$

with solution

$$W = \frac{b}{2a} \pm \sqrt{\left(\frac{b}{2a}\right)^2 - \frac{c}{a}} \; .$$

For computation convenience, this is written as

$$W = -\frac{1}{2}a^{-1}b + \sqrt{\left(\frac{1}{2}a^{-1}b\right)^2 - ca^{-1}} \tag{4.1-5}$$

where the negative root is discarded on physical grounds. Comparing (4.1-3) and (4.1-4) yields

$$a^{-1} = \frac{-K_v^2 A_v^2}{S_v - J_2 K_v^2 A_v^2} \tag{4.1-6}$$

$$b = J_1 + 2J_2 W_R \tag{4.1-7}$$

$$c = J_o + J_1 W_R + J_2 W_R^2 - (P_o - P_I) \tag{4.1-8}$$

Under normal operating conditions, Equations (4.1-5) - (4.1-8) uniquely and explicitly define flow W as a function of $P_O - P_I$, the valve positions and the recirculation flow. As a final consideration, it is conceivable that heads $(P_O - P_I)$ in excess of the maximum allowable could be encountered, particularly while removing the motor pump from the line by closing the throttle valve. Prediction of pump behavior under these conditions is beyond the scope of this model, but it is possible to avoid aborting the run on a Fortran error (square root of a negative number) in such an event. This is accomplished by comparing $P_O - P_I$ to the maximum allowable head as determined from

$$(P_O - P_I)\max = \frac{-b^2 a^{-1}}{4} + (J_O + J_1 W_R + J_2 W_R^2) \quad , \qquad (4.1\text{-}9)$$

and setting W = 0 when $P_O - P_I > (P_O - P_I)$ max.

This equation is derived from taking the partial of Equation (4.1-3) with respect to W, setting it equal to zero, and solving for the flow corresponding to the maximum head. Subsequent substitution into (4.1-3) yields Equation (4.1-9).

The above development forms the basis for MOPTV listed in Figure 4.1-2.

```
MACRO W,DWDPO=MOPTV(KV,AV,SV,J0,J1,J2,WR,DELP)
*   SEE SECTION 4.1 OF REPORT
*   GENERAL PURPOSE PUMP MACRO FOR REPRESENTING CONSTANT OR VARIABLE
*   SPEED PUMP WITH THROTTLE OR ISOLATION VALVE OPTIONAL.  REQUIRES
*   THAT USER SPECIFY RECIRCULATION FLOW AS INPUT.  USER MUST SPECIFY
*   PUMP CHARACTERISTIC AS SECOND ORDER POLYNOMIAL.
      JV=KV*KV*AV*AV
      IF(SV.EQ.0.) JV=1
*   IF ISOLATION VALVE IS OPEN, THROTTLE VALVE SETTING IS IMMATERIAL
*  AS IT DROPS OUT. SETTING JV=1. RESULTS IN AINV=-1/J2 AS APPROP.
      AINV=-JV/(SV-J2*JV)
      B=(J1+2.*WR*J2)
      BAINV=B*AINV
      CPART=WR*(J1+J2*WR)+J0
      DELPMX=-B*BAINV/4.+CPART
      IF(DELPMX-DELP) 1,1,2
    1 W=0.
      DWDPO=0.
      GO TO 3
    2 C=CPART-DELP
      W=-BAINV/2.+SQRT(BAINV*BAINV/4.-C*AINV)
      DWDPO=AINV/(2.*W+B*AINV)
    3 CONTINUE
ENDMAC
```

Figure 4.1-3. MOPTV MACRO

4.2 FLOW VERSUS PRESSURE DROP EXPRESSIONS

The pressure losses around the CAWS system are represented by six lumped resistances (Figure 4-2).

- The hot line
- The air blast heat exchanger heated zone
- The air blast heat exchanger inlet losses
- The cold line
- The core auxiliary heat exchanger heated zone
- The core auxiliary heat exchanger inlet losses

These losses are density dependent. The cold line losses and hot line losses are characterized by average fluid densities. The air blast exchanger and core auxiliary heat exchanger inlet losses are characterized by inlet densities, and the distributed losses through these components are characterized by the average fluid densities in the heated zone.

Differential pressure, mass flow rate and density ρ_{ci} are related by

$$\Delta P_i = K_i \frac{W_i^2}{\rho_{ci}} \qquad i = 1, \ldots, 6 \quad . \qquad (4.2\text{-}1)$$

Since water is assumed incompressible, ρ_{ci} is a function of temperature (or temperatures) only. Summing the individual losses to obtain the total loss around the loop, ΔP_L yields

$$\Delta P_L = \sum_{i=1}^{6} \Delta P_i = \sum_{i=1}^{6} \frac{K_i}{\rho_{ci}} \left(W_i^2\right) \quad , \qquad (4.2\text{-}2)$$

but

$$W_1 = W_2 = W_3 = W_4 = W_5 = W_6 = W \quad ;$$

hence,

$$\Delta P_L = W^2 \left(\sum_{i=1}^{6} \frac{K_i}{\rho_{ci}} \right)$$

which can be rearranged as

$$W = J \sqrt{\Delta P_L} \qquad (4.2\text{-}3)$$

where

$$J = 1 \bigg/ \sqrt{\sum_{i=1}^{6} \frac{K_i}{\rho_{ci}}} \quad . \qquad (4.2\text{-}4)$$

Equation (4.2-4) is programmed as:

```
        JAWPL = 1./SQRT(KPHSQ/RPHAV+KPCSQ/RPCAV+KAWSQ/RAWAV+
                KHWSQ/RAWAV+KHWISQ/RHWI+KAWISQ/RAWI).     (4.2-5)
```

4.3 PRESSURIZER MODEL

The pressurizer, Figure 4.3-1, serves as a pressure regulator. It is partially filled with water and partially filled with gas. Expansion or contraction of the water due to addition or removal of thermal energy is accommodated by compression or expansion of the gas. Attendant pressure fluctuations due to addition or removal of thermal energy can be further reduced by adding or removing gas if necessary.

The assumptions employed in the model developed below are

- The gas obeys the general gas law, e.g.,

  $$P = \rho RT \quad .$$

- Water is incompressible, e.g.,

  $$\left.\frac{\partial \rho}{\partial P}\right|_T = 0.$$

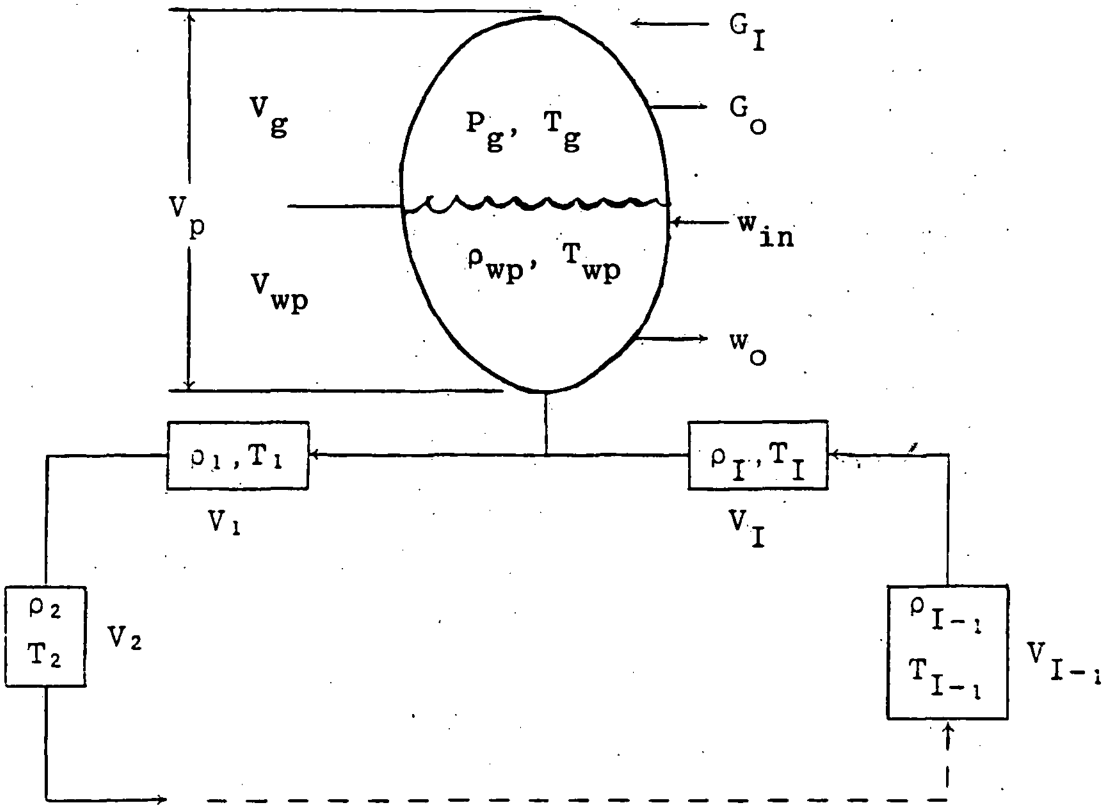

Figure 4.3-1. Pressurizer Schematic

- The pressurizer is always partially filled with water and partially filled with gas.
- The energy required for thermal expansion of the water is insignificant in comparision to that required to raise its temperature, e.g.

$$\frac{d(\rho T)}{dt} \simeq \rho \frac{dT}{dt} \quad .$$

- The thermal capacity of the gas in the pressurizer is negligible in comparison to that of the water. The gas is assumed to be in thermal equilibrium with the water in the tank at all times.
- The temperature of the water in the pressurizer is uniform at all points and, thus,

$$T_O = T_{wp} \quad .$$

Mass Balance - Water

$$\frac{d(\rho_{wp} V_{wp})}{dt} = w_{in} - w_o + w \qquad (4.3\text{-}1)$$

where

w_{in} = flow rate of makeup water into pressurizer (normally zero)

w_o = flow rate out through relief or drain value

w = water flow into pressurizer to accommodate thermal expansion or contraction in other components.

The water added or removed due to thermal expansion or contraction in other components is calculated from

$$w = -\sum_i V_i \left.\frac{\partial \rho}{\partial T}\right|_{T = T_i} \frac{dT_i}{dt} \qquad (4.3\text{-}2)$$

expanding Equation (4.3-1)

$$V_{wp} \left.\frac{\partial \rho_{wp}}{\partial T}\right|_{T=T_{wp}} \frac{dT_{wp}}{dt} + \rho_{wp} \frac{dV_{wp}}{dt} = w_{in} - w_o + w$$

and finally

$$\frac{dV_{wp}}{dt} = (w_{in} - w_o + w - V_{wp} \left.\frac{\partial \rho_{wp}}{\partial T}\right|_{T=T_{wp}} \frac{dT_{wp}}{dt}) \Big/ \rho_{wp} \quad . \qquad (4.3\text{-}3)$$

<u>Energy Balance - Water</u>

$$C_p \frac{d(\rho_{wp} V_{wp} T_{wp})}{dt} = C_p\, w_{in}\, T_{in} - C_p\, w_o\, T_{wp} - Q_{wp} + C_p(U(w)wT_I - U(-w)wT_{wp})$$

where U(x) is the unit step function equal to +1 if X is positive and -1 if X is negative.

Rearranging yields

$$\rho_{wp} V_{wp} \frac{dt_{wp}}{dt} = w_{in}\, T_{in} - w_o\, T_{wp} - Q_{wp}/C_p + U(w)wT_I - U(-w)wT_{wp} - T_{wp} \frac{d(\rho_{wp} V_{wp})}{dt} \quad . \qquad (4.3\text{-}4)$$

Multiplying Equation (4.3-1) by T_{wp} and inserting into (4.3-4) yields

$$\rho_{wp} V_{wp} \frac{dT_{wp}}{dt} = w_{in}\, T_{in} - w_o\, T_{wp} - Q_{wp}/C_p + U(w)wT_I - U(-w)wT_{wp} - T_{wp}(w_{in} - w_o + w) \quad .$$

Since

$$-wT_{wp} = -U(w)wT_{wp} + U(-w)wT_{wp} \quad ;$$

this reduces to

$$\frac{dT_{wp}}{dt} = \{w_{in}\,(T_{in} - T_{wp}) - Q_{wp}/C_p + U(w)wT_I - U(w)wT_{wp}\}/ \rho_{wp}\, V_{wp} \quad ,$$

and finally

$$\frac{dT_{wp}}{dt} = \{w_{in}(T_{in} - T_{wp}) + U(w)w(T_I - T_{wp}) - Q_{wp}/C_p\}/(\rho_{wp} V_{wp}) \quad . \tag{4.3-5}$$

Note that when $w < 0$, water at temperature T_{wp} is leaving the pressurizer; hence, $\frac{dT_{wp}}{dt}$ is not affected.

Mass Balance - Gas

$$\frac{d\{\rho_g(V_p - V_{wp})\}}{dt} = G_I - G_o$$

$$(V_p - V_{wp}) \frac{d\rho_g}{dt} = G_I - G_o + \rho_g \frac{dV_{wp}}{dt}$$

$$\rho_g = \frac{P_g}{R_g T_g} \quad .$$

Assuming T_g varies much more slowly than P_g yields

$$\frac{(V_p - V_{wp})}{R_g T_g} \frac{dP_g}{dt} = G_I - G_o + \rho_g \frac{dV_{wp}}{dt}$$

$$\frac{dP_g}{dt} = (G_I - G_o + \frac{P_g}{R_g T_g} \frac{dV_{wp}}{dt}) \frac{R_g T_g}{(V_p - V_{wp})} \quad . \tag{4.3-6}$$

Energy Balance - Gas

The energy content of the gas is assumed negligible in comparison to that of the water and gas temperature is assumed equal to the water temperature; hence,

$$T_g = T_{wp} \quad . \tag{4.3-7}$$

Equations (4.3-2), (4.3-3), (4.3-5), (4.3-6) and (4.3-7) along with table lookups for ρ(T) and $\left.\frac{\partial\rho}{\partial T}\right|_{T=T_a}$ form the basis for the pressurizer model shown in Figure 4.3-2.

```
*   *   PRESSURIZER MODEL

*       TPRG=TPRW
*       JPRRP=DTPRW*AFGEN(PARTRT,TPRW)*VPRW
*       RPRW=AFGEN(RFTSL,TPRW)
*       WPR=BPHT+BAWT+BPCT+BHWT
*       THWX=TPC9
*       DTPRW=(WPRI*(TPRI-TPRW)-QPR/KUNWCP+(THWX-TPRW)*LIMIT(0.0,...
*       .1E6,-WPR))/RPRW/VPRW
*       TPRW=INTGRL(ITPRW,DTPRW)
*       DVPRW=(WPRI-WPRO-WPR-JPRRP)/RPRW
*       VPRW=INTGRL(IVPRW,DVPRW)
*       DPPRG=((GPRI-GPRO)*KUNGR/144.*TPRG+PPRG*DVPRW)/(KPRV-VPRW)
*       PPRG=INTGRL(IPPRG,DPPRG)
```

Figure 4.3-2. Listing of Pressurizer Model.

where BPHT, BAWT, BPCT and BHWT are the thermal compression/ expansion terms associated with the various components in the CAWS.

Note: The * in column 1 of the model indicates that the pressurizer is "commented out" of the current program. The pressure PPRG is specified by the value IPPRG and is held constant. This was done since there was insufficient design data on the pressurizer volume and mode of control on gas pressure.

5. PRIMARY LOOP PROCESS FLOW MODEL DEVELOPMENT

A block diagram showing the GCFR reactor core model is given in Figure 5-1. Depending upon mode of operation, helium from the main or auxiliary cooling loops mixes in the upper plenum, flows down through the core channels absorbing energy and again mixes in the lower plenum. Again, depending upon mode of operation, it is drawn to the main or auxiliary cooling loops. The description of the reactor core model considers the plenum energy balances (upper plenum and lower plenum from Figure 5-1) in which the helium dynamics are lumped along with the method for calculating reactor pressure.

5.1 PLENUMS

Several assumptions are made in the plenum energy balances. It is convenient to first list the assumptions and then examine their effects on a generalized energy balance. The resulting modified form can then be applied to all of the volumes considered. The assumptions are that:

1. Helium obeys the ideal gas equations-of-state.
2. Heat transfer coefficients vary with helium flow raised to the 0.8 power but are not dependent on temperature.
3. Flows are in instantaneous equilibrium with the circulator flows.
4. Perfect mixing occurs within each volume.

The thermal equations are derived from an energy balance applied to a fixed volume V (ft^3) (Figure 5.1-1) containing helium

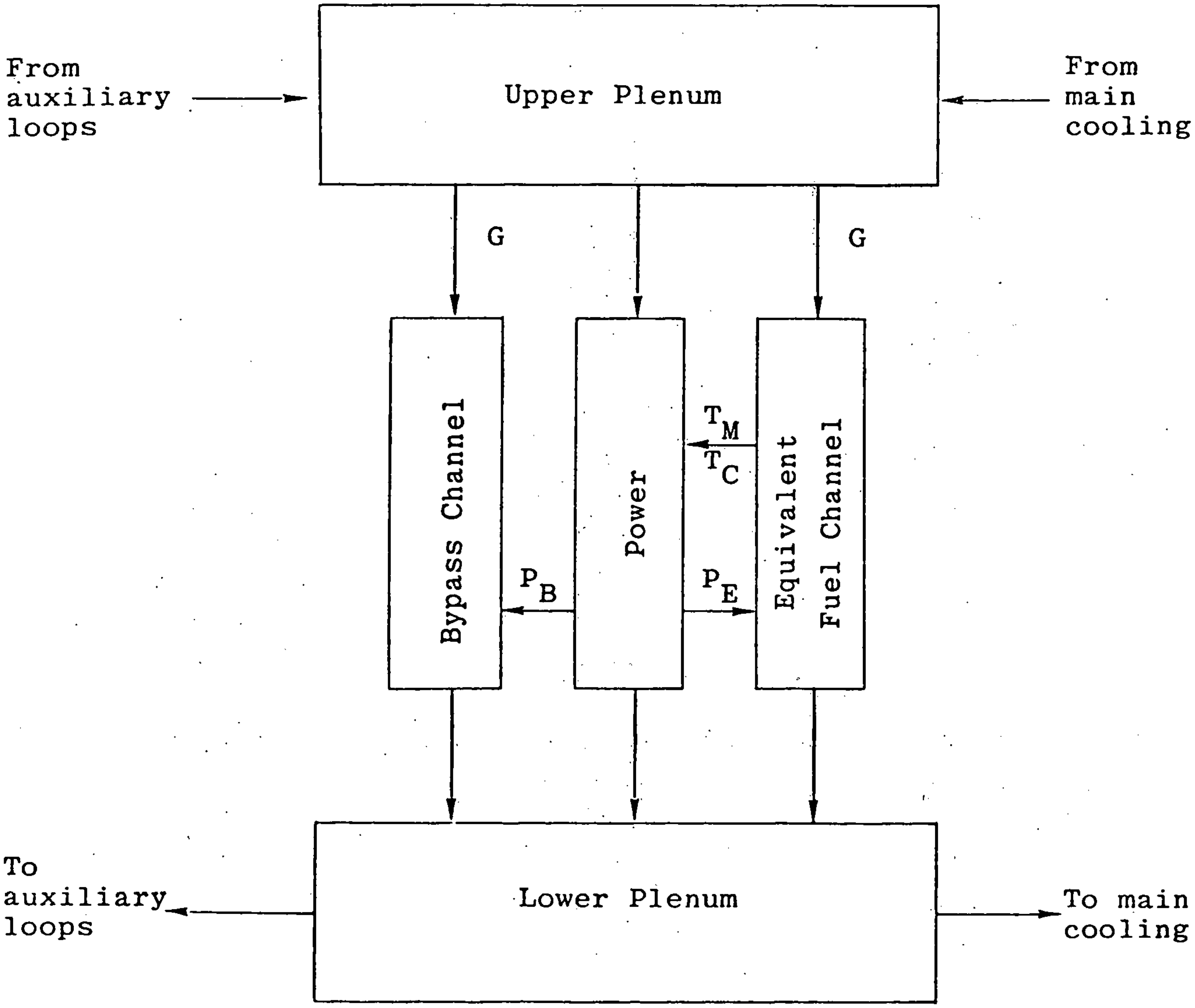

Figure 5-1. Block Diagram of Reactor Core Model

of mass m (lb) and internal energy U (Btu/lb).

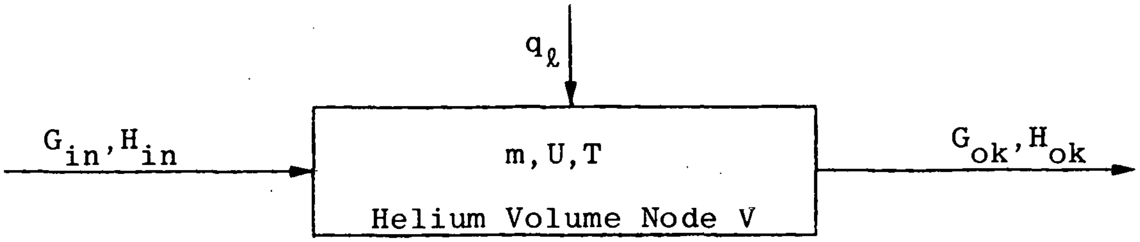

Figure 5.1-1. Energy Balance

Helium enters the volume thru N inlet flow paths with flow rates G_{in} (lb/sec) n = 1,...N and enthalpies H_{in} (Btu/lb) n = 1,...N leaves through K exit paths with flow rates G_{ok} (lb/sec) k = 1,...K and enthalpies H_{ok} (Btu/lb) k = 1,...K. Heat is transfered to the helium from L surrounding structural elements at rates q_ℓ $\ell = 1,...L$. The energy balance is given by

$$\left(\begin{array}{l}\text{Rate of increase}\\ \text{in internal energy}\end{array}\right) = \left(\begin{array}{l}\text{Rate of addition}\\ \text{due to convection}\end{array}\right) + \left(\begin{array}{l}\text{Rate of addition}\\ \text{of energy due to}\\ \text{heat transfer from}\\ \text{structural elements}\end{array}\right)$$

and its mathematical equivalent

$$\frac{d(mU)}{dt} = \left(\sum_{n=1}^{N} G_{in} H_{in} - \sum_{k=1}^{K} G_{ok} H_{ok} \right) + \sum_{\ell=1}^{L} q_\ell \quad .$$

Assumption 1 implies $U = C_v T$ and $H = C_p T$ and hence, the energy balance is written as

$$C_v \frac{d(mT)}{dt} = C_p \left(\sum_{n=1}^{N} G_{in} T_{in} - \sum_{k=1}^{K} G_{ok} T_{ok} \right) + \sum_{\ell=1}^{L} q_\ell \quad .$$

Assumption 4 implies that $T_{ok} = T$, $k = 1,\ldots K$ and hence, the energy balance becomes

$$C_v \frac{d(mT)}{dt} = C_p \left(\sum_{n=1}^{N} G_{in} T_{in} - T \sum_{k=1}^{K} G_{ok} \right) + \sum_{\ell=1}^{L} q_\ell \quad .$$

Assumption 3 implies that

$$\sum_{k=1}^{K} G_{ok} = \sum_{n=1}^{N} G_{in} \quad ,$$

and

$$\frac{dm}{dt} = 0 \quad .$$

The energy balance reduces to

$$mC_v \frac{dT}{dt} = C_p \sum_{n=1}^{N} G_{in} (T_{in} - T) + \sum_{\ell=1}^{L} q_\ell \quad .$$

Finally, Assumption 2 suggests that

$$q_\ell = J_\ell (T_\ell - T) \qquad \ell = 1,\ldots L$$

where T_ℓ is the volume-averaged temperature of the ℓ^{th} structural element and J_ℓ is the product of the heat transfer coefficient and heat transfer surface area expressed in the form

$$J_\ell = K_\ell (G/G_r)^{0.8} \qquad \ell = 1,\ldots L \tag{5.1-1}$$

where G is the total helium flow rate through the volume (i.e., $G = \sum_{n=1}^{N} G_{in}$) and K_ℓ is the heat transfer coefficient at the reference helium flow rate G_r (generally 100% rated conditions). The energy balance is now written in final form as

$$\frac{dT}{dt} = \left[C_P \sum_{n=1}^{N} G_{in} \, (T_{in} - T) + \sum_{\ell=1}^{L} J_\ell \, (T_\ell - T) \right] \Big/ (mC_v) . \tag{5.1-2}$$

The temperature associated with each structural component is determined from another energy balance which upon dividing by the thermal inertia of the component C_ℓ is given by

$$\frac{dT_\ell}{dt} = J_\ell \, (T - T_\ell)/C_\ell \qquad \ell=1,\ldots L \quad . \tag{5.1-3}$$

Equations (5.1-1), (5.1-2), and (5.1-3) as developed from the generalized energy balance are next applied to each plenum volume. The equations are written in a form suitable for programming. They utilize the variable names in which they are presently programmed.

5.1.1 Upper Plenum

The main cooling loops are normally modeled with a single equivalent loop which is considered representative of KCCN (normally 3) loops in the actual plant. The helium flow rate per loop GCCA and exit temperature TCCHOA are input from the other models. In auxiliary cooling mode of operation, a single equivalent loop is considered representative of KCAN loops, each with a flow rate GCAA, and exit temperature TCAHOA to be input from other models.

One structural element is considered in the upper plenum, the grid plate. Equations (5.1-1), (5.1-2), and (5.1-3) applied to the upper plenum in simulation notation are

```
DTUPH=(KUNHCP*(KCCNA*GCCA*(TCCHOA+460.-TUPH)+KCANA*GCAA*...
          (TCAHOA+460.-TUPH)+JGPK*(TGPM-TUPH))/(KUNHCV*MUPH)

 JGPK=KGPK*(GREH/KREGK)**0.8/3600.

DTGPM=JGPK*(TUPH-TGPM)/KGPC
```

where $D_V \equiv \frac{d}{dt}$ (when used as the first letter in a variable name)

TUPH = upper plenum helium temperature (°R)

GCCA/GCAA = helium flow rate per loop for main/auxiliary cooling loop (lbs/sec)

TCCHOA/TCAHOA = exit helium temperature from main/auxiliary loop (°F)

KCCN/KCAN = number of equivalent main/auxiliary loops in simulation

KUNHCP/KUNHCV = specific heat of helium at constant pressure/volume (Btu/lb)

KGPK = heat transfer coefficient (assumed at 1000 Btu/ft^2/°F/hr)

KGPC = thermal capacity per unit area for plate thickness of .42 in and stainless steel at 1000°F (Btu/ft^2/°F)

and MUPH is the helium mass (lbs) in the upper plenum, as defined in Section 5.2.

5.1.2 Lower Plenum

The core model considers KRENN (number fuel pins in reactor) equivalent fuel channels each accorded a flow rate GREH (lbs/sec). The exit temperature is TREH06 (^{o}R), and a single bypass channel accorded a flow rate GBPH (lbs/sec) with exit temperature

TBPH (^oR). No structural elements are currently considered; hence, only Equation 5.1-2 applies with the latter term on the righthand side dropped to obtain

DTLPH = (KUNHCP * (KRENN * GREH * (TREH06 - TLPH) + GBPH
 * (TBPH - TLPH)))/(KUNHCV * MLPH)

where TLPH is the lower plenum helium temperature (°R), and MLPH is the lower plenum mass (lbs).

5.2 REACTOR PRESSURE

The primary loop pressure PNSS is based upon an overall mass balance applied to the primary loop inventory. It is convenient to first derive the expression in general terms for a constant mass system containing N volumes (V_i i=1,...N) and then to apply it to the present case. The total system mass M_T is given by

$$M_T = \sum_{i=1}^{N} \rho_i V_i$$

where ρ_i is the helium density in the ith volume. The individual densities ρ_i can vary with time, but the total system mass is constant. The density in the ith volume is determined from the ideal gas law written as

$$\rho_i = P_i/(RT_i)$$

where P_i and T_i are the absolute pressure and temperature of the helium in the ith volume and R is the gas constant for helium. The assumption is now made that the pressure variation around the primary loop is small in comparison to the absolute pressure at any point. Thus, all P_i are well approximated by a characteristic pressure P, and the expression for total system mass can be approximated by

$$M_T = \frac{P}{R} \sum_{i=1}^{N} \frac{V_i}{T_i}$$

and subsequently resolved in terms of the characteristic pressure to obtain

$$P = \frac{RM_T}{\sum_{i=1}^{N} \frac{V_i}{T_i}}$$

In simulation notation, this becomes

```
PNSS = KUNGR*MNSS/(144.*(KUPV/TUPH+KLPV/TLPH
     + KCCNA*KODVA/TODHA))
```

where

KUNGR = helium gas constant (ft/^{o}R)

MNSS = total helium mass in reactor (lbs)

KUPV/KLPV = upper, lower plenum volumes (ft^3)

and where KODVA and TODHA refer to the main cooling loop volume per loop and the temperature at the inlet to the main circulator. The term KCCNA*KODVA/TODHA has meaning only when the reactor core model is part of the system model simulating normal operation. When operating as a stand-alone model or as part of the auxiliary cooling simulation, the term is suppressed by setting KODVA to zero. Total system mass MNSS is adjusted accordingly.

The mass of helium in the upper and lower plenums (MUPH and MLPH) is then determined from

MUPH = 144.*PNSS*KUPV/(KUNGR*TUPH)

and

MLPH = 144.*PNSS*KLPV/(KUNGR*TLPH) .

5.3 AUXILIARY CIRCULATOR

The auxiliary circulator is a motor-driven variable-speed compressor. The dynamics of the mechanism, represented by its inertia, was assumed to be represented by a first order differential equation with a time constant of 1 sec. The circulator speed is then found by integrating the equation. With the speed determined the helium flow rate can be established according to the circulator performance curve. The circulator performance was represented by the Fan law over the entire range from the depressurized design conditions to pressurized operation. The circulator model was then represented by the following equations

DNCAA = (NCAD - NCAA)/1.

NCAA = INTGRL (INCAA, DNCAA)

GCAA = KCAR * 144. * PNSS/TCAHOA/KUNGR * NCAA

Where the circulator performance coefficient KCAR is evaluated at the depressurized design condition (see Appendix A).

6. THERMAL MODEL DEVELOPMENT

This section presents thermal models of the various system components which, when combined with the primary and secondary process-flow models, form the CACS simulation code CASY. Except as noted in each section, the mathematical representations are the same as those in Ref. 1. Several parts of the equation development are identical to Ref. 1, but are presented in the interest of making this document as self-explanatory as practicable.

6.1 PIPE THERMAL MODELS

The pipe line model was developed with the following assumptions:

- End point weighting.
- The metal thermal capacity has been lumped with the water thermal capacity.
- The variation in water thermal capacity with temperature due to density changes is reflected.

End-point weighting simplifies the mathematical representation and precludes seesaw which can be troublesome with step or rapid ramp changes in inlet temperature. Lumping the metal and water thermal capacities to obtain effective water thermal capacity represents considerable mathematical simplification. Justification of this simplification was presented in Appendix A, Section A.3.1. The pipe line model calculates density and the rate of thermal expansion or contraction of water for use in the process-flow and pressurizer models. Since density as a function of nodal temperature is available, it is a simple matter to represent changes in water thermal capacity due to density changes, and it is incorporated.

The schematic representation of the cold line pipe model is shown in Figure 6.1-1. Each node is represented by the four equations coded in MACRO PIPE1, which is shown in Figure 6.1-2.

The first equation calculates the nodal density as a function of nodal temperature by means of table lookup and linear extrapolation utilizing AFGEN RFTSL. The second equation calculates the rate of change of temperature and is developed from a thermal energy balance

$$C_p \rho_i V_i \frac{dT_i}{dt} = C_p W T_{iI} - C_p W T_{iO}$$

where

T_i, T_{iI}, T_{iO} = nodal average, inlet, and exit fluid temperatures (°R),

W = mass flow rate of water (lb/sec),

C_p = heat capacity of water (Btu/lb/°R),

ρ_i = density of water at temperature T_i (lb/ft^3).

Assuming the exit temperature is equal to the average temperature $T_{iO} = T_i$ and dividing by the thermal capacity of water yields

$$\frac{dT_i}{dt} = C_p W (T_{iI} - T_i)/(C_p \rho_i V_i) .$$

Next, the thermal capacity of water $C_p \rho_i V_i$ is replaced by the effective thermal capacity

$$C_{eff} = C_p \rho_i V_i + C_{mi} ,$$

where C_{mi} represents the thermal capacity of the metal in the ith node to yield

$$\frac{dT_i}{dt} = C_p W (T_{iI} - T_i)/(C_p \rho_i V_i + C_{mi}) .$$

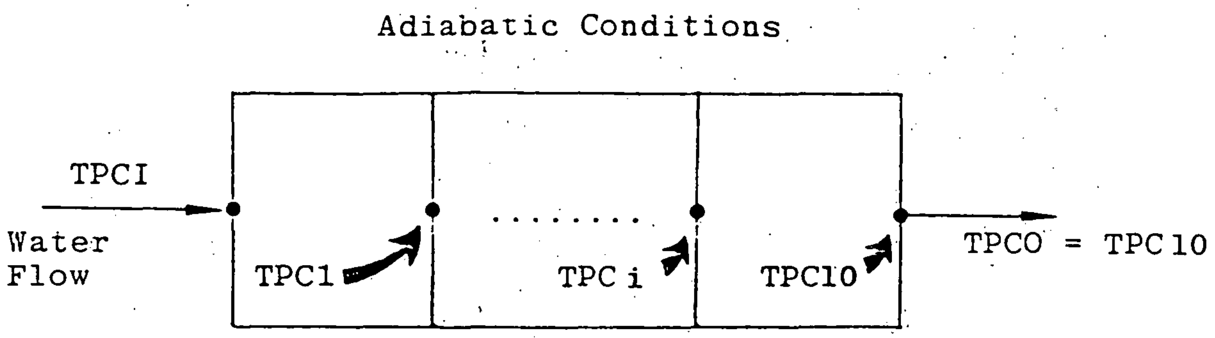

Figure 6.1-1. Pipe Model

```
MACRO DTF,RF,JPRT=PIPE1(FLO,TFI,VOL,MCAP,TF,ITF)
*    SEE SECTION 6.1 OF REPORT
*    PIPE THERMAL NODE WITH COMBINED METAL AND FLUID THERMAL CAPACITANCE
       RF=AFGEN(RFTSL,TF)
       DTF=FLO*(TFI-TF)/(MCAP/KUNWCP+VOL*RF)
       JPRT=VOL*DTF*AFGEN(PARTRT,TF)
       TF=INTGRL(ITF,DTF)
ENDMAC
```

Figure 6.1-2. Listing of PIPE1 MACRO

and finally

$$\frac{dT_i}{dt} = W(T_{iI} - T_i)/(C_{mi}/C_p + \rho_i V_i)$$

which by comparison to the MACRO shows

$$DTF = \frac{dT_i}{dt}$$

$$FLO = W$$

$$TF = T_i$$

$$TFI = T_{iI}$$

$$MCAP = C_{mi}/C_p$$

$$RF = \rho_i$$

$$VOL = V_i$$

The rate of expansion or contraction of water in the ith node is determined from the third equation for input to the pressurizer model. The $\frac{\partial \rho}{\partial T}\Big|_{T=T_i}$ is found by table lookup and linear extrapolation using AFGEN PARTRT with average nodal temperature as the independent variable. The fourth equation is the standard integrator.

The pipe models are now formed by a MACRO call for each node as shown in Figure 6.1-3 for 10 node pipe models.

The hot leg model is identical except that component designator PC is replaced by PH and the inlet temperature is the output of the core auxiliary heat exchanger THWO rather than the output of the air blast heat exchanger TAWO. Note that the average density and the thermal expansion or contraction for the line as a whole are calculated as part of the thermal models

```
*  *  *  *  *  *  *  *  *  PIPE THERMAL MODELS  *  *  *  *  *  *  *  *
*  *  *  *  *  *  *  *  *  SECTION 6.1          *  *  *  *  *  *  *  *



*     HOT LINE MODEL

      DTPH1,RPH1,BPH1=PIPE1(WFLOW,THWO,KPHV,KPHC,TPH1,ITPH1)
      DTPH2,RPH2,BPH2=PIPE1(WFLOW,TPH1,KPHV,KPHC,TPH2,ITPH2)
      DTPH3,RPH3,BPH3=PIPE1(WFLOW,TPH2,KPHV,KPHC,TPH3,ITPH3)
      DTPH4,RPH4,BPH4=PIPE1(WFLOW,TPH3,KPHV,KPHC,TPH4,ITPH4)
      DTPH5,RPH5,BPH5=PIPE1(WFLOW,TPH4,KPHV,KPHC,TPH5,ITPH5)
      DTPH6,RPH6,BPH6=PIPE1(WFLOW,TPH5,KPHV,KPHC,TPH6,ITPH6)
      DTPH7,RPH7,BPH7=PIPE1(WFLOW,TPH6,KPHV,KPHC,TPH7,ITPH7)
      DTPH8,RPH8,BPH8=PIPE1(WFLOW,TPH7,KPHV,KPHC,TPH8,ITPH8)
      DTPH9,RPH9,BPH9=PIPE1(WFLOW,TPH8,KPHV,KPHC,TPH9,ITPH9)
      DTPH10,RPH10,BPH10=PIPE1(WFLOW,TPH9,KPHV,KPHC,TPH10,ITPH10)

      TPHO=TPH10

      RPHAV=(RPH1+RPH2+RPH3+RPH4+RPH5+RPH6+RPH7+RPH8+RPH9+RPH10)/KPHN
      BPHT=BPH1+BPH2+BPH3+BPH4+BPH5+BPH6+BPH7+BPH8+BPH9+BPH10


*     COLD LINE MODEL

      DTPC1,RPC1,BPC1=PIPE1(WFLOW,TAWO,KPCV,KPCC,TPC1,ITPC1)
      DTPC2,RPC2,BPC2=PIPE1(WFLOW,TPC1,KPCV,KPCC,TPC2,ITPC2)
      DTPC3,RPC3,BPC3=PIPE1(WFLOW,TPC2,KPCV,KPCC,TPC3,ITPC3)
      DTPC4,RPC4,BPC4=PIPE1(WFLOW,TPC3,KPCV,KPCC,TPC4,ITPC4)
      DTPC5,RPC5,BPC5=PIPE1(WFLOW,TPC4,KPCV,KPCC,TPC5,ITPC5)
      DTPC6,RPC6,BPC6=PIPE1(WFLOW,TPC5,KPCV,KPCC,TPC6,ITPC6)
      DTPC7,RPC7,BPC7=PIPE1(WFLOW,TPC6,KPCV,KPCC,TPC7,ITPC7)
      DTPC8,RPC8,BPC8=PIPE1(WFLOW,TPC7,KPCV,KPCC,TPC8,ITPC8)
      DTPC9,RPC9,BPC9=PIPE1(WFLOW,TPC8,KPCV,KPCC,TPC9,ITPC9)
      DTPC10,RPC10,BPC10=PIPE1(WFLOW,TPC9,KPCV,KPCC,TPC10,ITPC10)

      TPCO=TPC10

      RPCAV=(RPC1+RPC2+RPC3+RPC4+RPC5+RPC6+RPC7+RPC8+RPC9+RPC10)/KPCN
      BPCT=BPC1+BPC2+BPC3+BPC4+BPC5+BPC6+BPC7+BPC8+BPC9+BPC10
```

Figure 6.1-3. Listing of 10 Node Pipe Models for use in the process-flow and pressurizer models. This serves as a reminder that these equations must be modified if the number of nodes are changed by the user.

6.2 HEAT EXCHANGER MODELS

The schematic representation of the model is shown in Figure 6.2-1. Each node is represented by the equations coded in MACRO SPCFHX as shown in Figure 6.2-2. Development of the MACRO equations is facilitated by the sketch shown below for a single node.

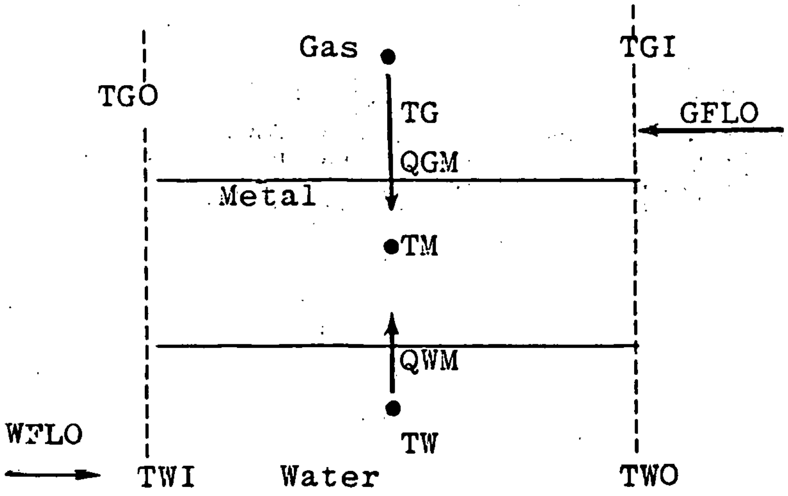

Figure 6.2-1. Sample Heat Exchanger Node Model Schematic

```
MACRO TGO,TWO,DTM,DTW,QGM,QWM,RW,BW=SPCFHX(TGI,TWI,ITM,TM,ITW,TW,...
     MCAP,VOL,WTG1,WTG2,WTW1,WTW2,JGCP,WFLOW,JC,JHTW)
*    SEE SECTION 6.2 OF REPORT
*   SINGLE PHASE COUNTER FLOW HEAT EXCHANGER WITH INCOMPRESSABLE
*   FLUID ON W SIDE AND NEGLIGIBLE FLUID THERMAL CAPACITY ON G SIDE
*   TGO=GAS EXIT TEMP, QGM=ENERGY TRANSFER GAS TO METAL
*   RW=AVERAGE NODAL DENSITY, TW=AVERAGE NODAL TEMP,
*   QWM=HEAT TRANSFER WATER TO METAL, TWO=WATER EXIT TEMP
      RW=AFGEN(RFTSL,TW)
      TGO=(TGI*(1.-WTG1*JC)+JC*TM)/(1.+WTG2*JC)
      QGM=JGCP*(TGI-TGO)
      TWO=(TW-WTW1*TWI)/WTW2
      QWM=JHTW*(TW-TM)
      DTM=(QWM+QGM)/MCAP
      TM=INTGRL(ITM,DTM)
      DTW=(WFLOW*(TWI-TWO)-QWM/KUNWCP)/VOL/RW
      BW=DTW*VOL*AFGEN(PARTRT,TW)
      TW=INTGRL(ITW,DTW)
ENDMAC
```

Figure 6.2-2. Listing of MACRO SPCFHX

The gas side energy balance is algebraic. The exit temperature TGO is determined by simultaneous solution of

QGM = JHT*(TG-TM)

QGM = KCPG*GFLO*(TGI-TGO)

and

TG = WTGI*TGI+WTG2*TGO

where

JHT = lumped overall coefficient of heat transfer from gas to metal $\left(\frac{\text{BTU}}{^{\circ}\text{F-Sec}}\right)$

KCPG = specific heat of gas (BTU/lb)

WTG1, WTG2 = gas side weighting, generally 0.5, but always constrained to WTG1 + WTG2 = 1.

The unknowns QGM and TG are eliminated by substituting the third equation into the first (to eliminate TG) and subsequently subtracting the result from the second equation to obtain

KCPG*GFLO*(TGI-TGO) = JHT*(WTG1*TGI+WTG2*TGO-TM)

Defining

JC = JHT/(KCPG*GFLOW) , (6.2-1)

and rearranging yields

TGO*(1+WTG2*JC) = TGI*(1-WTG1*JC)+JC*TM

and, finally,

TGO = (TGI*(1-WTGI*JC)+JC*TM)/(1+WTG2*JC) (6.2-2)

The energy transferred from gas to metal is subsequently calculated from the second of the three original equations written as

QGM = JG*(TGI-TGO) (6.2-3)

where

JG = KPPG*GFLO (6.2-4)

Equations (6.2-1) and (6.2-4) are not included in MACRO SPCFHX. The defined parameters are instead provided as inputs. The reason is that they are the same for all nodes when the heated zone is broken into equally spaced divisions.

The fourth equation in MACRO SPCFHX is a simple rearrangement of

TW = WTW1*TWI+WTW2*TWO

which relates average, inlet, and exit temperatures.

The fifth equation calculates the flow of heat from the water to the metal, e.g.,

QWM = JHTR*(TW-TM) ,

where JHTR (BTU/^{O}F/sec) is the overall coefficient of heat transfer from water to metal, which is a MACRO input.

The metal and water temperatures are obtained from differential energy balances given by

MCAP*DTM = (QWM+QGM)

and

KUNWCP*VOL*RW*DTW = (KUNWCP*WFLOW*(TWI-TWO)-QWM)

where

KUNWCP = specific heat of water (BTU/lb/^{O}F)

RW = nodal density (lbs/Ft^{3})

MCAP = nodal thermal capacity of metal (BTU/^{O}F)

VOL = nodal volume of water (Ft^{3}).

6.2.1 Core Auxiliary Heat Exchanger

The core auxiliary heat exchanger model is represented schematically in Figure 6.2.1-1. The heated zone employs six equally spaced divisions, each represented as described in Section 6.2 of this report. The inlet and outlet headers are represented by a single node. The thermal capacity of containment surfaces peculiar to each is lumped with the water thermal capacity.

The program listing for the CAHE model is given in Figure 6.2.1-2.

The last two equations calculate average density RHWAV of the water in the heated zone and the total rate of expansion or contraction BHWT for use in the process-flow and pressurizer models. The calculations are included here as a reminder that they must be modified if the number of nodes in the heated zone is changed.

The heat transfer coefficients for the CAHE are calculated in the MACRO HTKOE. The gas side thermal resistance can be expressed as

$$R_{He} = \frac{3600}{h}$$

where the heat transfer coefficient is defined as

$$h = \frac{k_G}{D_H} (.023)\ N_{R_e}^{0.8} * N_{p_r}^{1/3}$$

also the Reynolds number can be expressed as

$$N_{R_e} = \left(\frac{\dot{m}_H D_H}{\mu_G A_F} \right)$$

and the Prandtl number as

$$N_{p_r} = \left(\frac{C_{p_G} \mu_G}{k_G} \right)$$

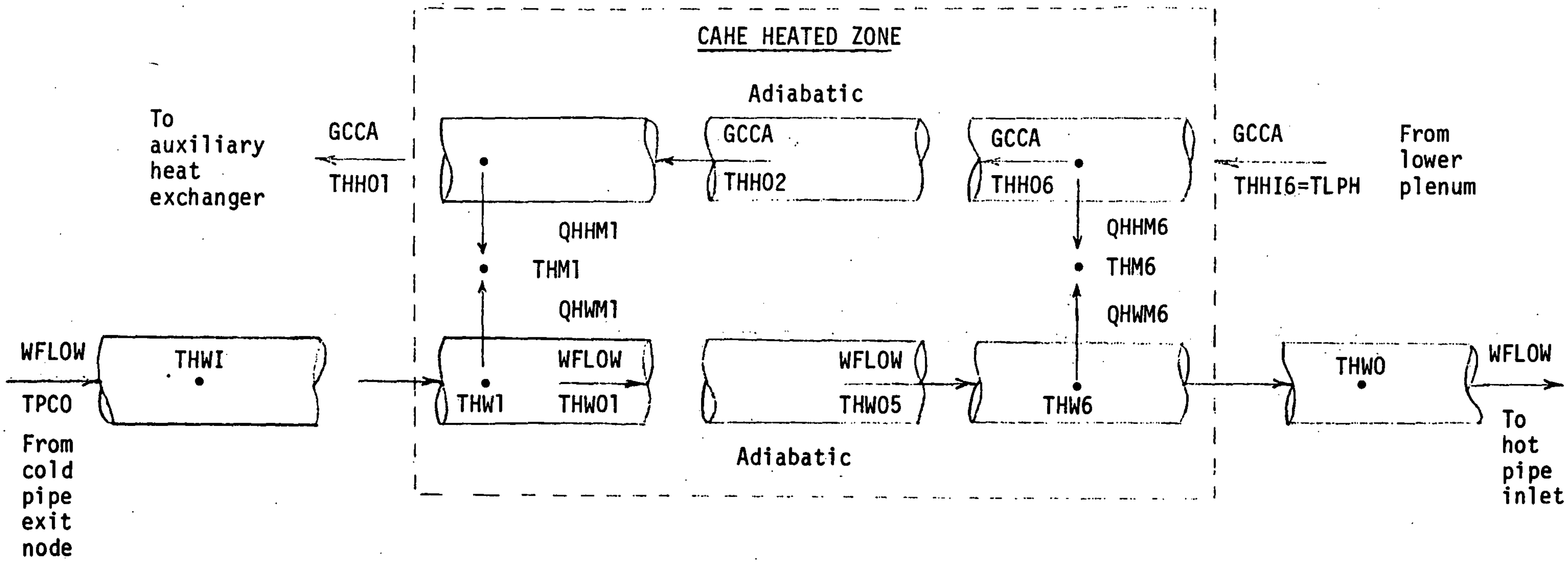

Figure 6.2.1-1. Core Auxiliary Heat Exchanger Modeling Schematic

```
*        CAHE INLET AND EXIT WATER HEADER MODELS

        DTHWI,RHWI,BHWI=PIPE1(WFLOW,TPCO,KHWVI,KHMCI,THWI,ITHWI)
        DTHWO,RHWO,BHWO=PIPE1(WFLOW,THWO6,KHWVO,KHMCO,THWO,ITHWO)

*       CAHE HEATED ZONE MODEL

        MHHI6=144.*FNSS*KHHVI6/(KUNGR*THHI6)
        DTHHI6=GCAA*KUNHCF*(TLPH-THHI6)/(KUNHCV*MHHI6)
        THHI6=INTGRL(ITHHI6,DTHHI6)


        THH6,JHHM6,JHWM6=HTKOE(WFLOW,GCAA,JHHCP,THHI6,THHO6,THM6,THW6)
        THH5,JHHM5,JHWM5=HTKOE(WFLOW,GCAA,JHHCP,THHO6,THHO5,THM5,THW5)
        THH4,JHHM4,JHWM4=HTKOE(WFLOW,GCAA,JHHCP,THHO5,THHO4,THM4,THW4)
        THH3,JHHM3,JHWM3=HTKOE(WFLOW,GCAA,JHHCP,THHO4,THHO3,THM3,THW3)
        THH2,JHHM2,JHWM2=HTKOE(WFLOW,GCAA,JHHCP,THHO3,THHO2,THM2,THW2)
        THH1,JHHM1,JHWM1=HTKOE(WFLOW,GCAA,JHHCP,THHO2,THHO1,THM1,THW1)



        JHHCP=GCAA*KUNHCF
        THHO6,THWO6,DTHM6,DTHW6,QHHM6,QHWM6,RHW6,BHW6=SFCFHX(THHI6,...
          THWO5,ITHM6,THM6,ITHW6,THW6,KHMC,KHWV,KHHW1,KHHW2,...
          KHWW1,KHWW2,JHHCP,WFLOW,JHHM6,JHWM6)
        THHO5,THWO5,DTHM5,DTHW5,QHHM5,QHWM5,RHW5,BHW5=SFCFHX(THHO6,...
          THWO4,ITHM5,THM5,ITHW5,THW5,KHMC,KHWV,KHHW1,KHHW2,...
          KHWW1,KHWW2,JHHCP,WFLOW,JHHM5,JHWM5)
        THHO4,THWO4,DTHM4,DTHW4,QHHM4,QHWM4,RHW4,BHW4=SFCFHX(THHO5,...
          THWO3,ITHM4,THM4,ITHW4,THW4,KHMC,KHWV,KHHW1,KHHW2,...
          KHWW1,KHWW2,JHHCP,WFLOW,JHHM4,JHWM4)
        THHO3,THWO3,DTHM3,DTHW3,QHHM3,QHWM3,RHW3,BHW3=SFCFHX(THHO4,...
          THWO2,ITHM3,THM3,ITHW3,THW3,KHMC,KHWV,KHHW1,KHHW2,...
          KHWW1,KHWW2,JHHCP,WFLOW,JHHM3,JHWM3)
        THHO2,THWO2,DTHM2,DTHW2,QHHM2,QHWM2,RHW2,BHW2=SFCFHX(THHO3,...
          THWO1,ITHM2,THM2,ITHW2,THW2,KHMC,KHWV,KHHW1,KHHW2,...
          KHWW1,KHWW2,JHHCP,WFLOW,JHHM2,JHWM2)
        THHO1,THWO1,DTHM1,DTHW1,QHHM1,QHWM1,RHW1,BHW1=SFCFHX(THHO2,...
          THWI,ITHM1,THM1,ITHW1,THW1,KHMC,KHWV,KHHW1,KHHW2,...
          KHWW1,KHWW2,JHHCP,WFLOW,JHHM1,JHWM1)

        BHWT=BHWI+BHW1+BHW2+BHW3+BHW4+BHW5+BHW6+BHWO

        RHWAV=(RHW1+RHW2+RHW3+RHW4+RHW5+RHW6)/KHWN
```

Figure 6.2.1-2. Listing of CAHE Inlet and
Exit Water Header Models

where (see Reference 8 for numerical values)

μ_G = viscosity of the gas = $f(T_G)$ = HVIS

$= a_\mu * T_G^{\,b_\mu}$ $\quad a_\mu = 6.388 \times 10^{-4};\ b_\mu = .687$

k_G = thermal conductivity of the gas = $f(T_G)$ = HCON

$= a_k * T_G^{\,b_k}$ $\quad a_k = 1.062 \times 10^{-3};\ b_k = .701$

$\dot{m}_H$ = gas flow rate = HFLOW

P_w = wetted perimeter = π * number of tubes * outside diameter of the tubes

A_F = flow area

D_H = hydraulic diameter = $4\left(\frac{A_F}{P_w}\right)$

T_G = temperature of gas

C_{p_G} = specific heat of the gas = HSPH

Now writing R_{He} as

$$R_{He} = \left(\frac{3600}{.023}\right) * D_H * \left(\frac{D_H}{A_F}\right)^{-.8} * \left(\frac{1}{k_G}\right) * \left(\frac{\dot{m}_H}{\mu_G}\right)^{-.8} * \left(\frac{C_{p_G} * \mu_G}{k_G}\right)^{-1/3}$$

defining

KHHVK = a_μ

KHHVKE = b_μ

KHHCK = a_k

KHHCKE = b_k

$$\text{KHHRX} = \left(\frac{3600}{.023}\right) * D_H * \left(\frac{D_H}{A_F}\right)^{-.8}$$

results in the equation

$$R_{He} = \text{KHHRX/(HCON*(HFLOW*3600./HVIS)**.8*(HSPH*HVIS/HCON)**.333)}$$

The tube wall thermal resistance is given by

$$R_{MET} = \frac{\left(\frac{d_o}{2}\right)\left(\ln\left(\frac{d_o}{d_i}\right)\right)}{k}$$

where

d_o = tube outside diameter

d_i = tube inside diameter

k = thermal conductivity = $f(T_M)$

From Reference 8

$$k = 6.25 + .0055\ (T_M - 460)\ .$$

Now let

$$\text{KHMRX} = \left(\frac{d_o}{2}\right)\left(\ln\left(\frac{d_o}{d_i}\right)\right)$$

$$\text{KHMAK} = 6.25$$

$$\text{KHMBK} = .0055$$

$$R_{MET} = \frac{\text{KHMRX}}{\text{KHMAK} + \text{KHMBK}\ (T_M - 460)}$$

The expression for the water side thermal resistance is given by the same expression as the gas side; namely,

$$R_{WAT} = \left(\frac{3600}{.023}\right) * D_H * \left(\frac{D_H}{A_F}\right)^{-.8} * \left(\frac{1}{k_w}\right) * \left(\frac{\dot{m}_w}{\mu_w}\right)^{-.8} * \left(\frac{C_{p_w} * \mu_w}{k_w}\right)^{-1/3}$$

where

D_H = hydraulic diameter = inside diameter of the tubes

A_F = flow area

μ_w = viscosity of the water = $f(T_w)$ = VIS

k_w = thermal conductivity of the water = $f(T_w)$ = CON

C_{p_w} = specific heat of the water = $f(T_w)$ = SPH

T_w = temperature of the water

$\dot{m}_w$ = water flow rate = WFLOW

Let

$$KHWRX = \left(\frac{3600}{.023}\right) * D_H * \left(\frac{D_H}{A_F}\right)^{-.8}$$

Resulting in the expression

R_{WAT} = KHWRX/(CON*(WFLOW*3600./VIS)**.8*(SPH*VIS/CON)**.333)

It is convenient to define two intermediate variables JWAT and JHEL, which represent area correction factors used to calculate the equivalent overall thermal resistance. These terms are evaluated by the expressions

JWAT = (KHWA/KHWN)/(.5*RMET*KHWA/KHHA+RWAT)

JHEL = (KHHA/KHWN/JG)/(.5*RMET+RHEL)

where

JG = (Gas flow rate) * (specific heat)

These relationships are programmed in the MACRO HTKOE shown in Figure 6.2.1-3.

```
MACRO TG,JAIR,JWAT=HTCOE(WFLOW,GFLRAT,JCGP,TG1,TG2,TMET,TWAT)
*   SEE APPENDIX C OF REPORT
      TG=(TG1+TG2)/2
PROCED RAIR=RESX(GFLRAT)
       RAIR=KAAR*GFLRAT*(KAAAU+KAABU*(TG/KAATR))**.681/...
       (KAAAK+KAABK*TG/KAATR)
ENDPRO
      RMET=KAMR/(KAMAK-KAMBK*TMET/KAMTR)
      CON=AFGEN(FCON,TWAT)
      VIS=AFGEN(FVIS,TWAT)
      SPH=AFGEN(FSPH,TWAT)
      RWAT=KAWRX/(CON*(WFLOW*3600./VIS)**.8*...
          (SPH*VIS/CON)**.333)
      JAIR=KAAA/KAWN/(0.5*RMET+RAIR)/JCGP
      JWAT=KAWA/KAWN/(0.5*RMET*KAWA/KAAA+RWAT)
ENDMAC
```

Figure 6.2.1-3. CAHE Heat Transfer MACRO

6.2.2 Air Blast Heat Exchanger

The air blast heat exchanger model is shown schematically in Figure 6.2.2-1. It is similar in form to the CAHE model except the heated zone has ten equal segments rather than six.

The program listing for this model is shown in Figure 6.2.2-2.

The heat transfer coefficients for the CAAB are calculated in the MACRO, HTCOE. The equations presented in this section and the values for the various parameters are found in Reference 8. The thermal resistance between the tube and the air can be expressed as

$$R_{AIR} = \frac{R_r \cdot (3600) \cdot \left(\frac{G_a}{G_r}\right)^{-.681} \left[\frac{a_\mu + b_\mu T_a}{a_\mu + b_\mu T_r}\right]^{.681}}{\left[\frac{a_k + b_k T_a}{a_k + b_k T_r}\right]}$$

where

R_r = reference air resistance

G_a = average air flow

G_r = reference air flow

T_a = average air temperature

T_r = reference air temperature

$a_\mu = 1.501 \times 10^{-2}$

$b_\mu = 5.429 \times 10^{-5}$

$a_k = 3.22 \times 10^{-3}$

$b_k = 2.195 \times 10^{-5}$

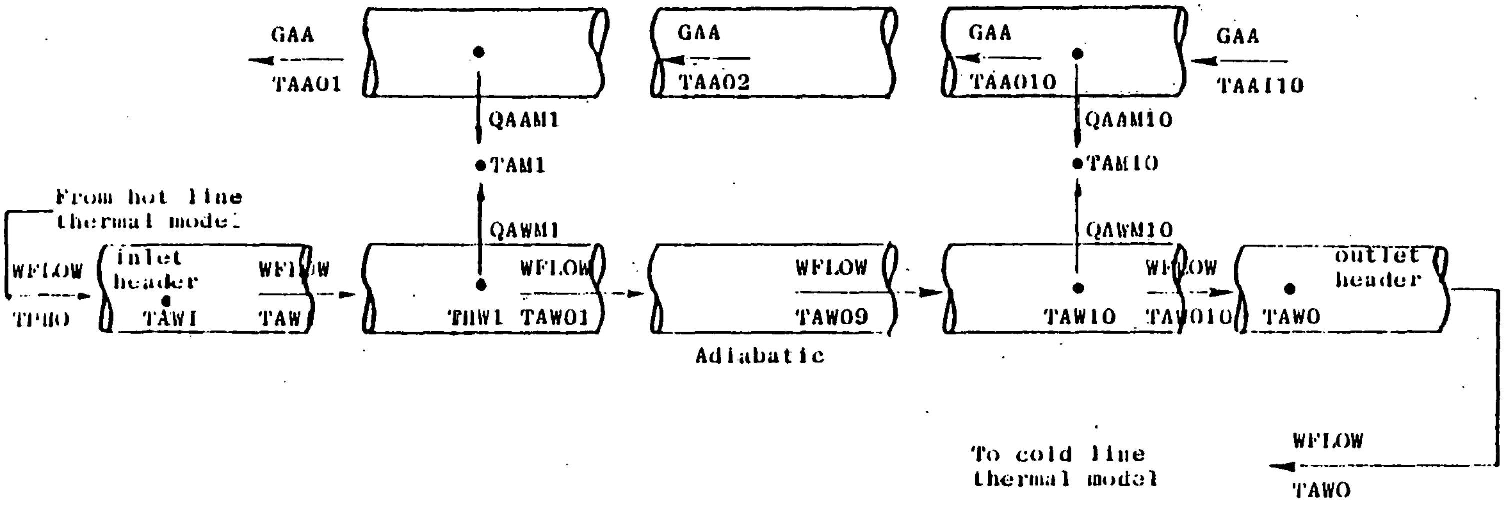

Figure 6.2.2-1. Air Blast Heat Exchanger Modeling Schematic

```
DTAWI,RAWI,BAWI=PIPE1(WFLOW,TFHO,KAWVI,KAMCI,TAWI,ITAWI)
DTAWO,RAWO,BAWO=PIPE1(WFLOW,TAWO10,KAWVO,KAMCO,TAWO,ITAWO)


TAA10,JAAM10,JAWM10=HTCOE(WFLOW,JAAGR,JAACP,TAAI10,TAAO10,...
TAM10,TAW10)
TAA9,JAAM9,JAWM9=HTCOE(WFLOW,JAAGR,JAACP,TAAO10,TAAO9,TAM9,TAW9)
TAA8,JAAM8,JAWM8=HTCOE(WFLOW,JAAGR,JAACP,TAAO9,TAAO8,TAM8,TAW8)
TAA7,JAAM7,JAWM7=HTCOE(WFLOW,JAAGR,JAACP,TAAO8,TAAO7,TAM7,TAW7)
TAA6,JAAM6,JAWM6=HTCOE(WFLOW,JAAGR,JAACP,TAAO7,TAAO6,TAM6,TAW6)
TAA5,JAAM5,JAWM5=HTCOE(WFLOW,JAAGR,JAACP,TAAO6,TAAO5,TAM5,TAW5)
TAA4,JAAM4,JAWM4=HTCOE(WFLOW,JAAGR,JAACP,TAAO5,TAAO4,TAM4,TAW4)
TAA3,JAAM3,JAWM3=HTCOE(WFLOW,JAAGR,JAACP,TAAO4,TAAO3,TAM3,TAW3)
TAA2,JAAM2,JAWM2=HTCOE(WFLOW,JAAGR,JAACP,TAAO3,TAAO2,TAM2,TAW2)
TAA1,JAAM1,JAWM1=HTCOE(WFLOW,JAAGR,JAACP,TAAO2,TAAO1,TAM1,TAW1)


JAACP=GAA*KUNACP
JAAGR=(GAA/KAAG)**-.681
TAAO10,TAWO10,DTAM10,DTAW10,QAAM10,QAWM10,RAW10,BAW10=SPCFHX(...
 TAAI10,TAWO9,ITAM10,TAM10,ITAW10,TAW10,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM10,JAWM10)
TAAO9,TAWO9,DTAM9,DTAW9,QAAM9,QAWM9,RAW9,BAW9=SPCFHX(TAAO10,...
 TAWO8,ITAM9,TAM9,ITAW9,TAW9,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM9,JAWM9)
TAAO8,TAWO8,DTAM8,DTAW8,QAAM8,QAWM8,RAW8,BAW8=SPCFHX(TAAO9,...
 TAWO7,ITAM8,TAM8,ITAW8,TAW8,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM8,JAWM8)
TAAO7,TAWO7,DTAM7,DTAW7,QAAM7,QAWM7,RAW7,BAW7=SPCFHX(TAAO8,...
 TAWO6,ITAM7,TAM7,ITAW7,TAW7,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM7,JAWM7)
TAAO6,TAWO6,DTAM6,DTAW6,QAAM6,QAWM6,RAW6,BAW6=SPCFHX(TAAO7,...
 TAWO5,ITAM6,TAM6,ITAW6,TAW6,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM6,JAWM6)
TAAO5,TAWO5,DTAM5,DTAW5,QAAM5,QAWM5,RAW5,BAW5=SPCFHX(TAAO6,...
 TAWO4,ITAM5,TAM5,ITAW5,TAW5,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM5,JAWM5)
TAAO4,TAWO4,DTAM4,DTAW4,QAAM4,QAWM4,RAW4,BAW4=SPCFHX(TAAO5,...
 TAWO3,ITAM4,TAM4,ITAW4,TAW4,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM4,JAWM4)
TAAO3,TAWO3,DTAM3,DTAW3,QAAM3,QAWM3,RAW3,BAW3=SPCFHX(TAAO4,...
 TAWO2,ITAM3,TAM3,ITAW3,TAW3,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM3,JAWM3)
TAAO2,TAWO2,DTAM2,DTAW2,QAAM2,QAWM2,RAW2,BAW2=SPCFHX(TAAO3,...
 TAWO1,ITAM2,TAM2,ITAW2,TAW2,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM2,JAWM2)
TAAO1,TAWO1,DTAM1,DTAW1,QAAM1,QAWM1,RAW1,BAW1=SPCFHX(TAAO2,...
 TAWI,ITAM1,TAM1,ITAW1,TAW1,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM1,JAWM1)


RAWAV=(RAW1+RAW2+RAW3+RAW4+RAW5+RAW6+RAW7+RAW8+RAW9+RAW10)/KAWN

BAWT=BAWI+BAW1+BAW2+BAW3+BAW4+BAW5+BAW6+BAW7+BAW8+...
     BAW9+BAW10+BAWO
```

Figure 6.2.2-2. Listing for Air Blast Heat Exchanger Model

Now define

$$KAAR = R_r*3600$$

$$KAAAK = a_k/(a_k+b_kT_r)$$

$$KAABK = b_kT_r/(a_k+b_kT_r)$$

$$KAAAU = a_\mu/(a_\mu+b_\mu T_r)$$

$$KAABU = b_\mu T_r/(a_\mu+b_\mu T_r)$$

$$GFRAT = G_a/G_r$$

$$TG = T_a$$

$$KAATR = T_r$$

then

$$R_{AIR} = KAAR*(GFRAT)**(-.681)*(KAAAU+KAABU*(TG/KAATR))**.681/(KAAAK+KAABK*TG/KAATR)$$

Thermal resistance of the tube wall can be expressed as

$$R_{MET} = \frac{\left(\frac{d_o}{2}\right)\left(\ln\left(\frac{d_o}{d_i}\right)\right)}{k}$$

where

d_o = tube outside diameter

d_i = tube inside diameter

and

k = thermal conductivity = $f(T_M)$

$= 29.1 + .0059 \cdot (T_{MET} - 460)/3600$

in terms of the reference metal temperature ($T_{Mr} = 722$)

$$k = .8837 \times 10^{-2} - .1183 \times 10^{-2} \, (T_{MET}/722)$$

$\therefore$

$$R_{MET} = \frac{\left(\frac{d_o}{2}\right)\left(\ln\left(\frac{d_o}{d_i}\right)\right)}{\left[.8837\text{x}10^{-2} - .1183\text{x}10^{-2}(T_{MET}/722)\right]}$$

now let

$$R_{MET} = R_r/K'$$

where

$$R_r = \text{reference metal resistance}$$

$$= R_{MET}\ (722)$$

$$= 1.08$$

also

$$K' = k \left\{ R_r/\left(\frac{d_o}{2}\right)\left[\ln\left(\frac{d_o}{d_i}\right)\right]\right\}$$

$$= k \cdot (130.65)$$

now

$$R_{MET} = \frac{R_r}{k \cdot (130.65)}$$

define

KAMR = R_r

KAMAK = $(130.65)(.8837\text{x}10^{-2})$

KAMBK = $(130.65)(.1183\text{x}10^{-2})$

KAMTR = reference metal temperature

Then R_{MET} = KAMR/(KAMAK-KAMBK*TMET/KAMTR)

The thermal resistance of the water side is defined as follows:

Let

$$R_{WAT} = \frac{3600}{h}$$

where the heat transfer coefficient is defined as

$$h = \frac{k_w}{D_H} \cdot (.023) \cdot \left(\frac{m_w D_H}{A_F \mu_w}\right)^{.8} \cdot \left(\frac{C_p \mu_w}{k_w}\right)^{1/3}$$

rearranging yields

$$R_{WAT} = 3600 \cdot \left(\frac{D_H}{.023}\right) \cdot \left(\frac{D_H}{A_F}\right)^{-.8} \cdot \left[\frac{k_w}{\left(\frac{\dot{m}_w}{\mu_w}\right)^{.8} \cdot \left(\frac{C_p \mu_w}{k_w}\right)^{1/3}}\right]$$

now defining

$$KAWRX = 3600 \frac{D_H}{.023} \cdot \frac{D_H}{A_F}^{-.8}$$

where

D_H = hydraulic diameter

= tube inside diameter

and

A_F = water flow area

μ_w = viscosity of water = $f(T_w)$ = VIS

k_w = thermal conductivity of water = $f(T_w)$ = CON

C_{p_w} = specific heat of water = $f(T_w)$ = SPH

T_w = temperature of water

$\dot{m}_w$ = water flow rate = WFLOW

Then R_{WAT} = KAWRX*CON/((WFLOW*3600./VIS)**.8*(SPH*VIS/CON)**.333)

It is convenient to define two intermediate variables, JAIR and JWAT, which represent area correction factors used to calculate the equivalent overall thermal resistance. These terms are evaluated by the expressions

JAIR = KAAA/KAWN/(0.5*RMET+RAIR)/JCGP

JWAT = KAWA/KAWN/(0.5*RMET*KAWA/KAAA+RWAT)

where

JCGP = (air flow rate) * (specific heat)

These expressions are programmed in the MACRO HTCOE as shown on Figure 6.2.2-3.

```
MACRO TG,JHEL,JWAT=HTKOE(WFLOW,HFLOW,JG,T1,T2,TM,TW)
*   SEE APPENDIX C OF REPORT
      TG=(T1+T2)/2
PROCED RHE=RESY(HFLOW)
      HSPH=1.242
      HVIS=KHHVK*TG**KHHVKE
      HCON=KHHCK*TG**KHHCKE
      RHE=KHHRX/(HCON*(HFLOW*3600./HVIS)**.8*...
            (HSPH*HVIS/HCON)**.333)
ENDPRO
      RMET=KHMRX/(KHMAK+KHMBK*(TM-460.))
      CON=AFGEN(FCON,TW)
      VIS=AFGEN(FVIS,TW)
      SPH=AFGEN(FSPH,TW)
      RWAT=KHWRX/(CON*(WFLOW*3600./VIS)**.8*...
         (SPH*VIS/CON)**.333)
      JWAT=(KHWA/KHWN)/(.5*RMET*KHWA/KHHA+RWAT)
      JHEL=(KHHA/KHWN/JG)/(.5*RMET+RHE)
ENDMAC
```

Figure 6.2.2-3. Air Blast Heat Exchanger Heat Transfer Coefficient MACRO

6.3 REACTOR MODEL

The active core model consists of a single equivalent fuel channel and a bypass channel. The fuel pin at the center of the equivalent fuel channel is based upon actual fuel pin geometry. Its properties, the rate of energy produced within it, and the fraction of total reactor flow which cools it represent the average for the 30,834 fuel pins in the reactor. Since some of the energy from the fission process appears in reactor elements other than the fuel pins (e.g., the control rods) and, since these elements are cooled by helium flowing through the core, fractions of total reactor power and helium flow are accorded to a bypass channel.

6.3.1 Equivalent Channel Model

The equivalent channel model is based upon a representative fuel pin. The fuel pins are cylindrical in appearance, with an annular cylinder of stainless steel cladding serving as the fuel container. The fuel is in the form of donut-shaped pellets stacked vertically within the cladding. The composition of the fuel pellets is varied to affect the power distribution within the reactor as a whole. It will be assumed that these variations do not affect the thermal properties of the fuel. The effect on axial power distribution will, however, be approximated.

As shown in Figure 6.3.1-1, a portion of the cladding surface has been artifically roughened to improve heat transfer from cladding to coolant. It also shows upper and lower axial regions in which the fuel composition contains a high concentration of isotopes which produce fuel through parasitic capture of neutrons. The power produced in these axial regions will thus be considerably lower than that produced in the central region, especially during early portions of the fuel cycle. The implication is that there should be a minimum of four axial regions included in the equivalent channel model. In current

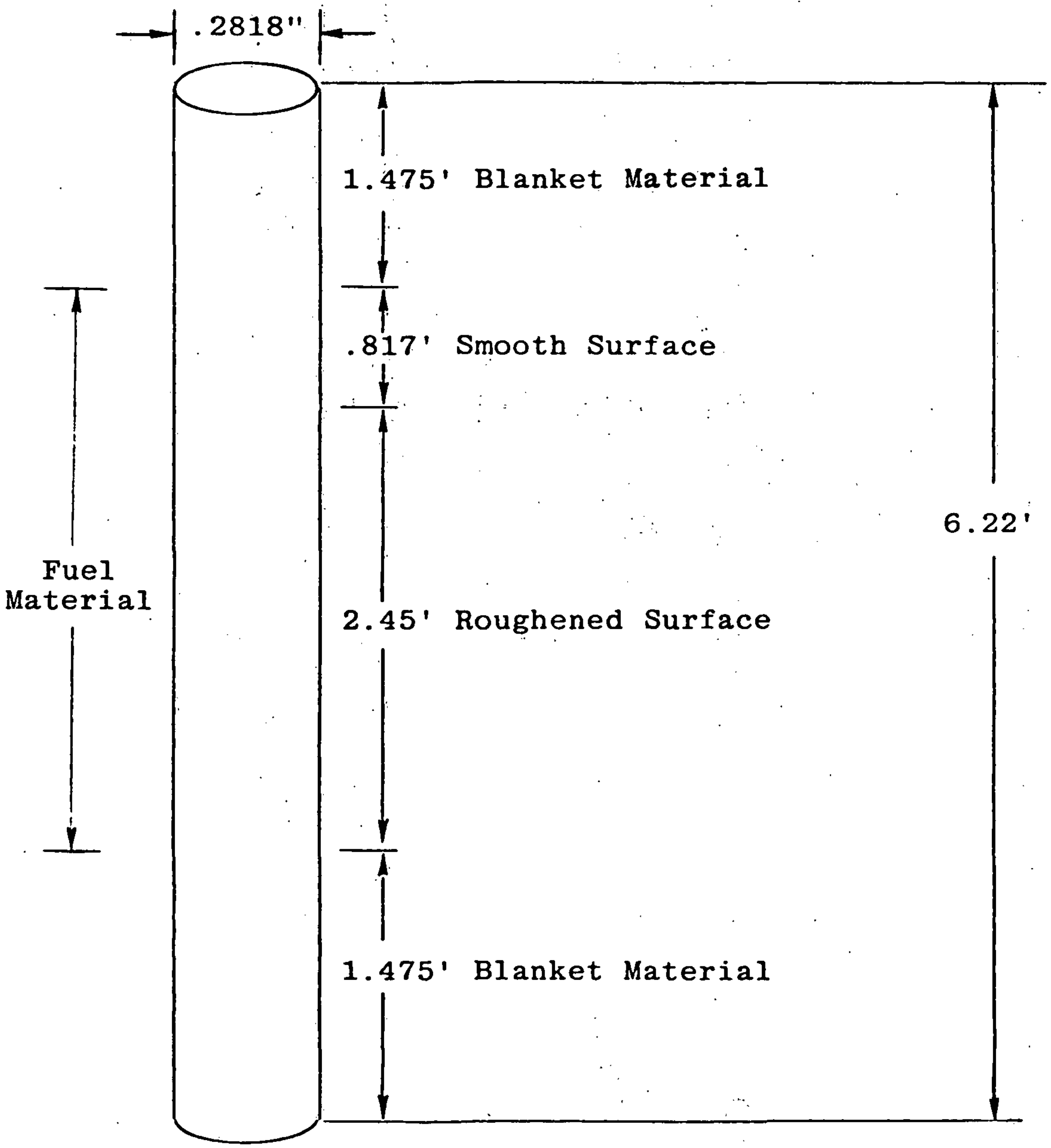

Figure 6.3.1-1. Representative Fuel Pin

configurations, the region with roughened surface is divided into three axial subdivisions. The resulting model, shown schematically in Figure 6.3.1-2, contains six axial regions. Each axial region contains three radial regions corresponding to fuel, cladding and coolant.

Several assumptions are made in the development of this model. It is convenient to summarize the major assumptions before proceeding.

1. Axial heat transfer between adjacent solid nodes is negligible in comparison to radial heat transfer.
2. Helium obeys the ideal gas law.
3. Helium mass flow is instantaneously in equilibrium with circulator flows and is uniform along the channel length.

The equivalent fuel channel model development can be accomplished on a modular basis wherein each module corresponds to one fuel region, as shown in Figure 6.3.1-3.

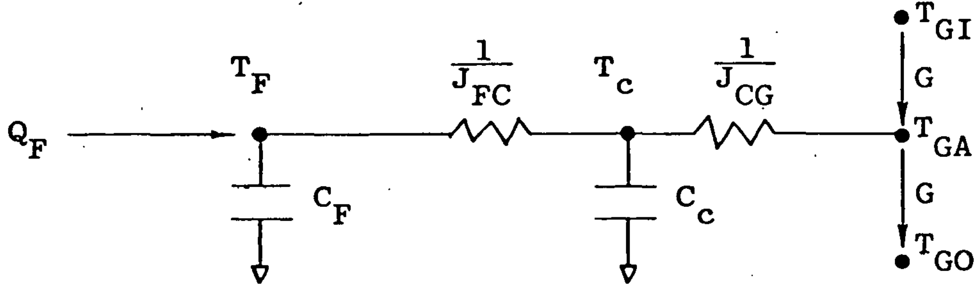

Figure 6.3.1-3. Single Equivalent Fuel Channel Module (MACRO CRNODE)

Inputs to this module are inlet helium temperature T_{GI}(^oR) and flow rate G (lbs/sec), heat generation rate within the fuel Q_F(Btu/sec), thermal conductances between fuel and cladding J_{FC} (Btu/sec/^oR) and cladding and coolant J_{CG} (Btu/sec/^oR), and the fuel and cladding volumes needed to calculate the thermal capacitances C_F (Btu/^oR) and C_c (Btu/^oR). Outputs are fuel temperatures T_F (^oR), cladding temperatures T_c (^oR), average helium temperature T_{GA} (^oR), and helium exit temperature T_{GO} (^oR). The describing equations are based upon energy balances written for the fuel, the cladding, and the coolant.

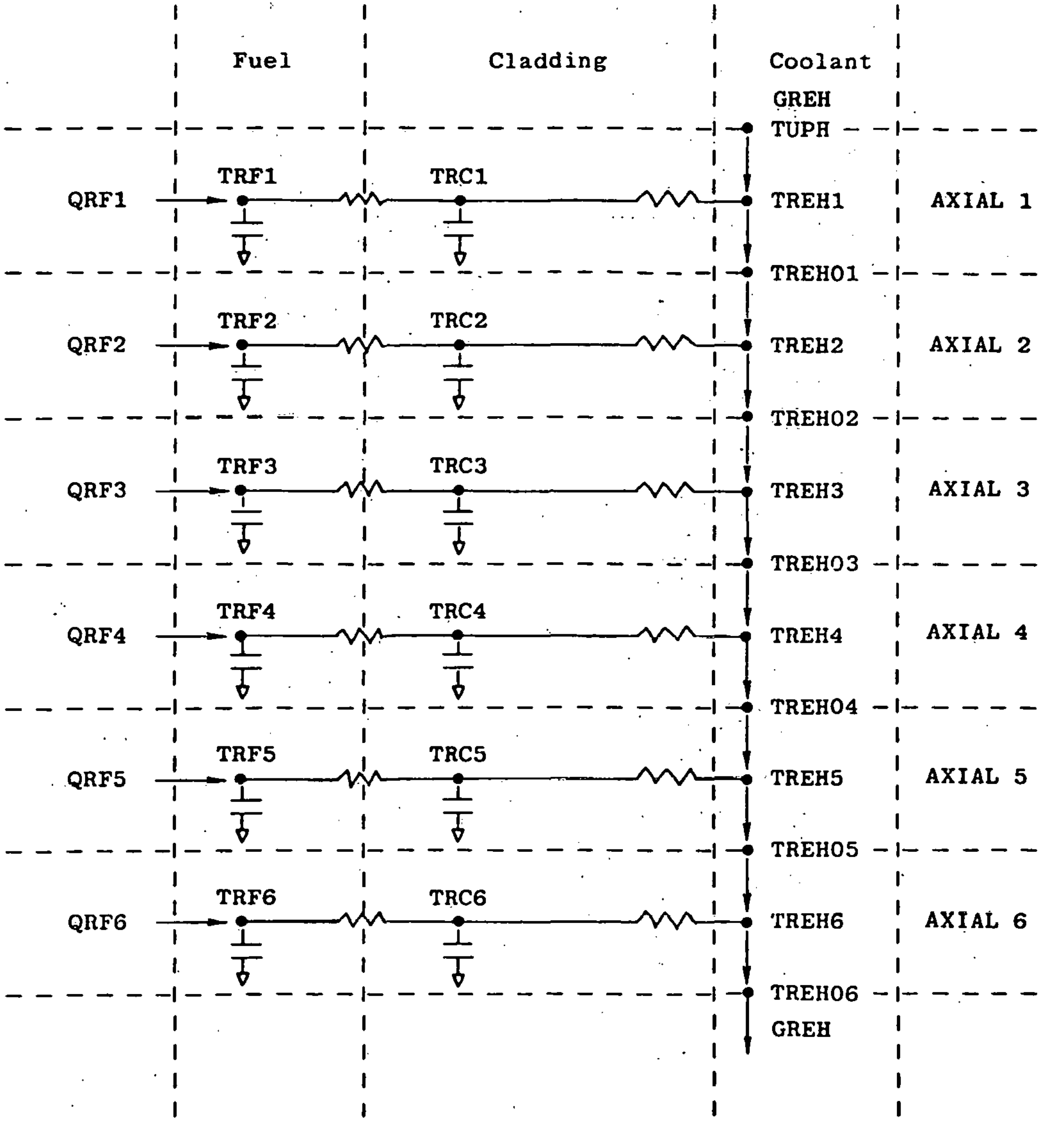

Figure 6.3.1-2. Modeling Schematic for the Equivalent Fuel Channel Model

The energy balance applied to the fuel can be expressed as

$$\begin{bmatrix}\text{Rate of change}\\ \text{of stored energy}\\ \text{in the volume}\end{bmatrix} = \begin{bmatrix}\text{Rate of heat}\\ \text{generation with-}\\ \text{in the volume}\end{bmatrix} - \begin{bmatrix}\text{Rate of heat}\\ \text{transfer}\\ \text{radially to}\\ \text{the cladding}\end{bmatrix}$$

which is equivalent mathematically to

$$C_F(DT_F) = Q_F - Q_{FC}$$

where $D = \frac{d}{dt}$ and Q_{FC} is the rate of energy transfer from fuel to cladding, which from Figure 6.3.1-3 can be written as

$$Q_{FC} = J_{FC}(T_F - T_C)$$

Dividing both sides of the energy balance by C_F yields

$$DT_F = (Q_F - Q_{FC})/C_F$$

The thermal capacity can be written as

$$C_F = (\rho C)_F V_F$$

where $(\rho C)_F = f(T_F)$

The energy balance for the cladding can be expressed as

$$\begin{bmatrix}\text{Rate of charge}\\ \text{of stored energy}\\ \text{in the cladding}\end{bmatrix} = \begin{bmatrix}\text{Rate of addition}\\ \text{by heat transfer}\\ \text{from the fuel}\end{bmatrix} - \begin{bmatrix}\text{Rate of loss by}\\ \text{heat transfer}\\ \text{to coolant}\end{bmatrix}$$

or in equation form

$$C_c(DT_c) = (Q_{FC} - Q_{CG})$$

where from Figure 6.3.1-3

$$Q_{CG} = J_{CG}(T_c - T_{GA})$$

The energy balance is converted to final form by dividing both sides to C_c to obtain

$$DT_c = (Q_{FC} - Q_{CG})/C_c$$

The thermal capacity is defined by

$$C_c = (\rho C)_c V_c$$

where

$$(\rho C)_c = f(T_c)$$

The energy balance for the coolant (helium) node can be expressed as

$$\begin{bmatrix}\text{Rate of change}\\ \text{of stored energy}\\ \text{in fluid volume}\end{bmatrix} = \begin{bmatrix}\text{Rate of gain of}\\ \text{thermal energy by}\\ \text{convection at the}\\ \text{inlet}\end{bmatrix} - \begin{bmatrix}\text{Rate of loss of}\\ \text{thermal energy}\\ \text{by convection}\\ \text{at the outlet}\end{bmatrix} + \begin{bmatrix}\text{Rate of heat}\\ \text{transfer from}\\ \text{the cladding}\\ \text{surface}\end{bmatrix}$$

which, neglecting energy storage in the helium, is mathematically equivalent to

$$0 = C_P G T_{GI} - C_P G T_{GO} + J_{CG}(T_c - T_{GA}) \qquad (6.3.1\text{-}1)$$

where T_{GO} and T_{GA} are both unknown, and a second expression is required relating the average temperature to the inlet and exit temperatures. It is customary to relate these according to

$$T_{GA} = J_w T_{GI} + (1. - J_w) T_{GO} \qquad (6.3.1\text{-}2)$$

where J_w is a linear weighting coefficient which can be related to the temperature distribution along the coolant channel. Alternatively, it can be determined from the expression

$$J_w = 1. - 1./(1. - \mathrm{EXP}(-J_L)) + 1./J_L \qquad (6.3.1\text{-}3)$$

where

$$J_L = J_{CG}/(G * C_p) \qquad (6.3.1\text{-}4)$$

Since the means of arriving at equation 6.3.1-3 requires discussion, the derivation will be postponed until equations 6.3.1-1 and 6.3.1-2 have been combined to eliminate T_{GA} and thus obtain T_{GO}. First, equation 6.3.1-1 is rewritten in light of equation 6.3.1-4 to read

$$0 = T_{GI} - T_{GO} + J_L(T_c - T_{GA}) \qquad (6.3.1\text{-}5)$$

Substituting from Equation 6.3.1-2

$$0 = T_{GI} - T_{GO} + J_L T_c - J_L J_w T_{GI} - J_L(1. - J_w) T_{GO} \qquad (6.3.1\text{-}6)$$

and solving for T_{GO} yields

$$T_{GO} = (T_{GI}(1. - J_L J_w) + J_L T_c)/(1. + J_L(1. - J_w)) \qquad (6.3.1\text{-}7)$$

which, along with Equations 6.3.1-2 through 6.3.1-4, determines T_{GA} and T_{GO}.

$$T_{GA} = T_c - \frac{1}{J_L} (T_c - T_{GI}) (1. - EXP(-J_L)) \qquad (6.3.1\text{-}8)$$

and

$$T_{GO} = T_{GI} + (T_c - T_{GI}) (1. - EXP(-J_L)) \qquad (6.3.1\text{-}9)$$

These equations are valid under steady-state conditions with a constant surface temperature. Defining $x = 1 - EXP(-J_L)$ and resolving Equation 6.3.1-9 in favor of T_c yields

$$T_c = \frac{1}{x} T_{GO} + (1. - \frac{1}{x}) T_{GI} \qquad (6.3.1\text{-}10)$$

Substituting into Equation 6.3.1-8 yields

$$T_{GA} = \frac{1}{x} T_{GO} + (1. - \frac{1}{x}) T_{GI} - \frac{x}{J_L} (\frac{1}{x} T_{GO} + (1. - \frac{1}{x}) T_{GI}) + \frac{x}{J_L} T_{GI} \qquad (6.3.1\text{-}11)$$

Simplifying,

$$\begin{aligned} T_{GA} &= (1. - \frac{1}{x} - \frac{x}{J_L} + \frac{1}{J_L} + \frac{x}{J_L}) T_{GI} + (\frac{1}{x} - \frac{1}{J_L}) T_{GO} \\ &= (1. - \frac{1}{x} + \frac{1}{J_L}) T_{GI} + (\frac{1}{x} - \frac{1}{J_L}) T_{GO} \qquad (6.3.1\text{-}12) \end{aligned}$$

Defining $J_w = 1. - \frac{1}{x} + \frac{1}{J_L}$

yields

$$T_{GA} = J_w T_{GI} + (1. - J_w) T_{GO} \qquad (6.3.1\text{-}13)$$

which is identical to Equation 6.3.1-2. Further, replacing x with (1. $EXP(-J_L)$) in the definition of J_w yields Equation 6.3.1-3.

The equivalent fuel channel model axial module is programmed in MACRO CRNODE, which is listed in Figure 6.3.1-4.

```
MACRO DTC,DTF,TGO,TGA=CRNODE(JGC,JCF,VF,VC,TGI,G,QRF,ITF,TF,ITC,TC)
*     SINGLE NODE FOR REACTOR EQUIVALENT FUEL CHANNEL MODEL
      JL=JGC/(G*KUNHCP)
      JW=1.-1./(1.-EXP(-JL))+1./JL
      TGO=(TGI*(1.-JL*JW)+JL*TC)/(1.+JL*(1.-JW))
      TGA=JW*TGI+(1.-JW)*TGO
      QGC=KUNHCP*G*(TGO-TGI)
      CF=0.5559*(52.492+0.03953*TF-1.512E-5*TF**2+2.203E-9*TF**3)
      CC=0.1196*(218.378+0.6541*TC-4.504E-4*TC**2+1.143E-7*TC**3)
      CAPF=VF*CF
      CAPC=VC*CC
      QFC=JCF*(TF-TC)
      DTF=(QRF-QFC)/CAPF
      TF=INTGRL(ITF,DTF)
      DTC=(QFC-QGC)/CAPC
      TC=INTGRL(ITC,DTC)
ENDMAC
```

Figure 6.3.1-4. Equivalent Fuel Channel MACRO CRNODE

It is accessed in the SYSL code for the six axial node equivalent channel model with the statements

```
DTRC1,DTRF1,TREHO1,TREH1=CRNODE(JRECK1,JRCFK1,KRFV1,KRCV1,TUPH,...
  GREH,QRF1,ITRF1,TRF1,ITRC1,TRC1)
DTRC2,DTRF2,TREHO2,TREH2=CRNODE(JRECK2,JRCFK2,KRFV2,KRCV2,...
  TREHO1,GREH,QRF2,ITRF2,TRF2,ITRC2,TRC2)
DTRC3,DTRF3,TREHO3,TREH3=CRNODE(JRECK3,JRCFK3,KRFV3,KRCV3,...
  TREHO2,GREH,QRF3,ITRF3,TRF3,ITRC3,TRC3)
DTRC4,DTRF4,TREHO4,TREH4=CRNODE(JRECK4,JRCFK4,KRFV4,KRCV4,...
  TREHO3,GREH,QRF4,ITRF4,TRF4,ITRC4,TRC4)
DTRC5,DTRF5,TREHO5,TREH5=CRNODE(JRECK5,JRCFK5,KRFV5,KRCV5,...
  TREHO4,GREH,QRF5,ITRF5,TRF5,ITRC5,TRC5)
DTRC6,DTRF6,TREHO6,TREH6=CRNODE(JRECK6,JRCFK6,KRFV6,KRCV6,...
  TREHO5,GREH,QRF6,ITRF6,TRF6,ITRC6,TRC6)
```

It will be noted that nodes are coupled through coolant temperatures. The output helium temperatures from node 1 becomes the input to node 2, and so on.

6.3.2 Thermal Conductances

The thermal conductances for the equivalent fuel channel model node can also be treated in modular fashion. The thermal resistances $1/J_{FC}$ and $1/J_{CG}$ are first broken into component parts for developmental purposes, as shown in Figure 6.3.2-1.

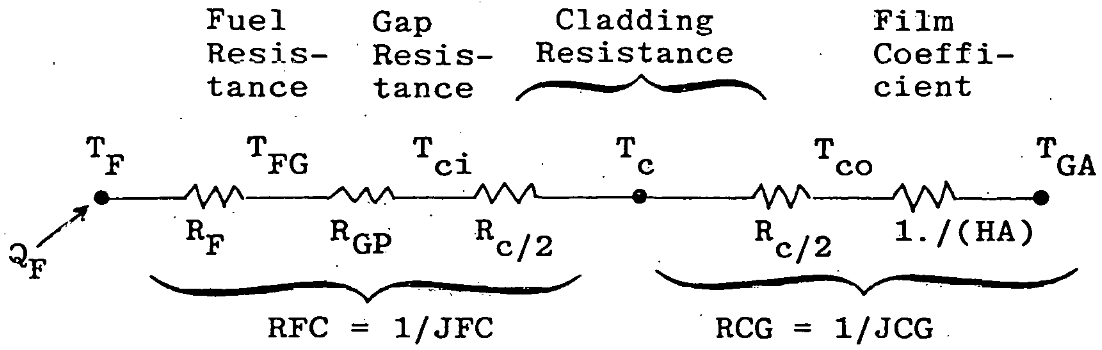

Figure 6.3.2-1. Schematic Representation of Thermal Conductance Module (MACRO CORHT)

The individual resistances are based upon the cross-section of a fuel pin shown in Figure 6.3.2-2.

The expression for fuel temperatures is developed by solution of

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{dT}{dr}\right) = -\frac{Q}{k_F} \qquad (6.3.2\text{-}1)$$

which, with negligible axial heat transfer, is valid at any axial position with boundary conditions

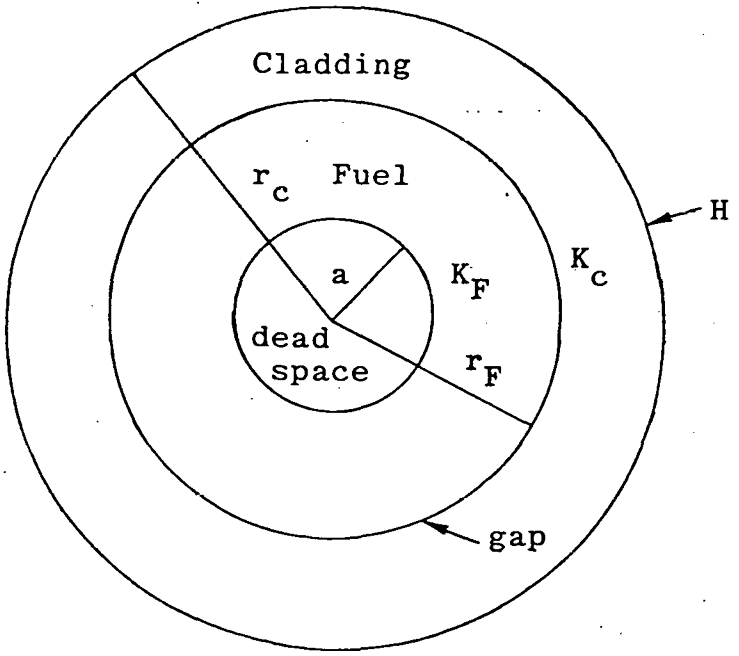

Figure 6.3.2-2. Cross-section of a Fuel Pin

$$\left.\frac{dT}{dr}\right|_{r=a} = 0 \quad ,$$

e.g., adiabatic boundary at r=a and

$$T\Big|_{r=r_F} = T_{FG}$$

where T_{FG} is the outer fuel surface temperature and Q is the volumetric rate of heating in the fuel region (assumed uniform $a \leq r \leq r_F$) multiplying Equation 6.3.2-1 by r and integrating

$$r\,\frac{dT}{dr} = -\,\frac{Qr^2}{2k_F} + C \quad . \qquad (6.3.2\text{-}2)$$

Applying the adiabatic boundary condition

$$C = \frac{Qa^2}{2k_F} \quad ,$$

Equation 6.3.2-2 becomes

$$\frac{dT}{dr} = \frac{Q}{2k_F}\left(\frac{a^2}{r} - r\right) \quad .$$

Integrating

$$T(r) = \frac{Qa^2}{2k_F}\,\ell n(r) - \frac{Qr^2}{4k_F} + C \qquad (6.3.2\text{-}3)$$

Applying the remaining boundary condition

$$C = T_{FG} + \frac{Qr^2{}_F}{4k_F} - \frac{Qa^2}{2k_F}\,\ell n(r_F)$$

and substituting into Equation 6.3.2-3

$$T(r) = T_{Fg} + \frac{a^2Q}{2k_F}\,\ell n\left(\frac{r}{r_F}\right) + \frac{r_F{}^2Q}{4k_F}\left[1 - \left(\frac{r}{r_F}\right)^2\right] \qquad (6.3.2\text{-}4)$$

To determine the resistance between the average fuel temperature and the temperature of the fuel surface at the gap, it is necessary to evaluate

$$T_F = \frac{\int_a^{r_F} rT(r)dr}{\int_a^{r_F} rdr}$$

with T(r) defined by Equation 6.3.2-4. The denominator is simply $(r_F^2 - a^2)/2$; hence,

$$T_F = \frac{2}{(r_F^2 - a^2)} \left\{ T_{FG} \int_a^{r_F} rdr + \frac{a^2 Q r_F^2}{2k_F} \int_{\frac{a}{r_F}}^{1} \left(\frac{r}{r_F} \ln \frac{r}{r_F}\right) d\frac{r}{r_F} \right.$$

$$\left. + \frac{Q}{4k_F} \int_a^{r_F} (r_F^2 - r^3)dr \right\} \quad . \qquad (6.3.2\text{-}5)$$

Equation 6.3.2-5 is valid at any axial position. Assuming it is also valid over the average, with T_F, T_{FG}, Q, and k_c referenced to the average over an axial length, L, allows R_F to be defined as

$$R_F = \frac{T_F - T_{FG}}{Q_F} = \frac{T_F - T_{FG}}{\pi(r_F^2 - a^2)LQ} \quad ,$$

which upon substitution of T_F from Equation 6.3.2-5 yields

$$R_F = \frac{1}{8\pi k_F L} \left[1 - 3\left(\frac{a}{r_F}\right)^2 - \frac{4\left(\frac{a}{r_F}\right)^4 \ln\left(\frac{a}{r_F}\right)}{\left[1 - \left(\frac{a}{r_F}\right)^2\right]} \right] \quad .$$

For $a = .0329/2$ and $r_F = .1219/2$, this becomes

$$R_F = .03229/(k_F L) \quad .$$

The regional axial length L is an input and fuel conductivity k_F (BTU/hr/ft/°F) is determined as a function of T_F (Ref. 4) according to

$$k_F = 57.78(.886) \Big[1/(18.2 + 0.0271\ T_F/1.8) + 5.5 \times 10^{-13}(T_F/1.8)^3\Big]/3600 \quad .$$

for fuel regions containing fuel material (20% enriched mixed oxide) and

$$k_F = 57.78(.896) \Big[1/(4.0 + 0.0257\ T_F/1.8) + 7.3 \times 10^{-13}(T_F/1.8)^3\Big]/3600 .$$

for fuel regions containing blanket material.

The cladding resistance R_c is determined from solution to

$$q = -k_c(2\pi rL)\frac{dT}{dr} \quad \text{where } k_c \text{ is the thermal conductivity} \qquad (6.3.2\text{-}6)$$

subject to the boundary condition

$$T(r)\Big|_{r=r_F} = T_{ci}$$

where the temperatures represent axial averages over length L, and q is the rate of heat transfer through the annular cladding region at steady state, thus

$$q = Q_F$$

Substituting for q in Equation 6.3.2-6 and integrating

$$T(r) = -\frac{Q_F}{2\pi Lk_c}\ \ell n\ r + C \quad .$$

Applying the boundary condition to determine C

$$C = T_{ci} + \frac{Q_F}{2\pi Lk_c}\ \ell n\ r_F$$

and substituting yields

$$T(r) = T_{ci} + \frac{Q_F}{2\pi Lk_c}\ \ell n\ \frac{r_F}{r} \quad , \qquad (6.3.2\text{-}7)$$

which defines the axially-average temperature at radius r. The cladding resistance R_c is defined by

$$R_c = \frac{T_{ci} - T_{co}}{Q_F} \quad .$$

Since $T_{co} = T(r_c)$, as evaluated by Equation 6.3.2-7, the expression for R_c becomes

$$R_c = \frac{\ell n\ \frac{r_c}{r_F}}{2\pi Lk_c} \quad .$$

For $r_F = .1219$ and $r_c = .1409$, this becomes

$$R_c = \frac{.02305}{Lk_c} \quad . \qquad (6.3.2\text{-}8)$$

The thermal conductivity of the cladding (Ref. 4) is determined from

$$k_c = (8.093782 + 4.348934 \times 10^{-13}\ (T_F - 460.))/3600.$$

The gap resistance is dominated by the thermal conductivity of helium. Heat transfer by radiation is assumed negligible. The gap resistance may thus be calculated from an expression identical to Equation 6.3.2-8 with r_c replaced by $r_F + r_g$ and k_c replaced by k_{GP}:

$$R_{GP} = \frac{\ell n \dfrac{r_F + r_g}{r_F}}{2\pi L k_{GP}} \qquad \text{where } r_g = \text{gap thickness}$$

For $r_F = .1219$ and $r_g = 0.$

$$R_{GP} = 0./(Lk_{GP})$$

The thermal conductivity of the gap fluid, assumed to be helium, is

$$k_{GP} = \frac{1.062 \times 10^{-13}}{3600.} T_{GP}{}^{0.701}$$

assuming that $T_{GP} \sim (T_F + T_c)/2$ yields

$$k_{GP} = 2.95E\text{-}7 * ((T_F + T_c)/2)^{.701} \qquad (6.3.2\text{-}9)$$

The heat transfer coefficient is evaluated from the Dittus-Boelter equation

$$H = 0.023 \frac{k_H}{D_H} R_e{}^{0.8} P_r{}^{0.4} \qquad (6.3.2\text{-}10)$$

for $R_e > 2300$. For $R_e < 2300$, Equation 6.3.2-10 is evaluated at $R_e = 2300$. For roughened surfaces, a multiplier is used in Equation 6.3.2-10, as will be described later. Utilizing the functional form of Equation 6.3.2-9 to define k_H with $D_H = \frac{.2818'}{12}$ and $P_r = .664$ reduces Equation 6.3.2-10 to

$$H = 8.28 \times 10^{-4} T_{GA}{}^{.701} R_e{}^{0.8}/3600$$

The multiplier for roughened surfaces is given by

$$F = 1 \qquad R_e < 9930$$

$$F = (R_e/9930)^{0.3} \qquad 9930 \leq R_e \leq 100{,}000$$

$$F = 2.155 \qquad R_e > 100{,}000$$

This expression was obtained directly from a MINGAF listing, and the origin is not known.* The surface area A is an input. The thermal conductances can now be calculated from

$$J_{FC} = 1/(R_F + R_{GP} + R_c/2)$$

and

$$J_{CG} = 1/(R_c/2 + 1/HA)$$

These equations are implemented in MACRO CORHT, listed in Figure 6.3.2-3.

```
MACRO JCG,JCF=CORHT(G,TC,TF,TG,A,L)
PROCED JCG,JCF=CORHT1(G)
      REY=3.055E8*G*TG**-.687
      IF(REY.LT.2300.)REY=2300.
      H=8.28E-4*TG**.701*REY**.8/3600.
      KC=1.693E-3+1.208E-6*TC
      RC=.02305/(KC*L)
      RCG=1./(H*A)+RC/2.
      JCG=1./RCG
      KF=57.78*.886*(1./(18.2+.0271*TF/1.8)+5.5E-13*(TF/1.8)**3)/3600.
      KH=2.95E-7*((TF+TC)/2.)**0.701
      RCF=.03229/(KF*L)+.0036/(KH*L)+RC/2.
      JCF=1./RCF
ENDPRO
ENDMAC
```

Figure 6.3.2-3. Core Heat Transfer MACRO CORHT

---

*Note: The roughness function was not included in the current version of CASY.

and are accessed by the statements in the simulation

```
JRECK1,JRCFK1=CORHT(GREH,TRC1,TRF1,TREH1,KREA1,KREL1)
JRECK2,JRCFK2=CORHT(GREH,TRC2,TRF2,TREH2,KREA2,KREL2)
JRECK3,JRCFK3=CORHT(GREH,TRC3,TRF3,TREH3,KREA3,KREL3)
JRECK4,JRCFK4=CORHT(GREH,TRC4,TRF4,TREH4,KREA4,KREL4)
JRECK5,JRCFK5=CORHT(GREH,TRC5,TRF5,TREH5,KREA5,KREL5)
JRECK6,JRCFK6=CORHT(GREH,TRC6,TRF6,TREH6,KREA6,KREL6)
```

6.3.3 Reactor Model Validation

The core model was evaluated (including a model of the reactor neutron kinetics) by initiating a scram at ten seconds and comparing the results to MINAUX (core only) scram. The comparisons are shown on Figures 6.3.3-1 and 6.3.3-2. The results show excellent agreement.

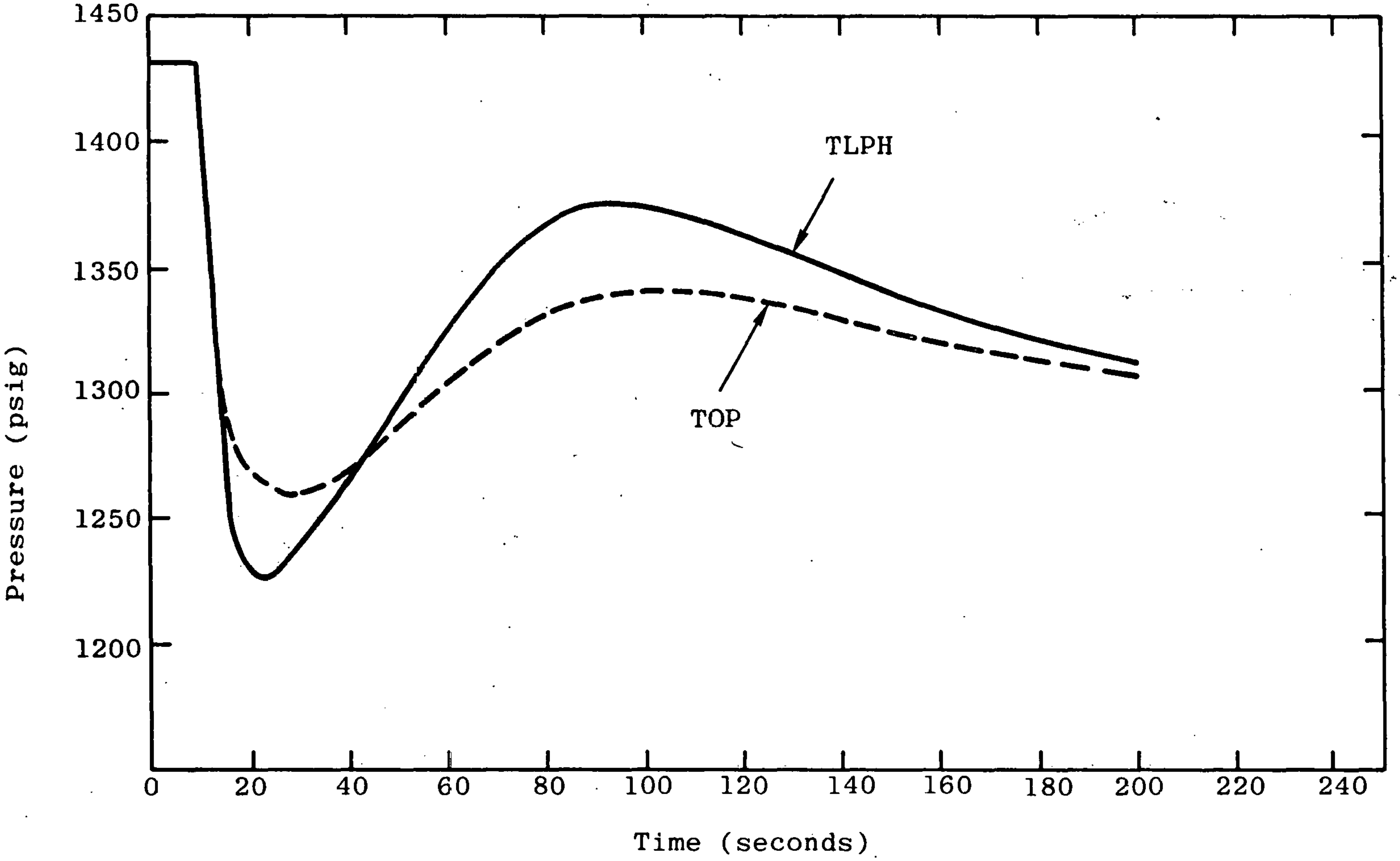

Figure 6.3.3-1. Comparison of CASY (Core Model) with MINAUX (Core Only) Showing the Lower Plenum Temperature in Response to a Scram Signal at 10 Seconds

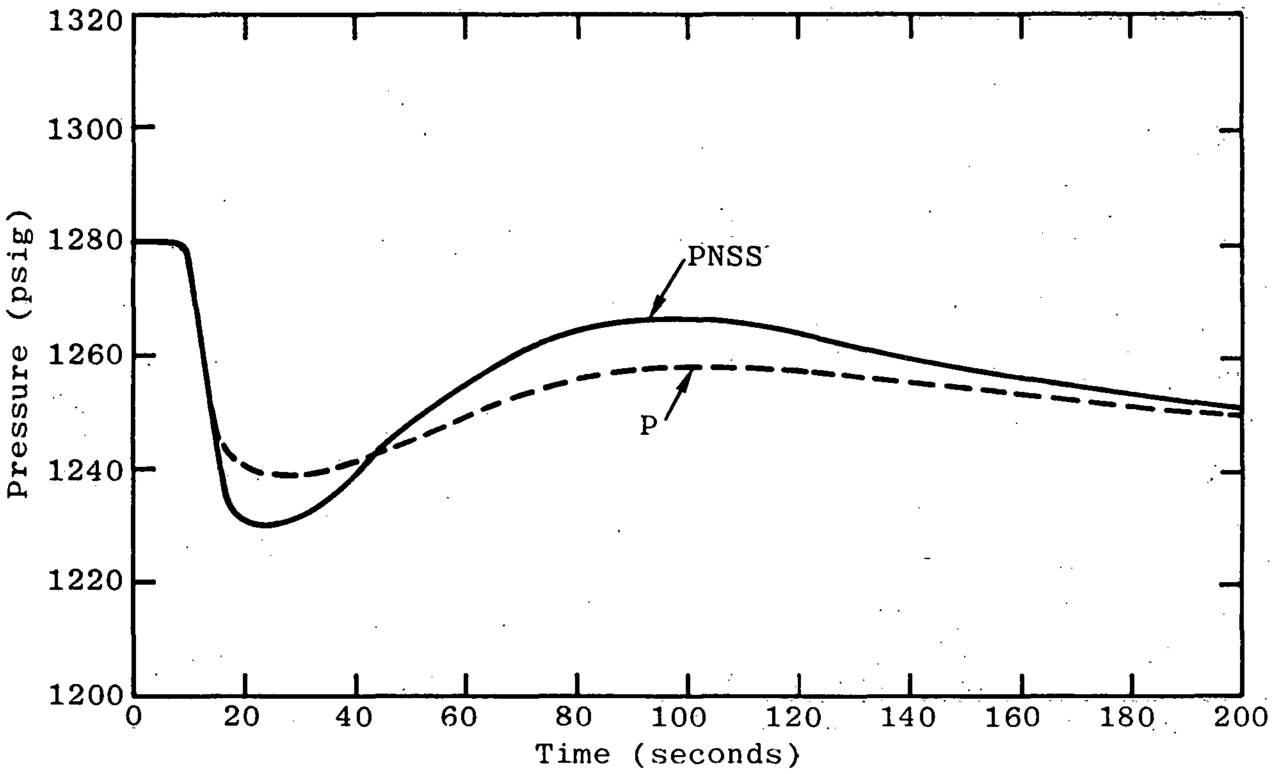

Figure 6.3.3-2. Comparison of CASY (Core Model) with MINAUX (Core Only) Showing the Reactor Pressure in Response to a Scram Signal at 10 Seconds.

7. INTEGRATED SYSTEM MODELS

There were two integrated system models developed. The first was named CAWS and consists of the secondary coolant system with core interface variables as parameters. The other was the total system simulation and is the CASY code.

7.1 CORE AUXILIARY WATER SYSTEM, CAWS

A schematic of the CAWS subsystem simulation is shown in Figure 7.1-1. A previously developed subsystem code AUXTRAN, reference 4, was modified to be similar to CAWS. Comparisons were made between these two independently developed codes to validate CAWS. The comparison of the CAWS model with the AUXTRAN code is shown by Figures 7.1-2 to 7.1-27. As can be observed, the validation is excellent. These validations were made for a 5% step change in inlet helium temperature (TLPH), helium flow rate (GCAA), water flow rate (WFLOW), air inlet temperature (TAAI1), and air flow rate (GAA). The largest difference is the outlet helium temperature. This difference is about 2^o. When compared to the 1200^o difference across the CAHE this represents about a 0.2% difference (this could probably be decreased by adjusting the helium to water heat transfer coefficient or effective heat transfer surface area).

7.2 CORE AUXILIARY SYSTEM SIMULATION, CASY

A core model including a circulator model but without reactor kinetics was added to CAWS. This integrated model is the complete CASY code. The schematic for the CASY code is shown on Figure 7.2-1 (page 113). The CASY code was checked by comparing the results of a modified reactor scram with a similar

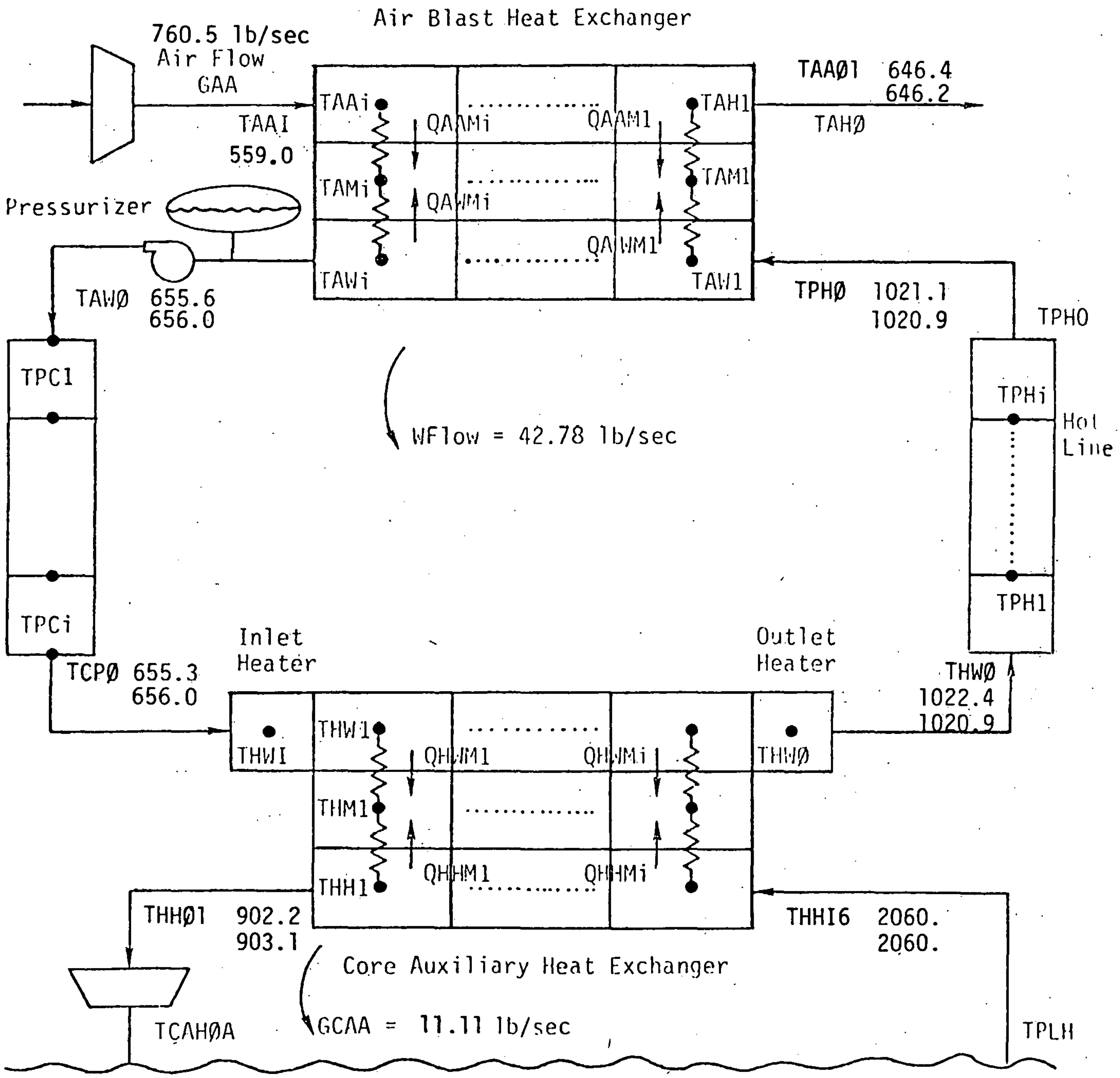

Figure 7.1-1. CAWS Steady-State Data

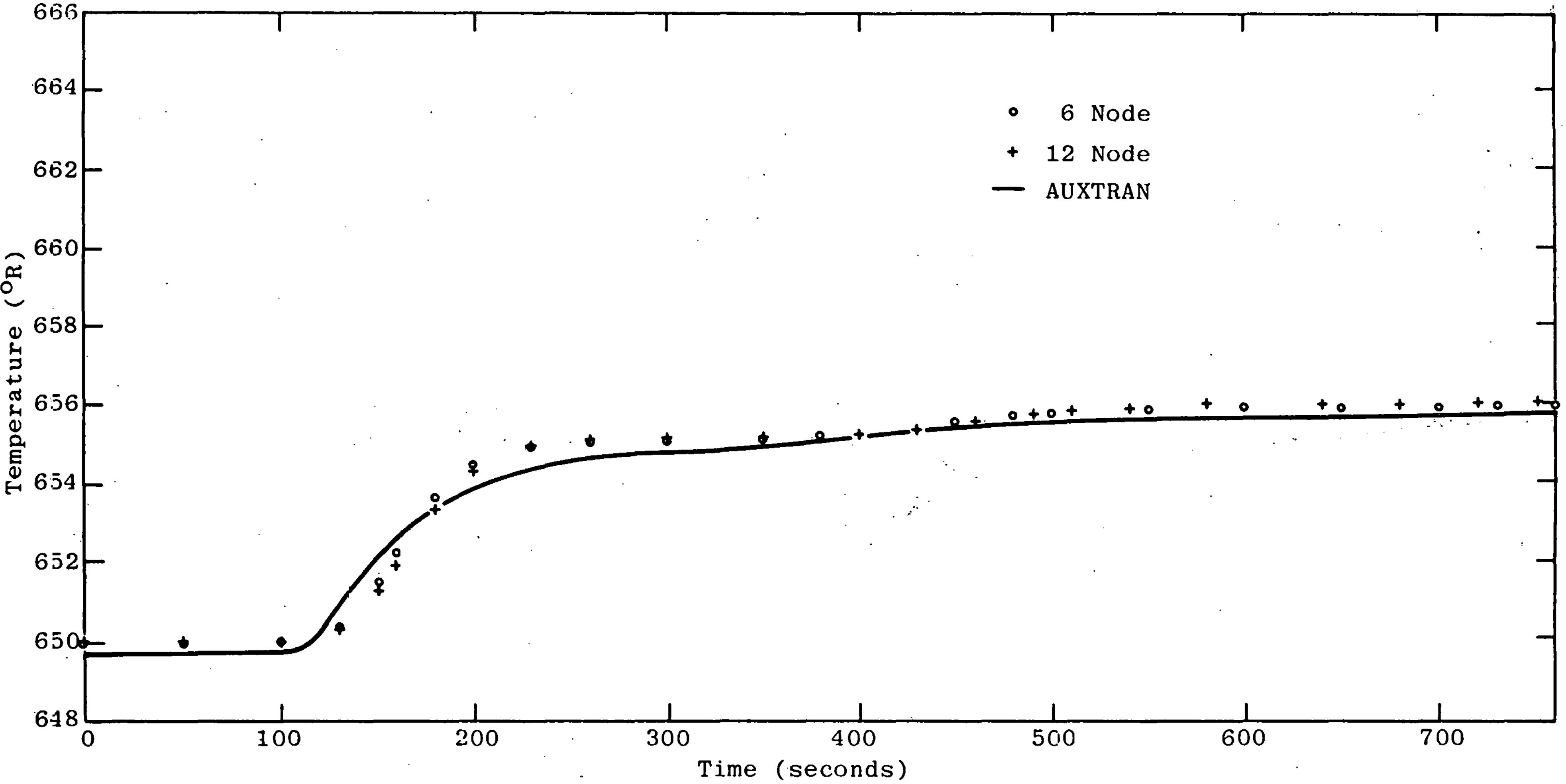

Figure 7.1-2. Air Blast Heat Exchanger Outlet Water Side Temperatures Comparison with AUXTRAN after 5% Step Change at Time = 0.0 in Helium Temperature in Lower Plenum.

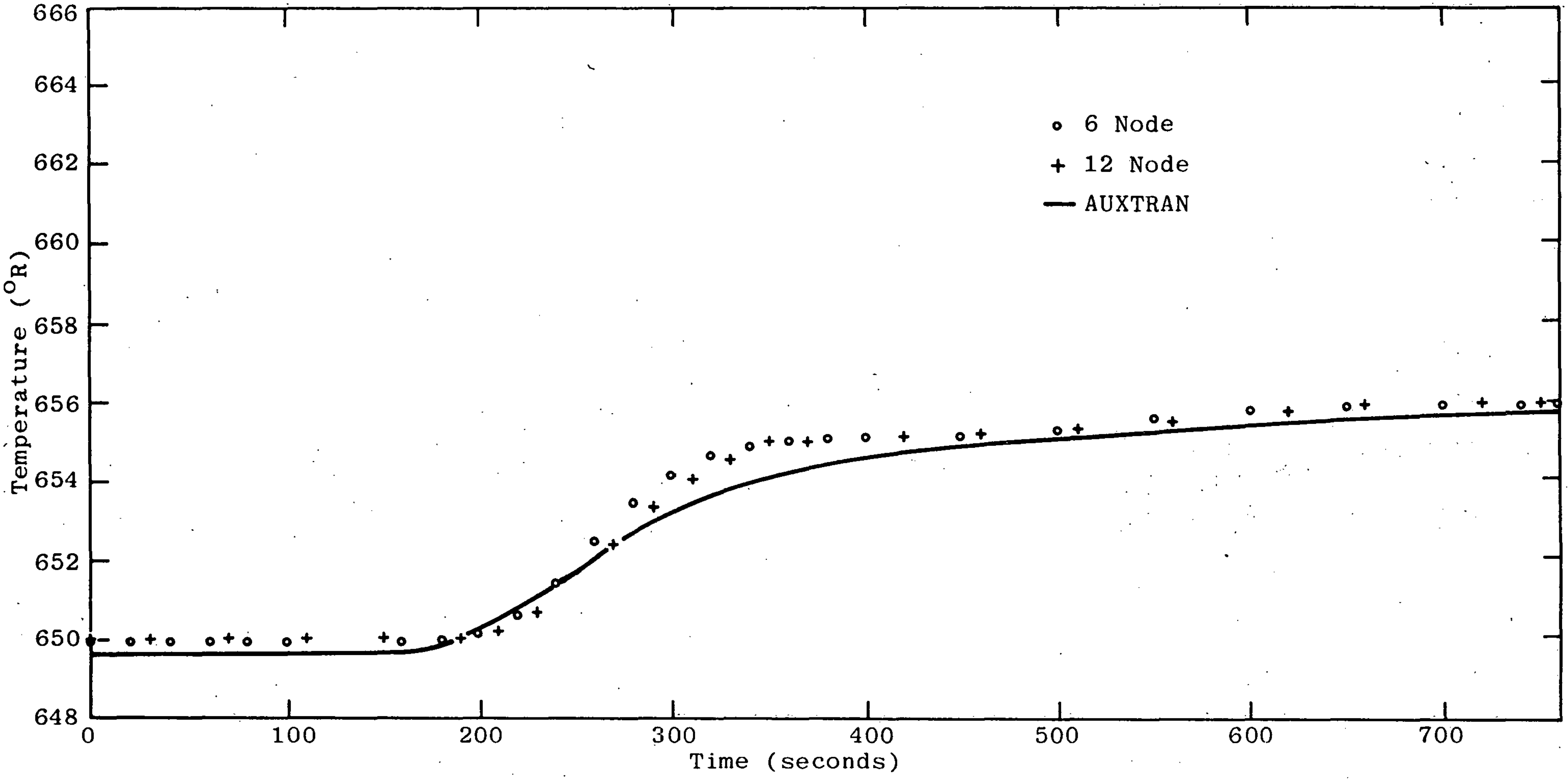

Figure 7.1-3. Outlet Water Temperature in the Cold Leg Comparison with AUXTRAN after 5% Step Change at Time = 0.0 in Helium Temperature in the Lower Plenum.

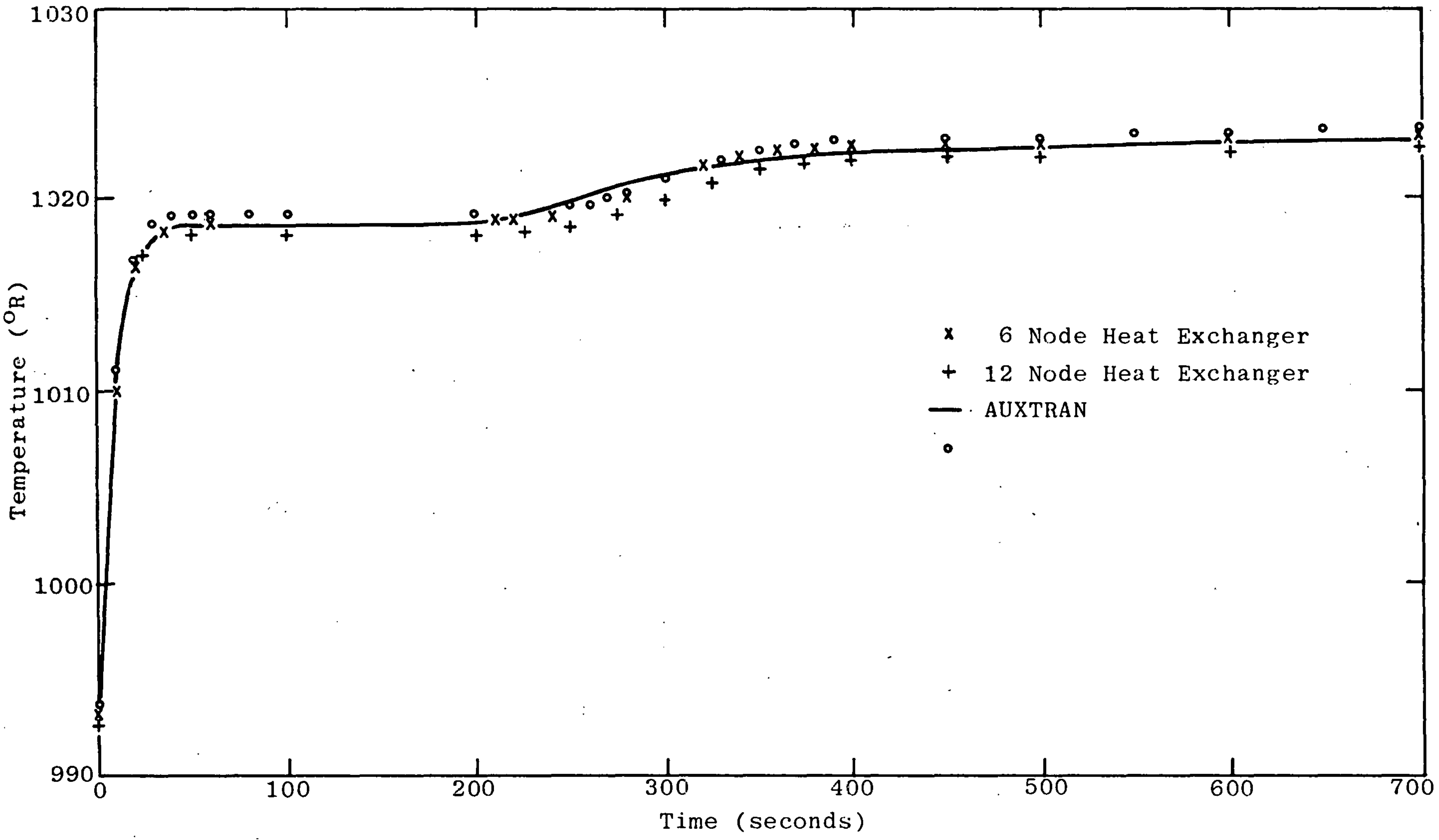

Figure 7.1-4. Outlet Water Temperature in the CAHE Comparison with AUXTRAN after 5% Step Change at Time = 0.0 in Helium Temperature in the Lower Plenum.

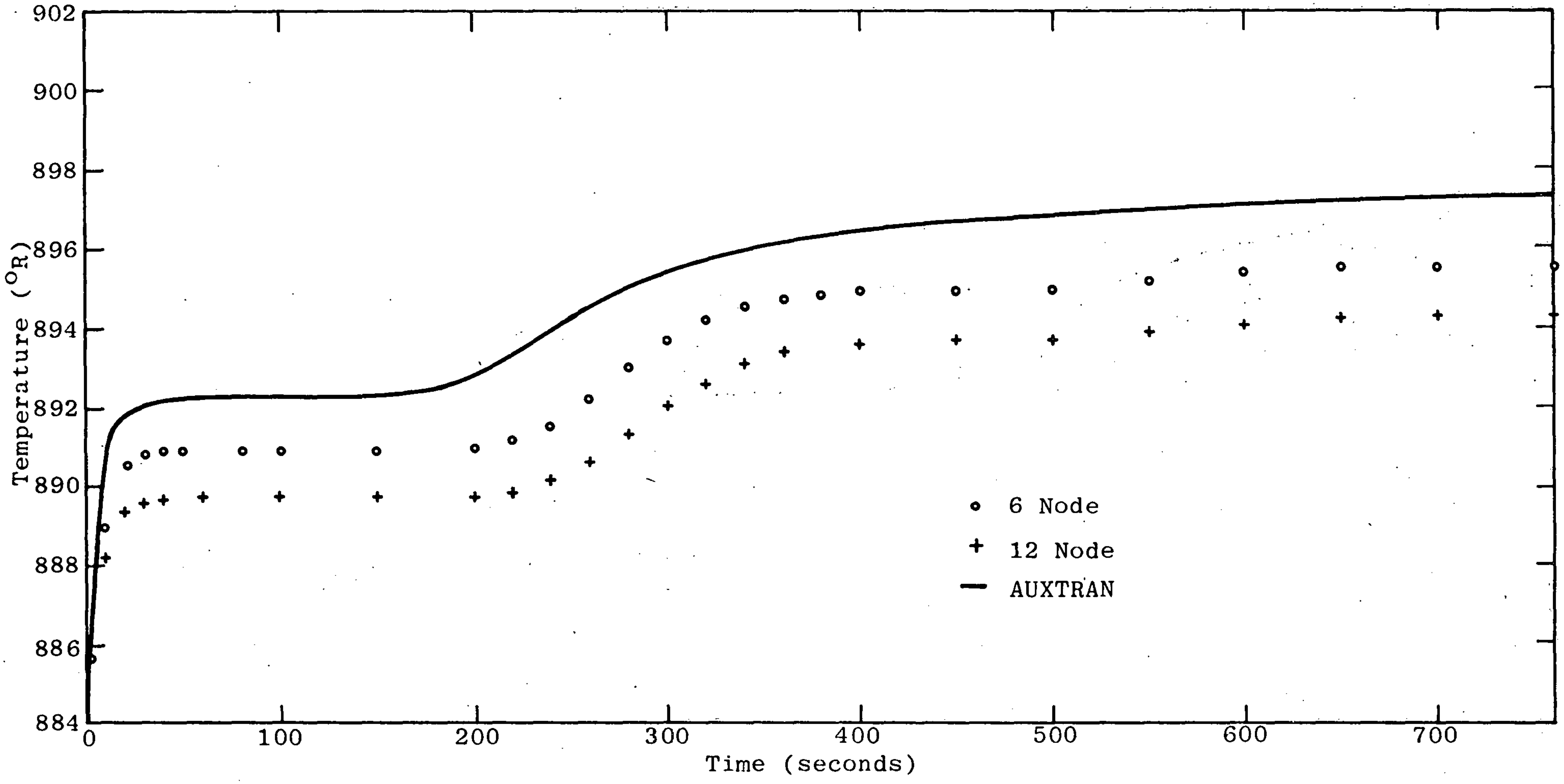

Figure 7.1-5. Outlet Helium Temperature in the CAHE Comparison with AUXTRAN after 5% Step Change in Helium Temperature in the Lower Plenum.

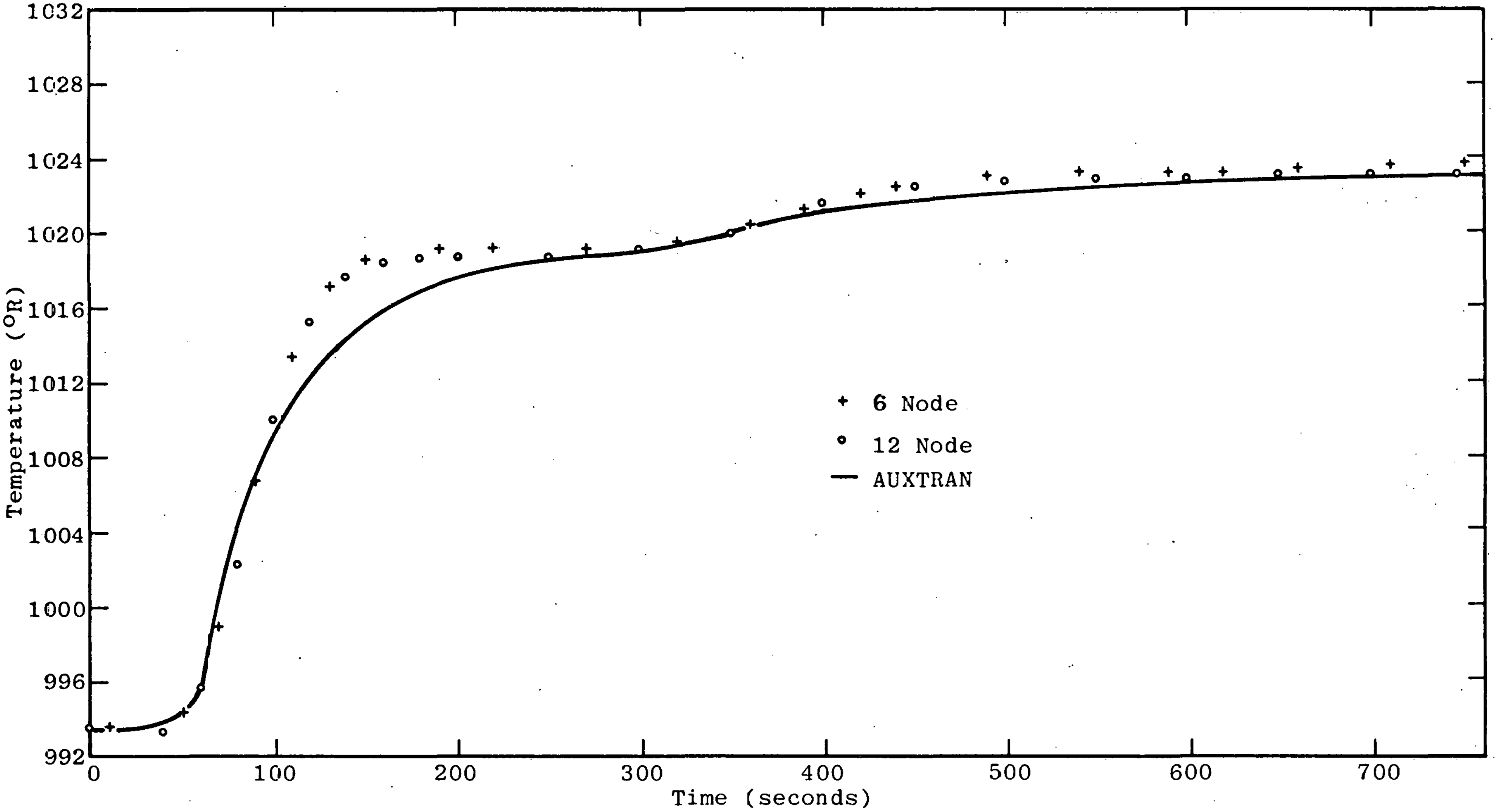

Figure 7.1-6. Outlet Wake Temperature in the Hot Leg Comparison with AUXTRAN after 5% Step Change at Time = 0.0 in Helium Temperature in the Lower Plenum.

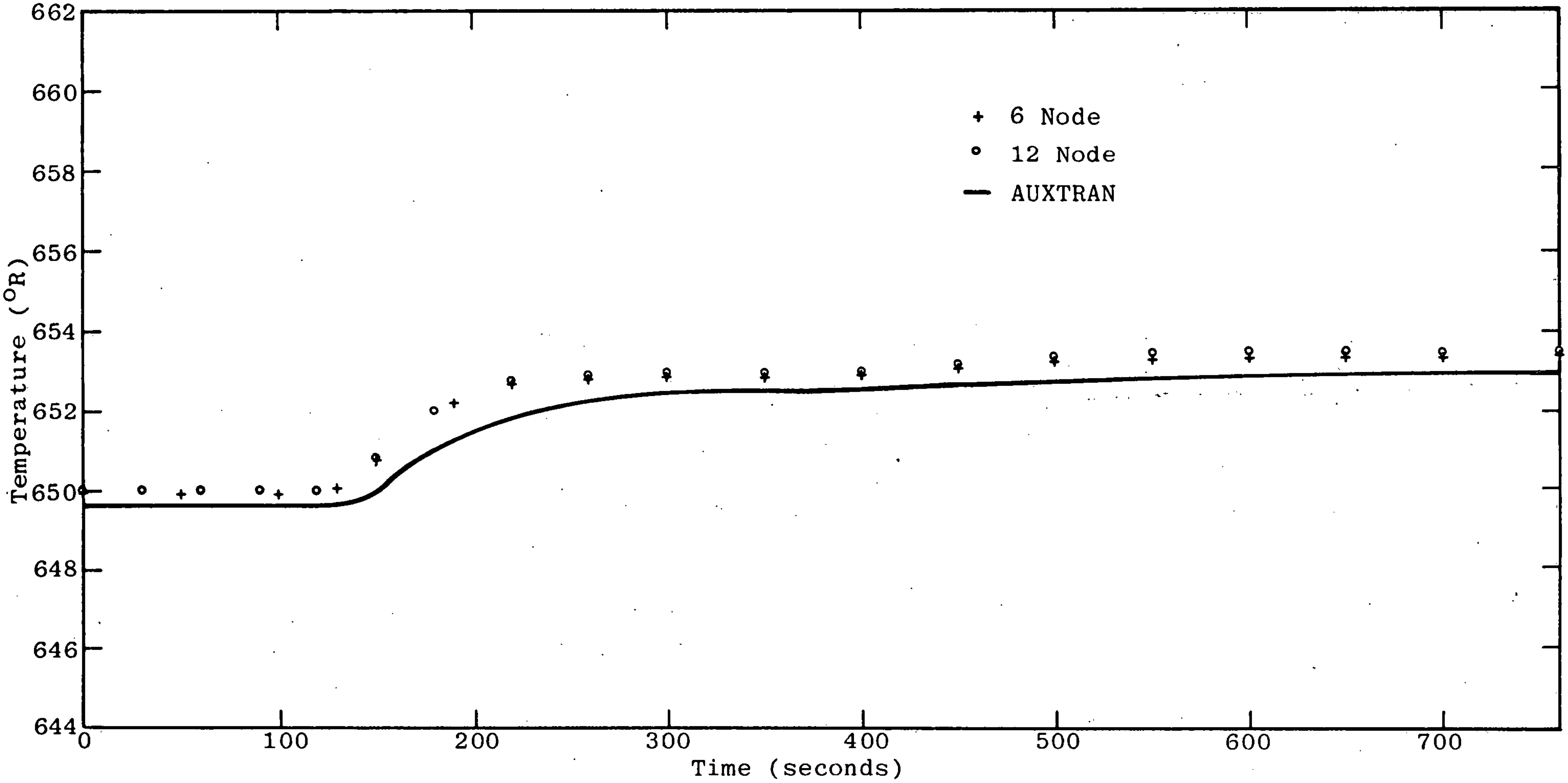

Figure 7.1-7. Outlet Water Temperature from the Air Blast Heat Exchanger Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Helium Flow Rate GCAA.

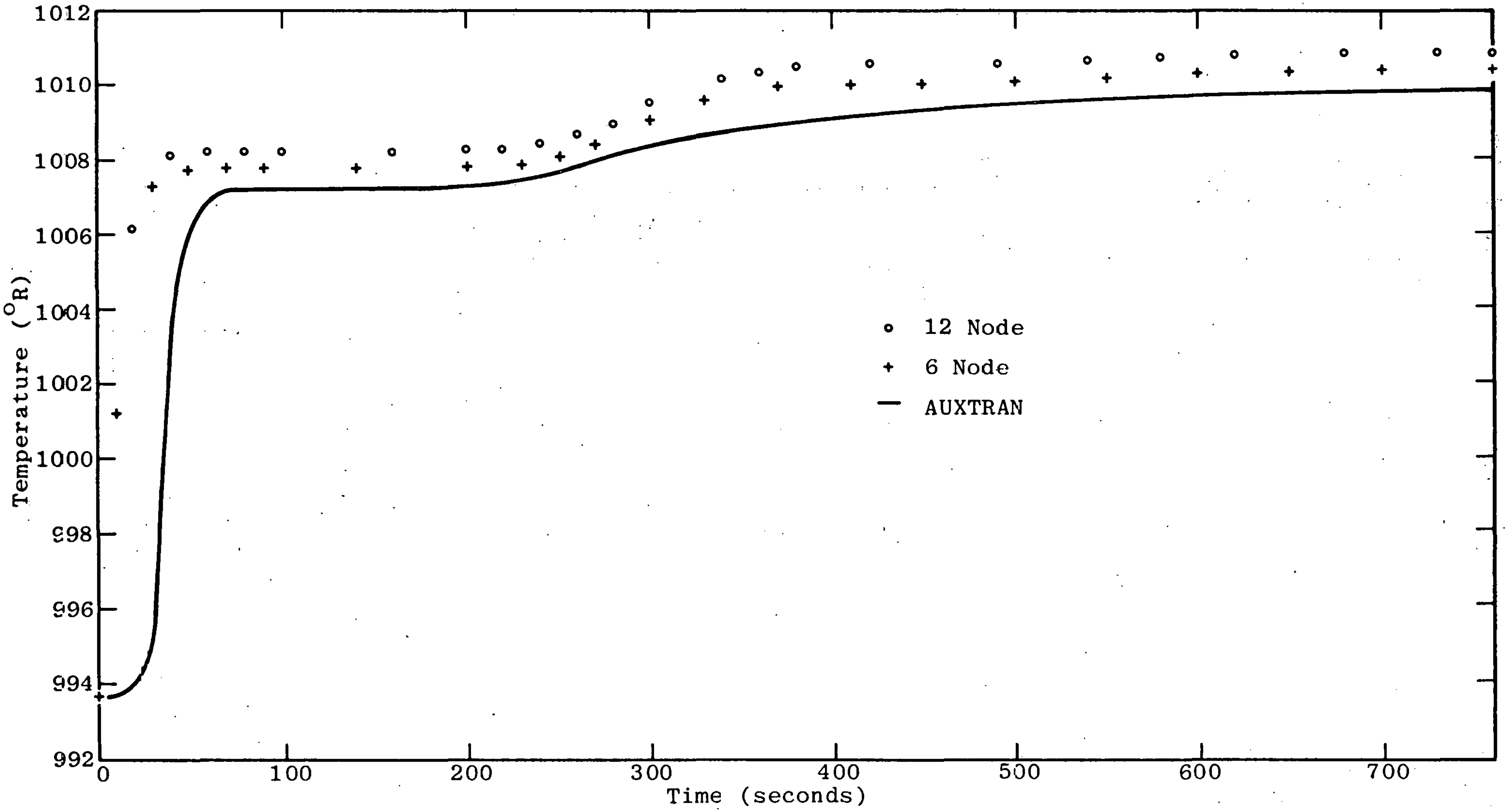

Figure 7.1-8. Outlet Water Temperature from the CAHE Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Helium Flow Rate GCAA.

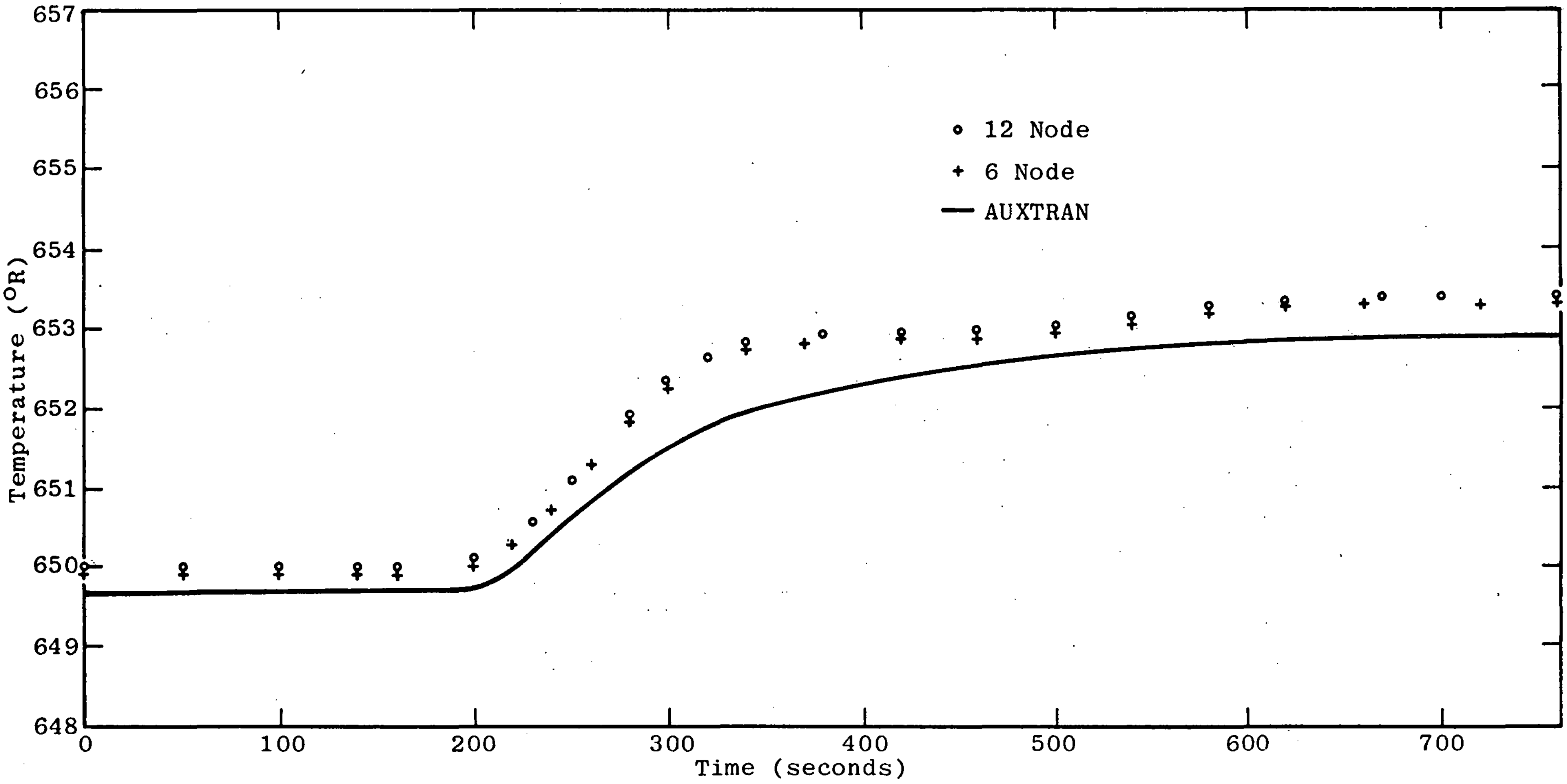

Figure 7.1-9. Outlet Water Temperature from the Cold Leg Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Helium Flow Rate GCAA.

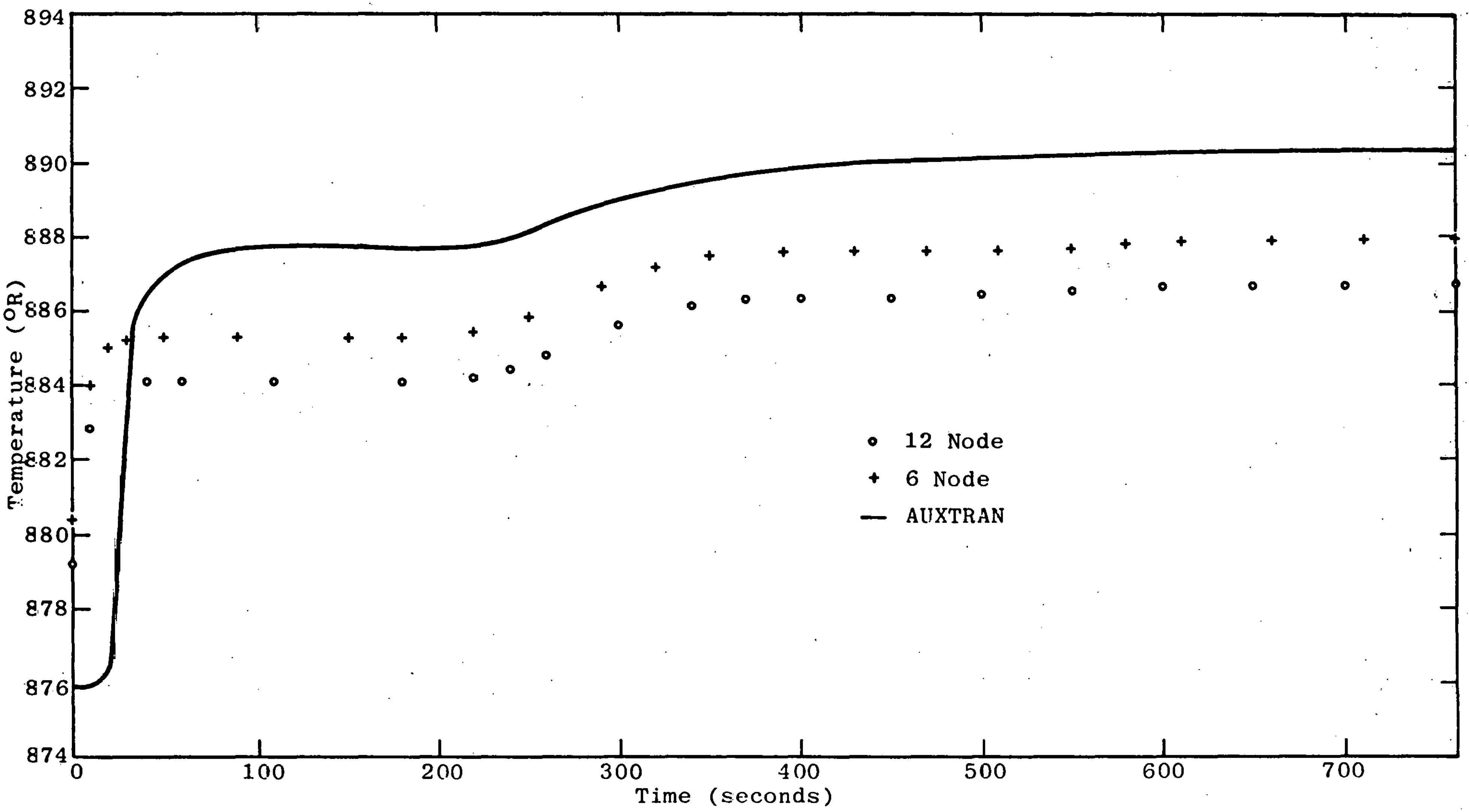

Figure 7.1-10. Outlet Helium Temperature from the CAHE Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Helium Flow Rate GCAA.

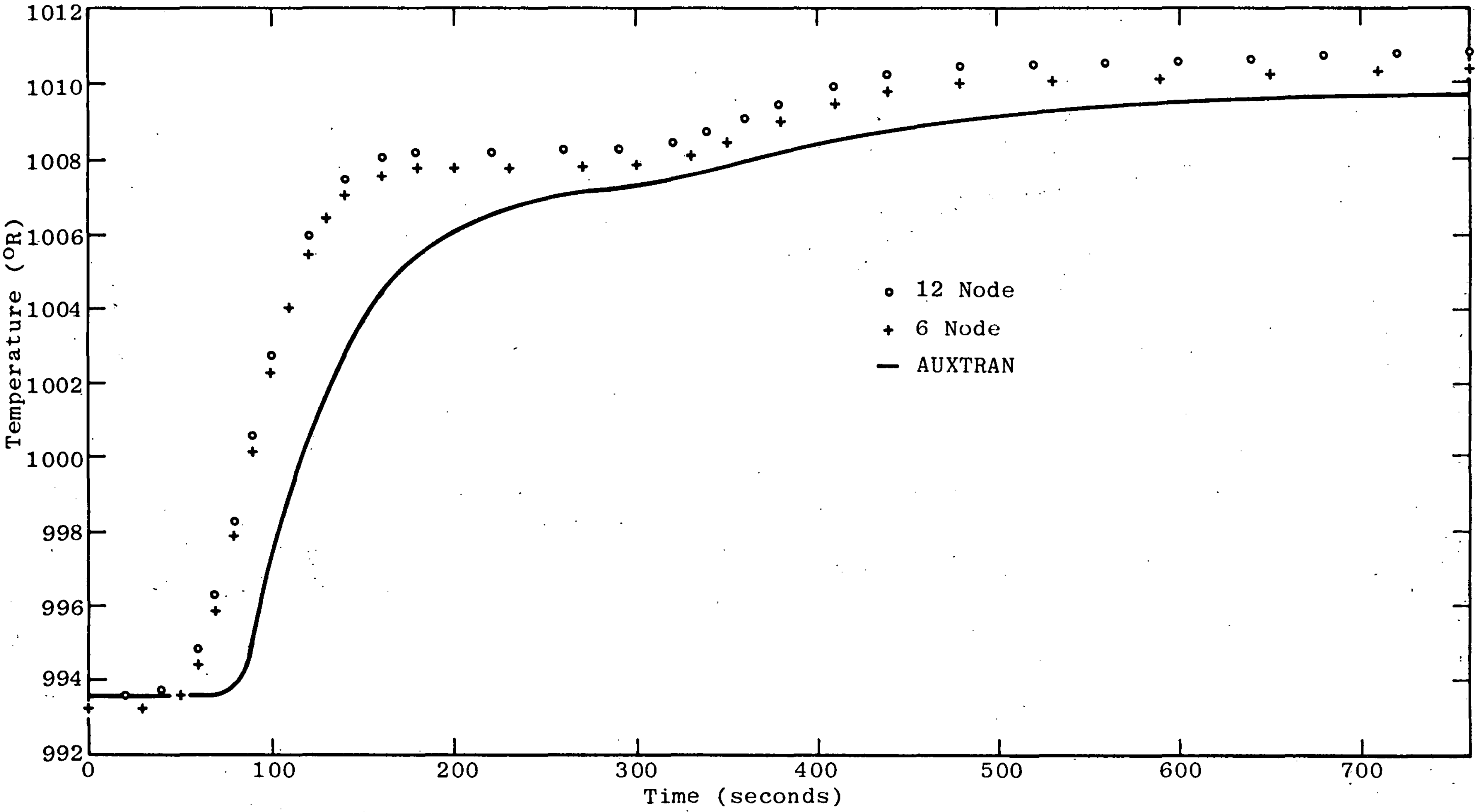

Figure 7.1-11. Outlet Water Temperature from the Hot Leg Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Helium Flow Rate GCAA.

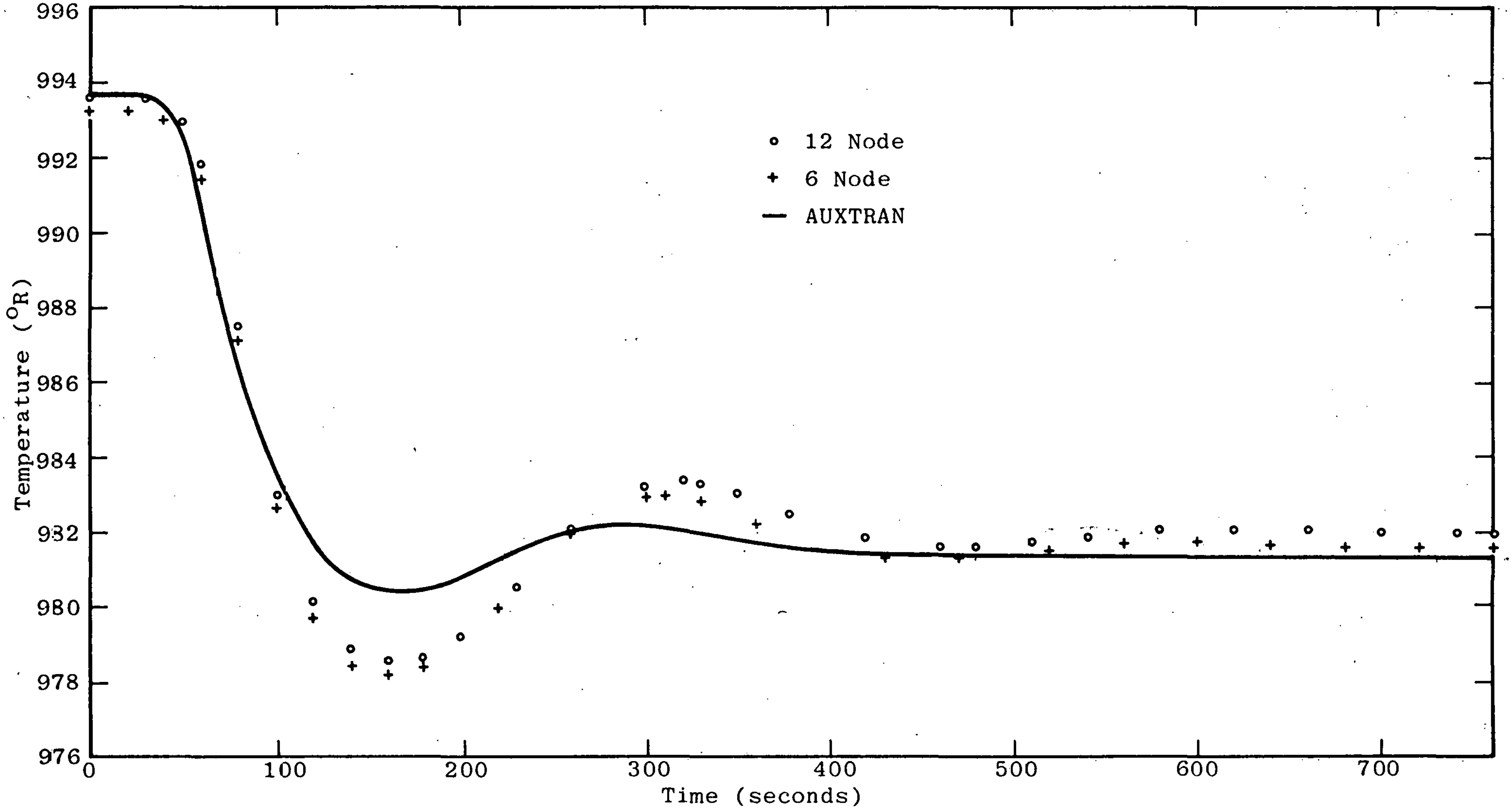

Figure 7.1-12. Outlet Water Temperature from the Hot Leg Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Water Flow Rate.

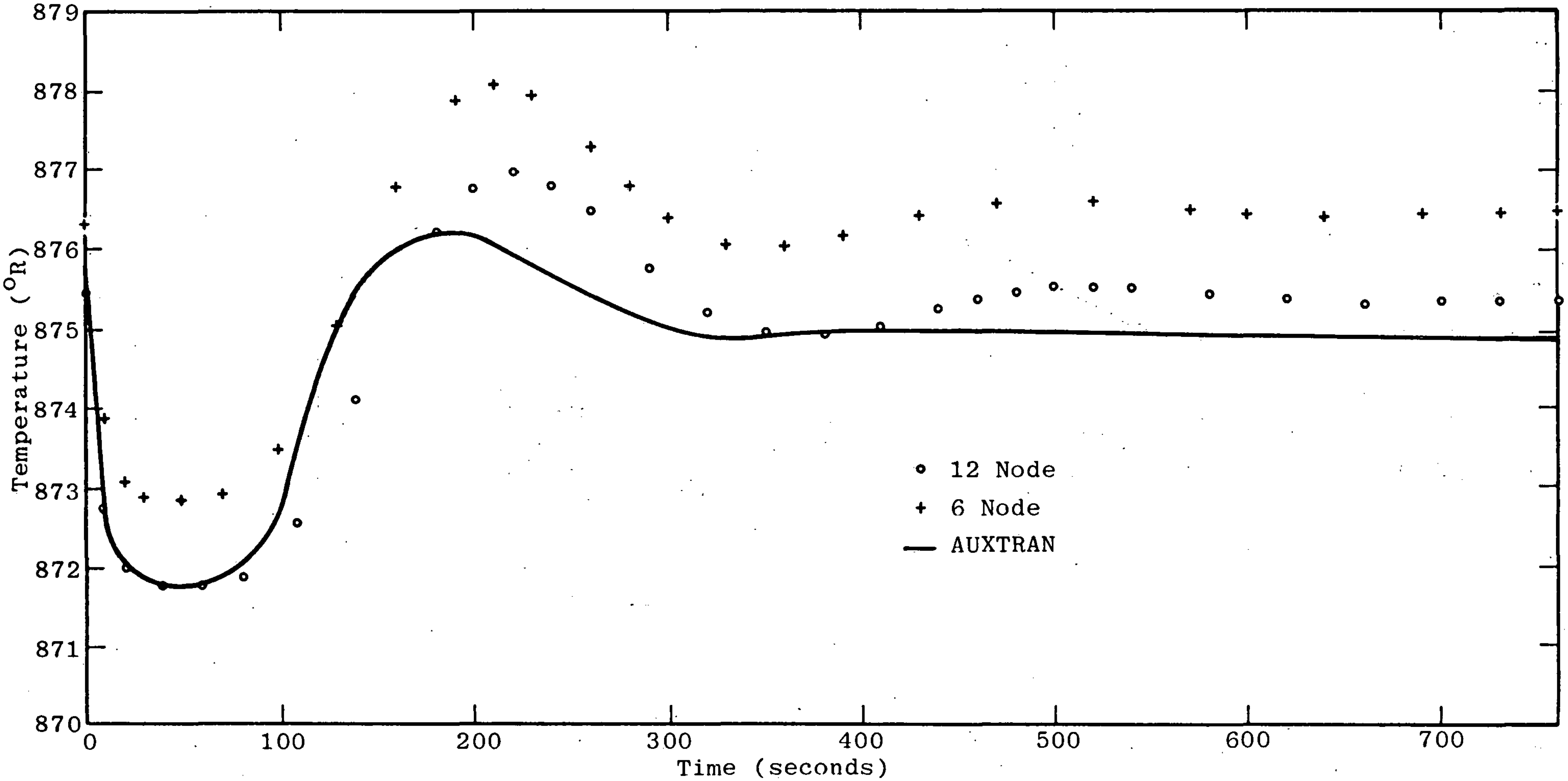

Figure 7.1-13. Outlet Helium Temperature from the CAHE Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Water Flow Rate.

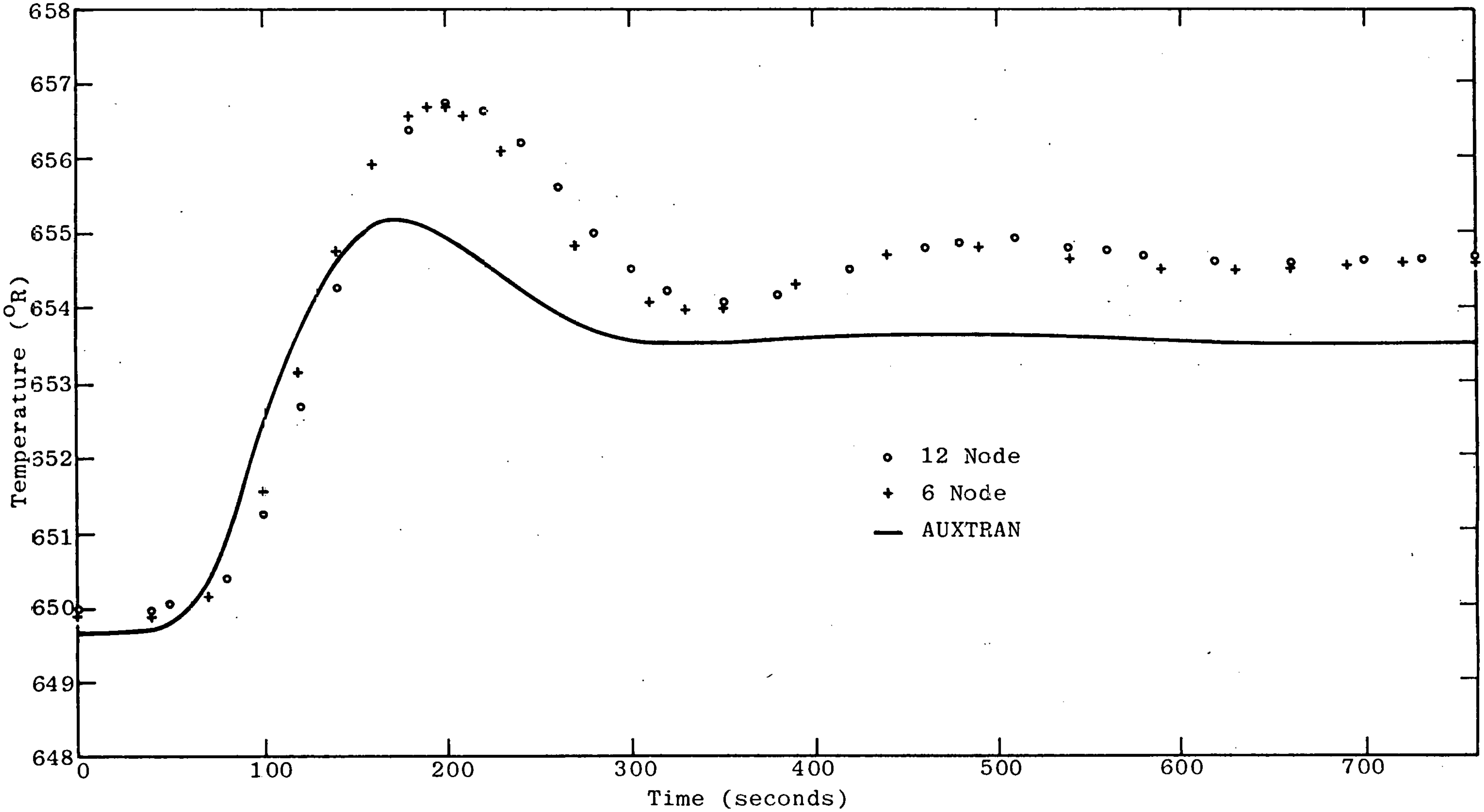

Figure 7.1-14. Outlet Water Temperature from the Cold Leg Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Water Flow Rate.

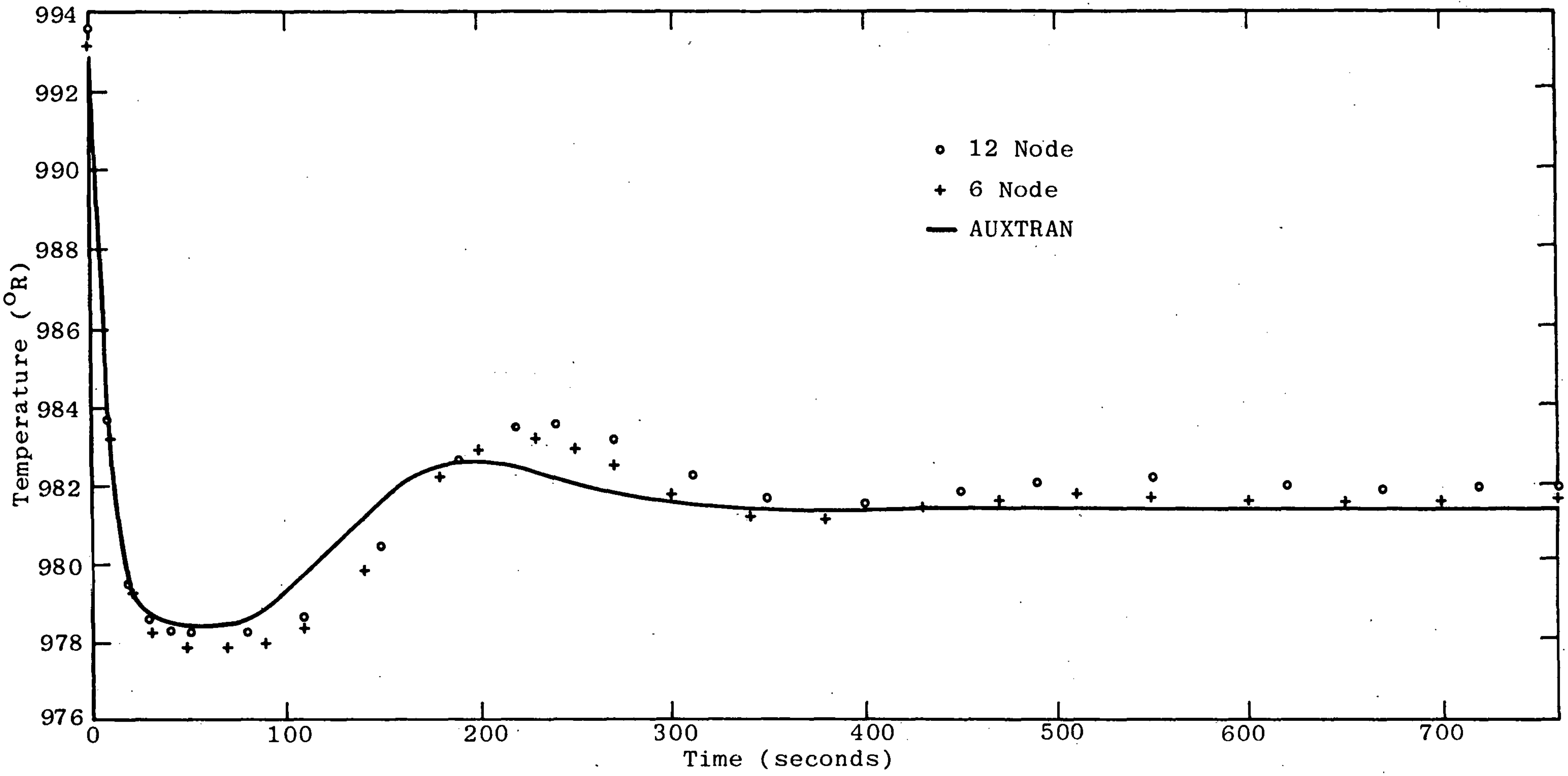

Figure 7.1-15. Outlet Water Temperature from the CAHE Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Water Flow Rate.

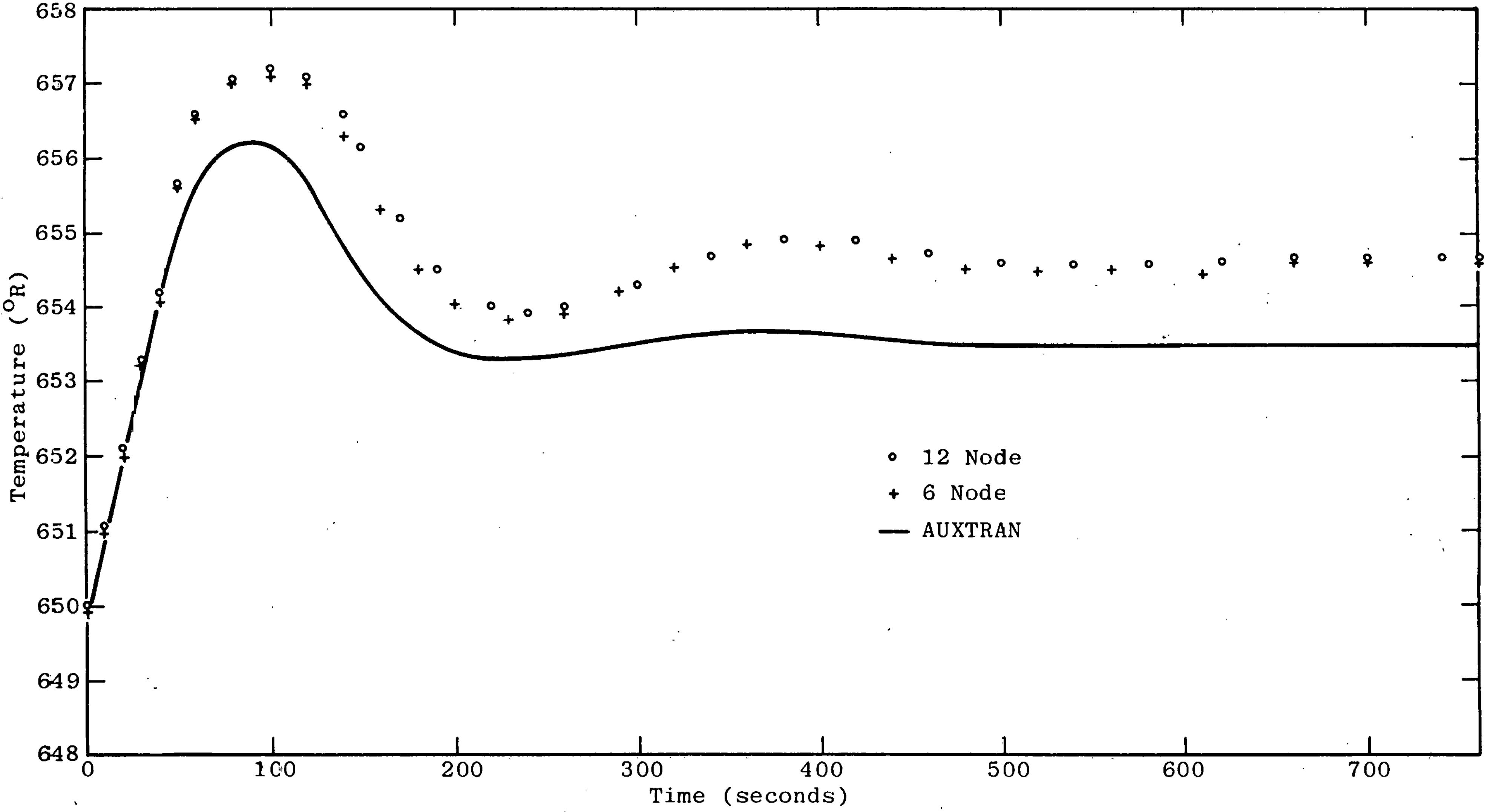

Figure 7.1-16. Outlet Water Temperature from the Air Blast Heat Exchanger Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Water Flow Rate.

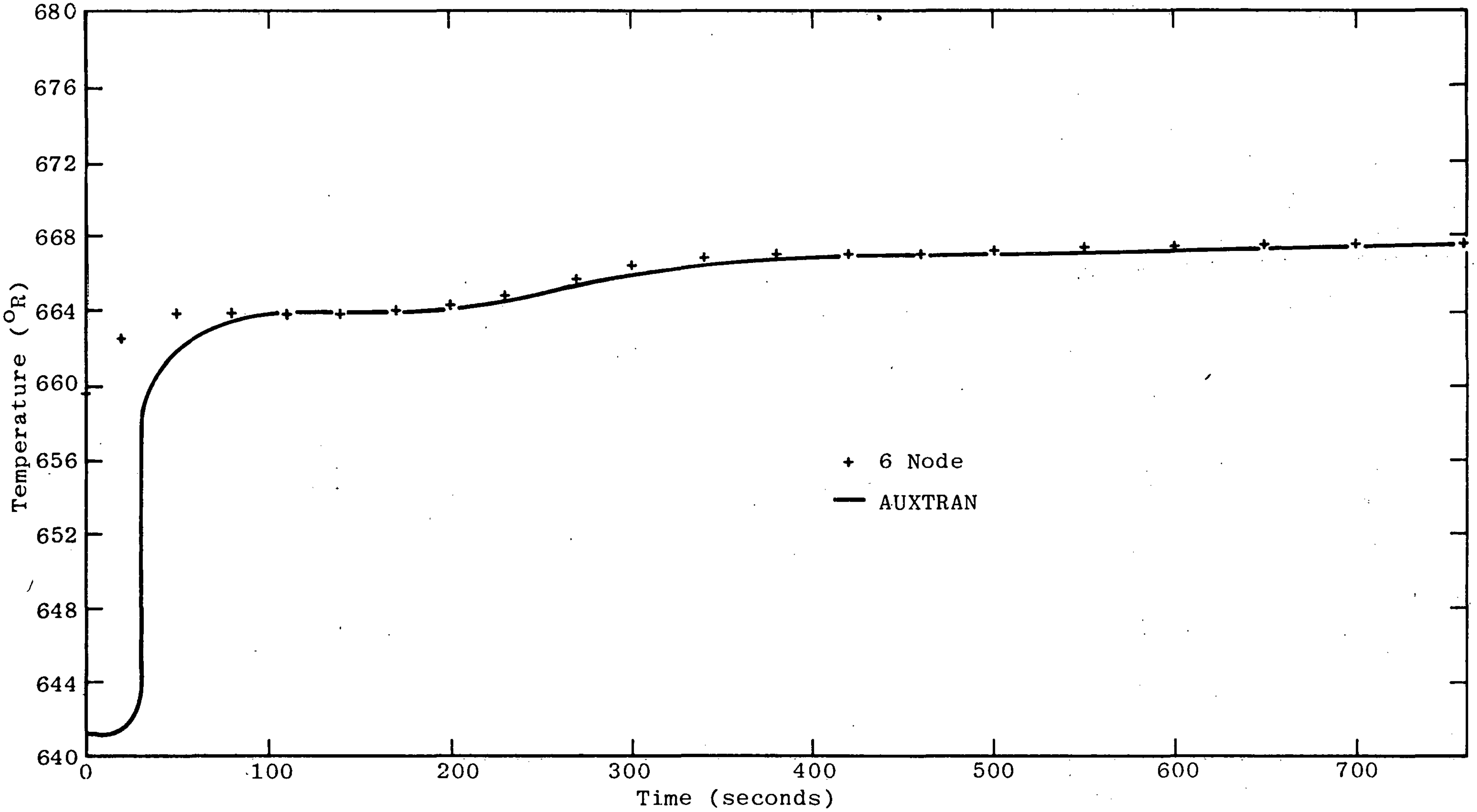

Figure 7.1-17. Outlet Air Temperature from the Air Blast Heat Exchanger Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Inlet Air Temperature.

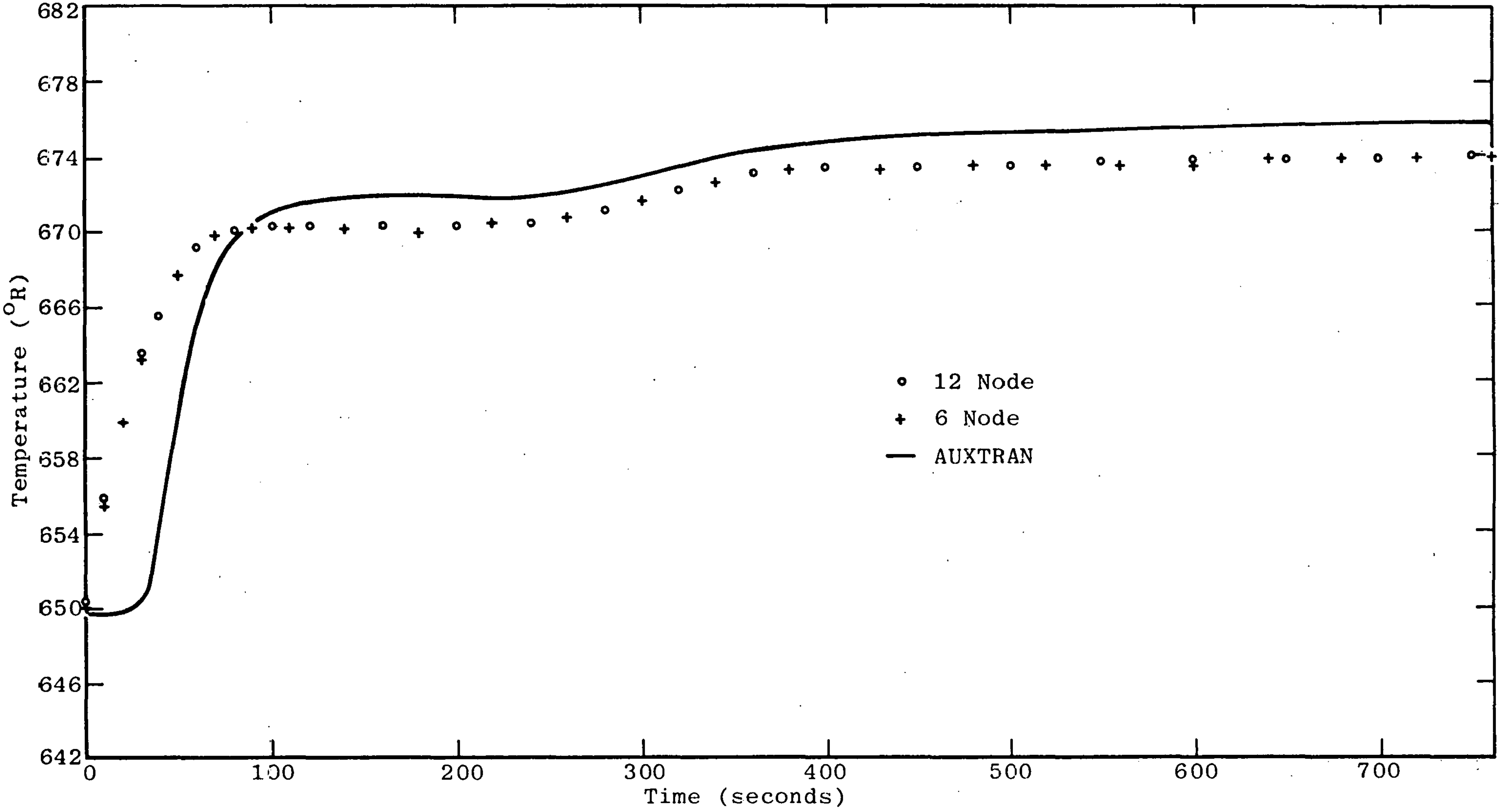

Figure 7.1-18. Outlet Water Temperature from the Air Blast Heat Exchanger Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Inlet Air Temperature.

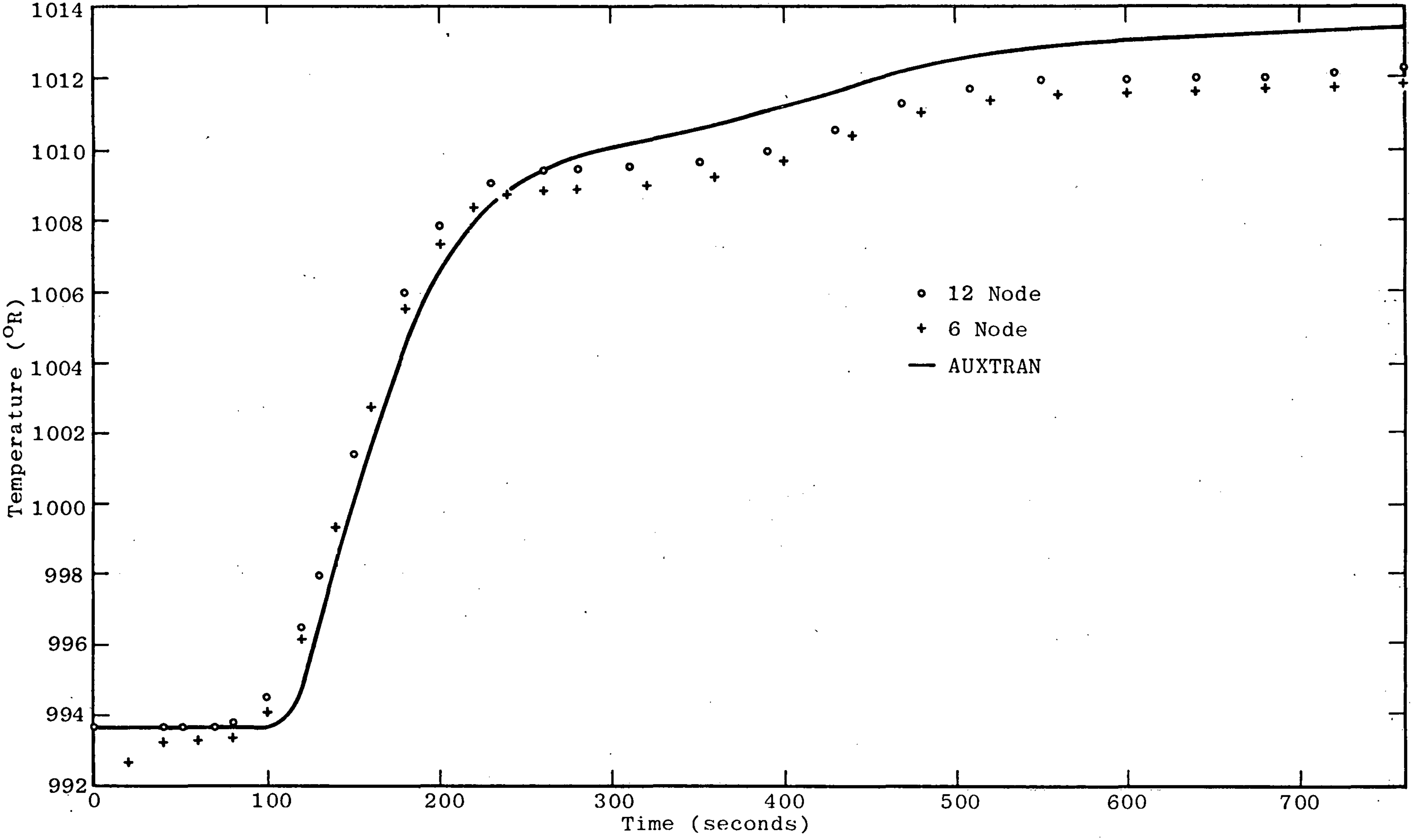

Figure 7.1-19. Outlet Water Temperature from the CAHE Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Inlet Air Temperature.

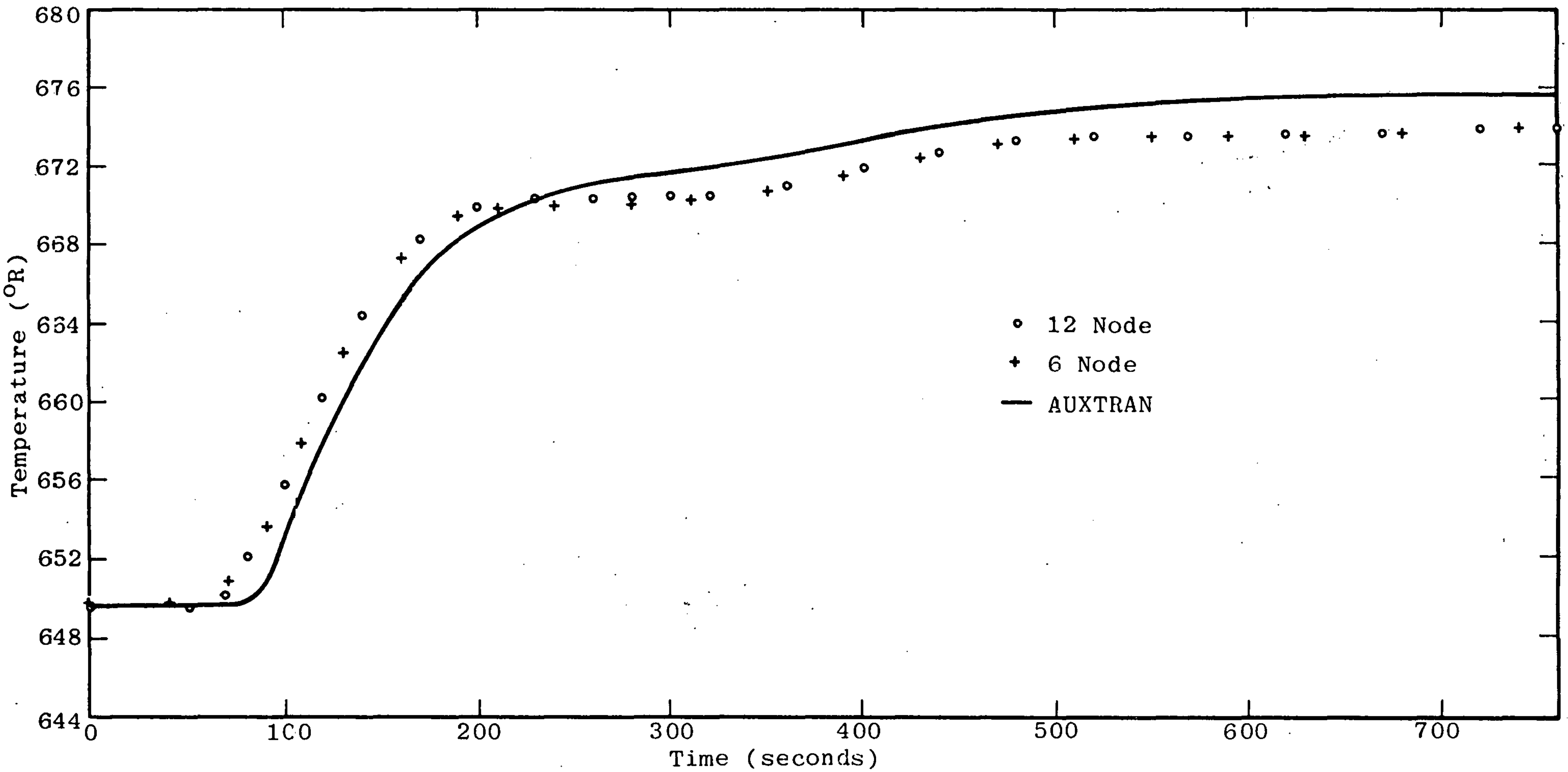

Figure 7.1-20. Outlet Water Temperature from the Cold Leg Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Inlet Air Temperature.

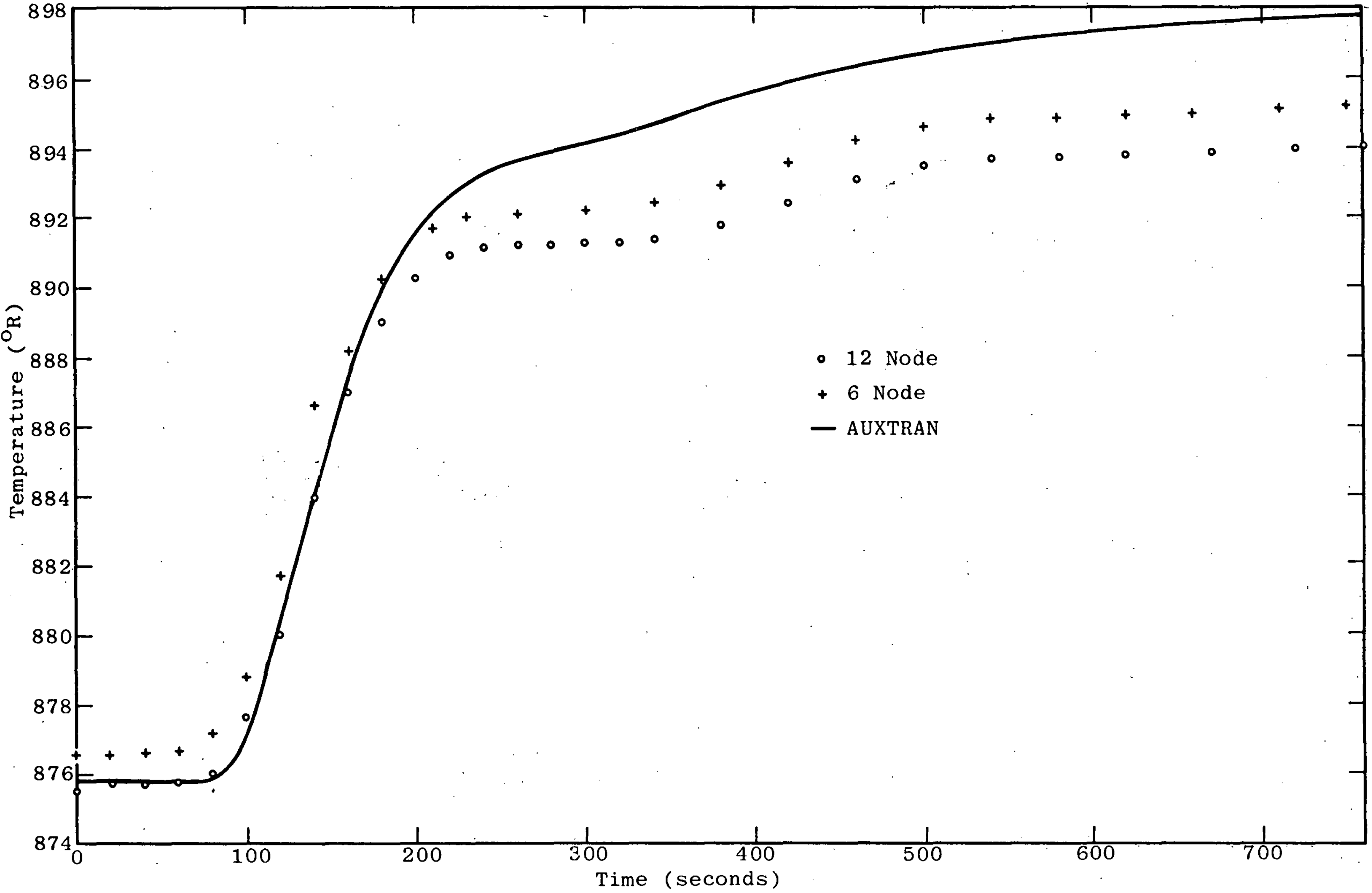

Figure 7.1-21. Outlet Helium Temperature from the CAHE Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Inlet Air Temperature.

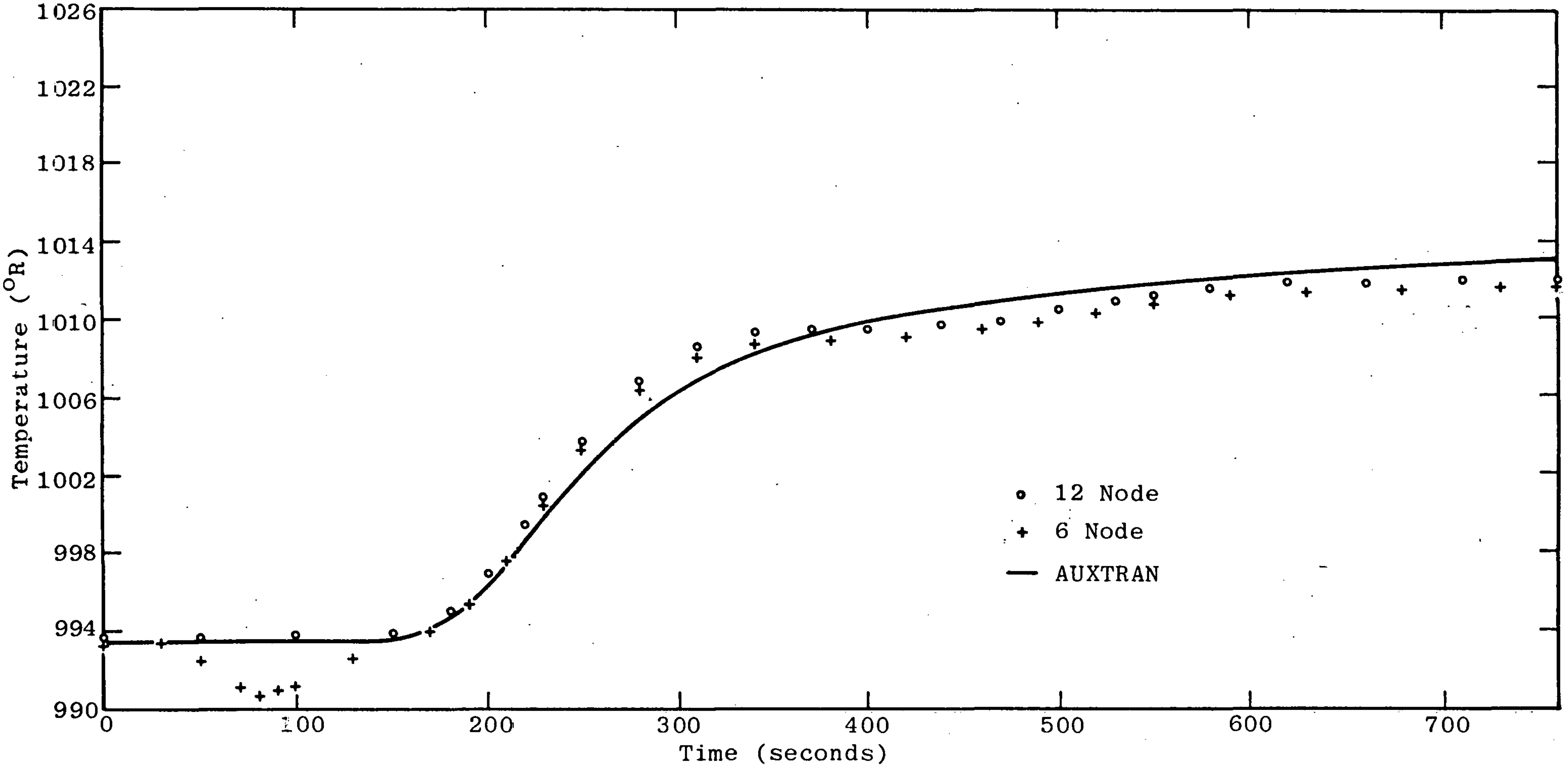

Figure 7.1-22. Outlet Water Temperature from the Hot Leg Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Inlet Air Temperature.

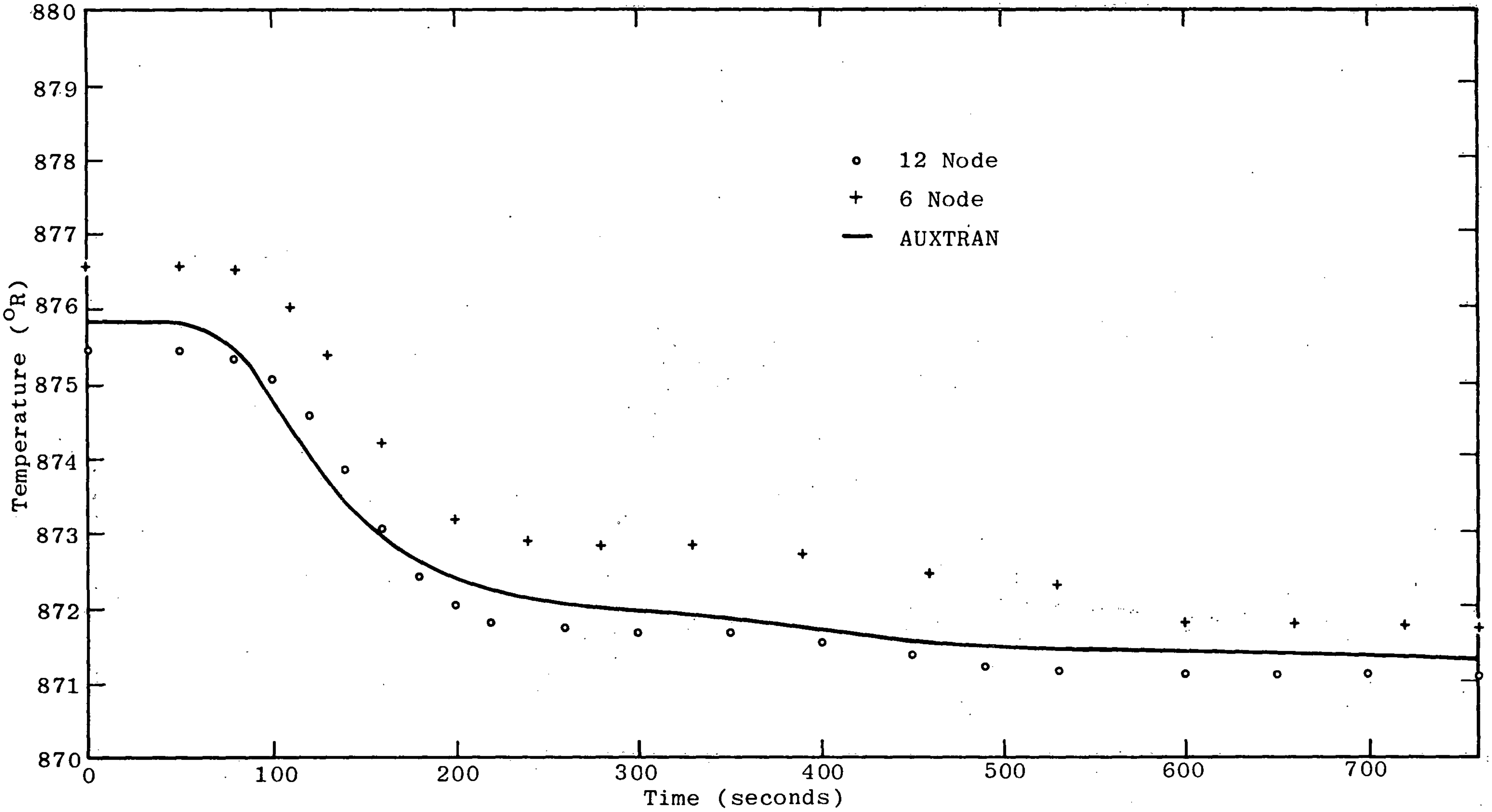

Figure 7.1-23. Outlet Helium Temperature from the CAHE Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Air Flow Rate.

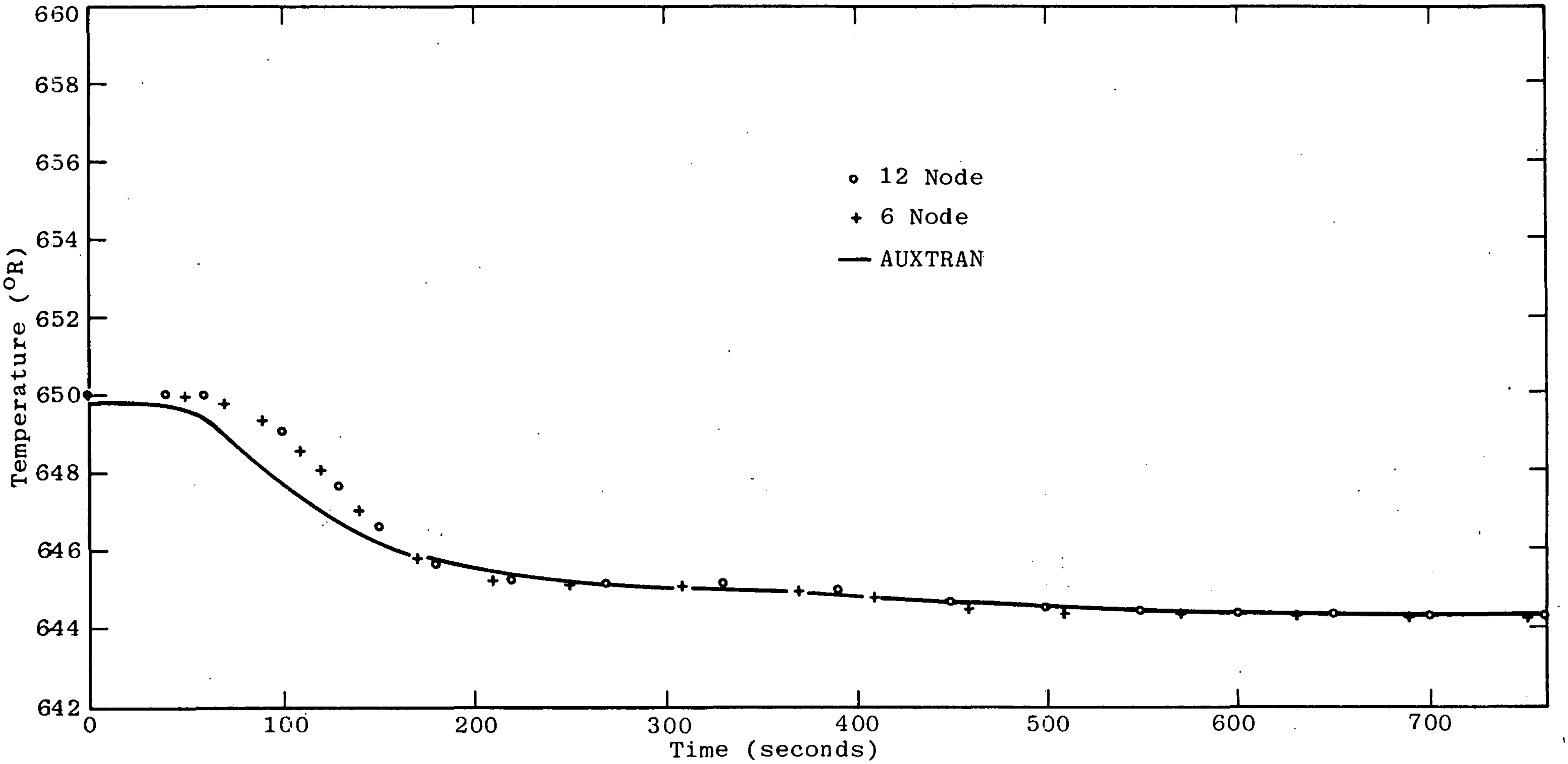

Figure 7.1-24. Outlet Water Temperature from the Cold Leg Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Air Flow Rate.

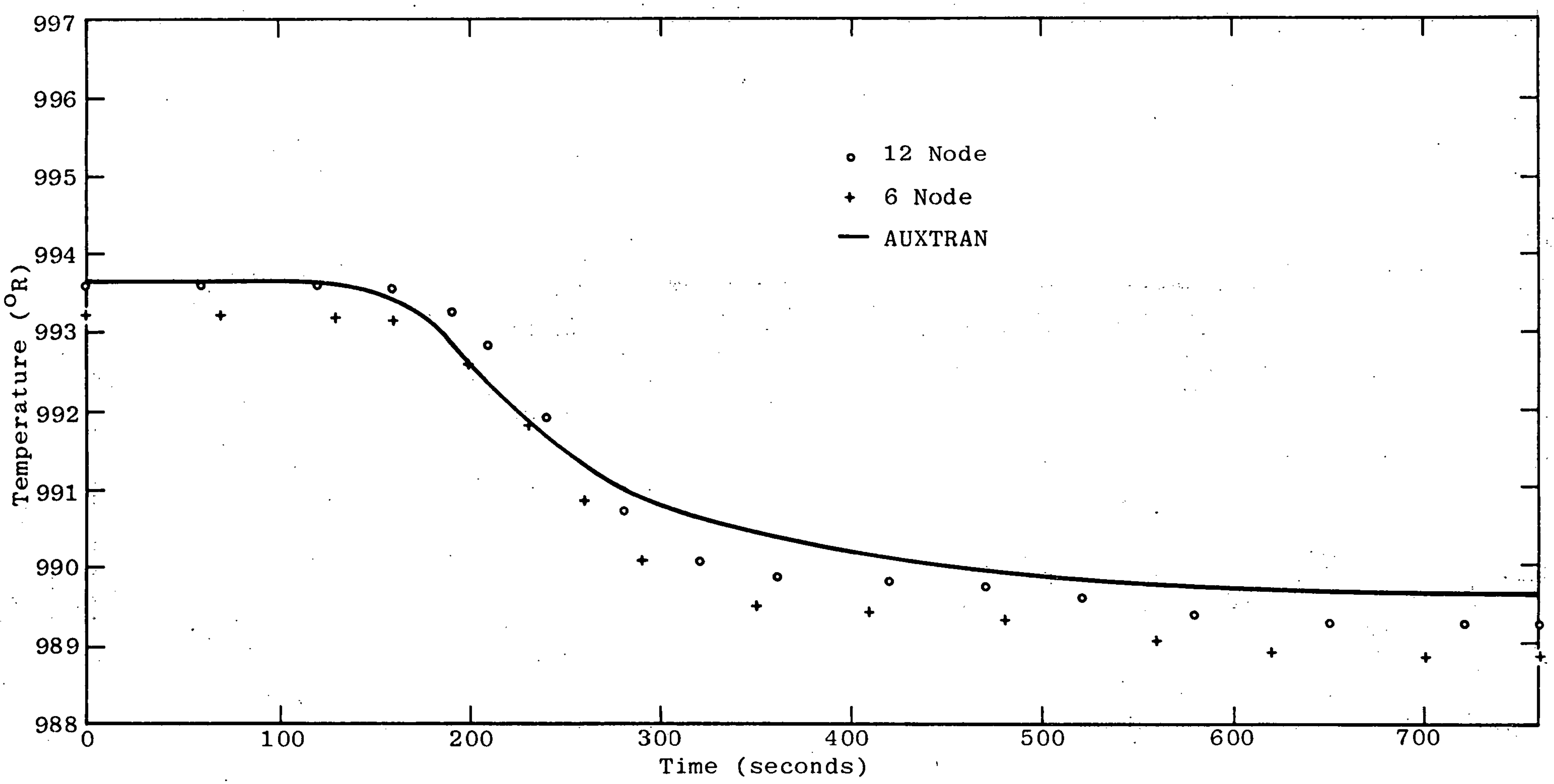

Figure 7.1-25. Outlet Water Temperature from the Cold Leg Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Air Flow Rate.

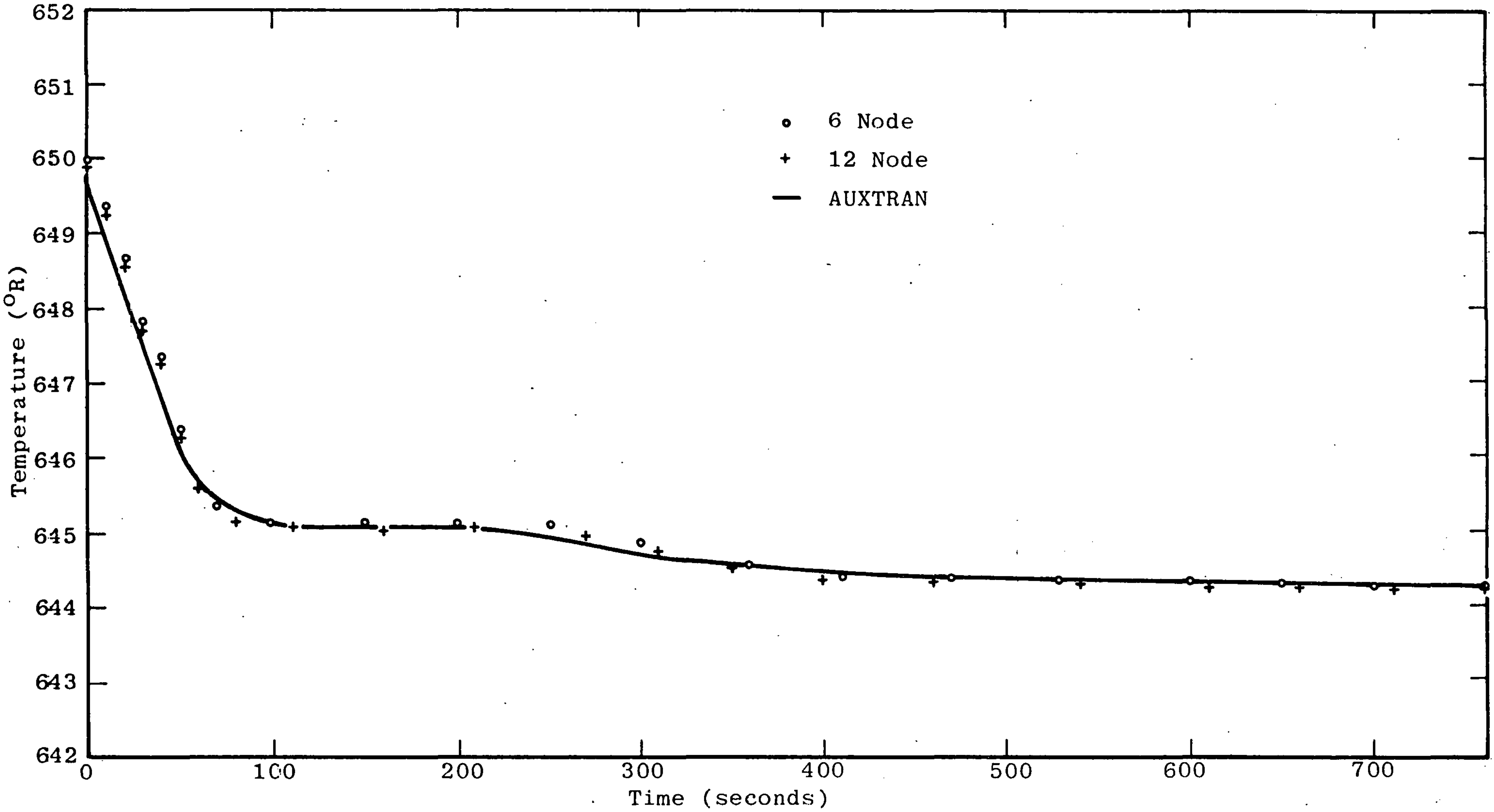

Figure 7.1-26. Outlet Water Temperature from Air Blast Heat Exchanger Comparison with AUXTRAN 5% Step Change at Time = 0.0 in Air Flow Rate.

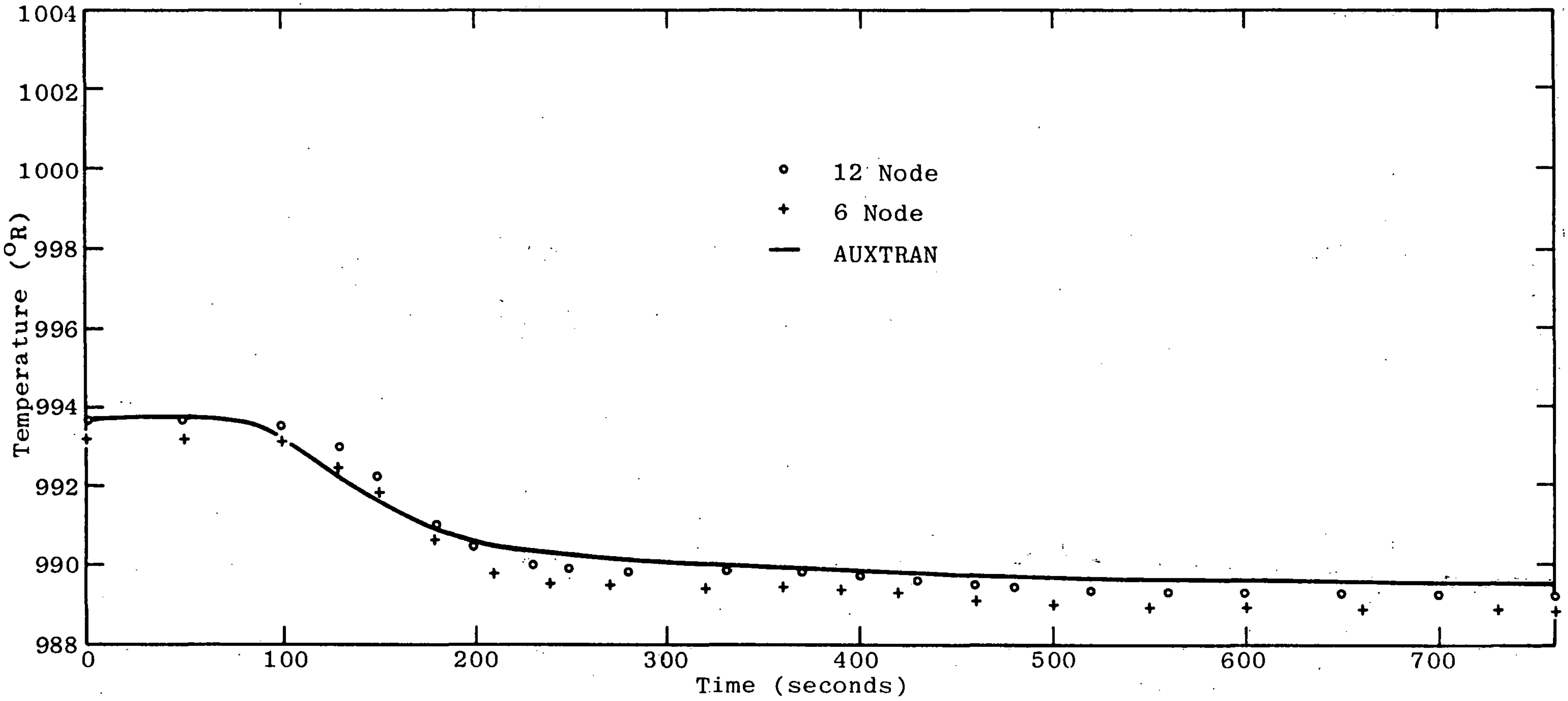

Figure 7.1-27. Outlet Water Temperature from the CAHE Comparison with AUXTRAN after a 5% Step Change at Time = 0.0 in Air Flow Rate.

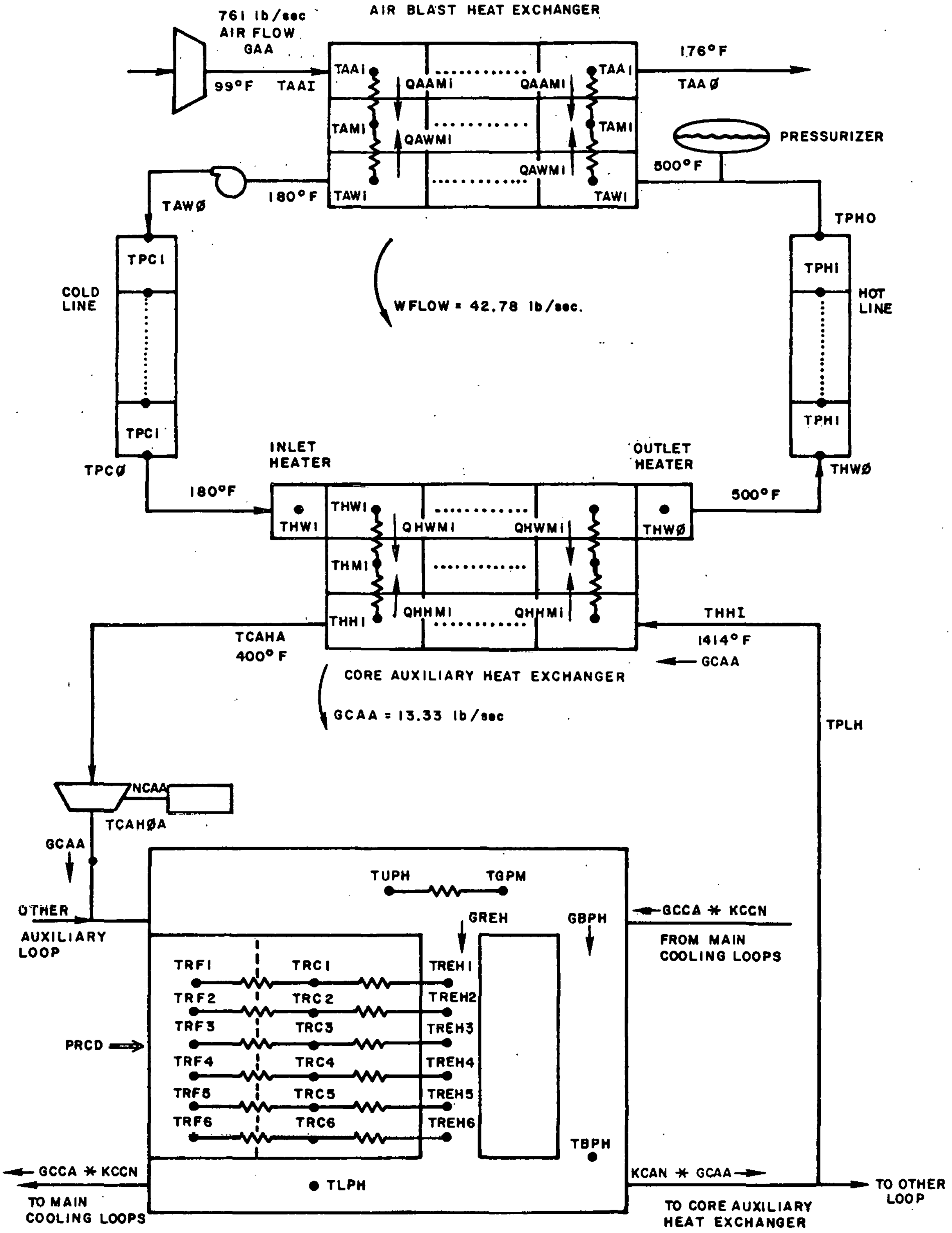

Figure 7.2-1. CASY Schematic

scram using MINGAF, reference 3. The reactor scram was modified in the sense that the reactor power and helium flow rates were preprogrammed to be a specified value dependent upon the time after scram. The water side temperatures were fixed during standby at 1060 °R with a small water and air flow. When scram occurs, the water flow was stepped up to the design value of 42.78 lb/sec and the air flow stepped up to 760.5 lb/sec. Thirty seconds after scram, the auxiliary circulator flow was programmed to increase rapidly. The comparisons are shown in Figures 7.2-2 to 7.2-8. Note, during these comparisons the upper plenum volume was removed to agree with the MINGAF code. The results of a scram transient with this volume node back in CASY are also shown in the figures.

7.3 CONTROL

There are currently 3 controllers programmed in the CASY simulation. Each of the controllers is a two mode controller which can be represented schematically by Figure 7.3-1.

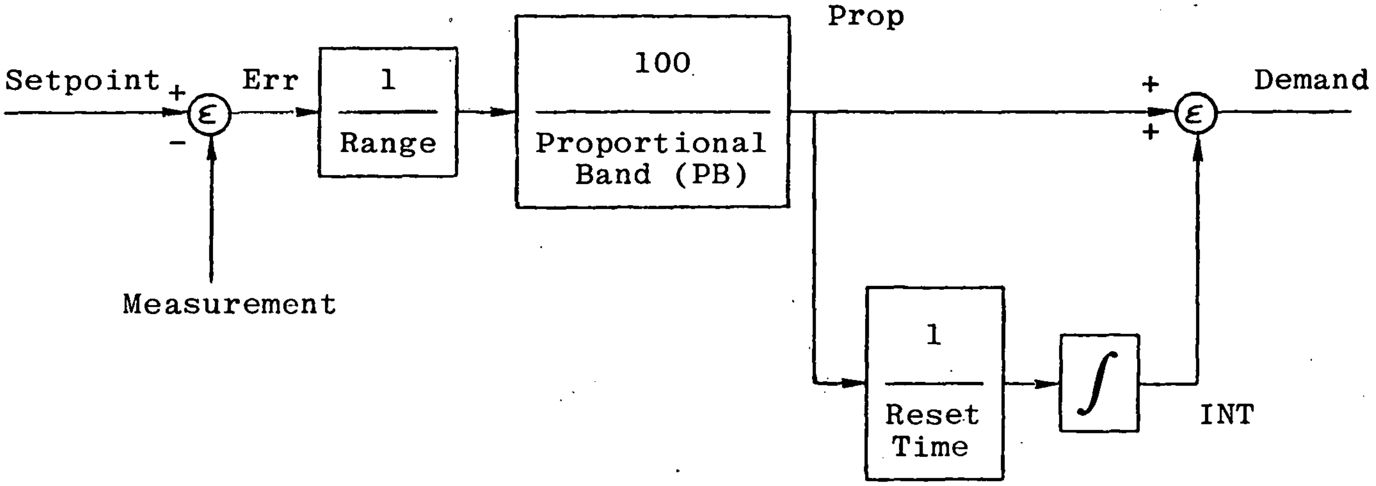

Figure 7.3-1. Typical Two Mode Control Diagram

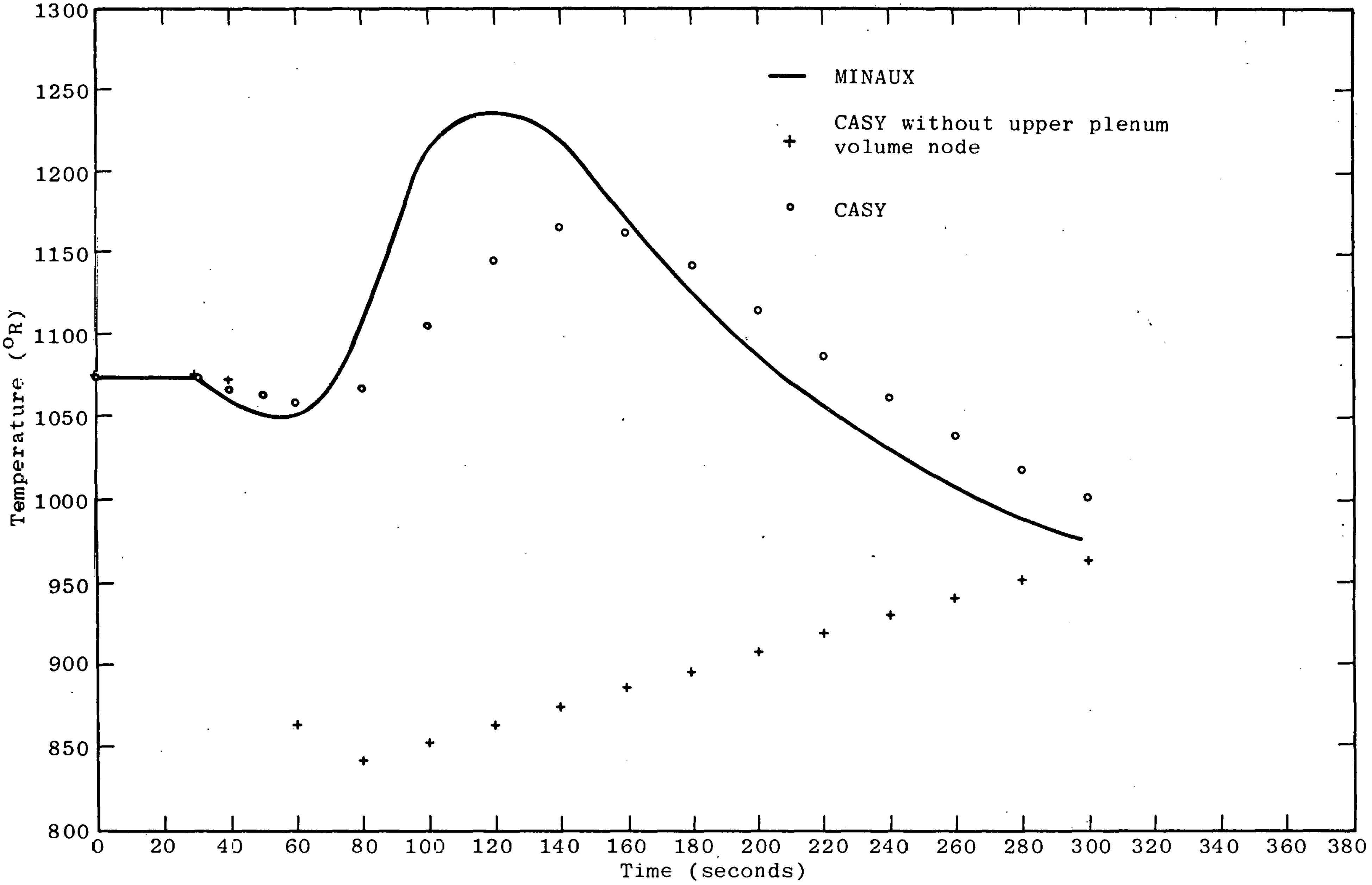

Figure 7.2-2. Comparison of MINAUX and CASY Showing Upper Plenum Helium Temperature to the Core in Response to a Scram Signal at 30 Seconds.

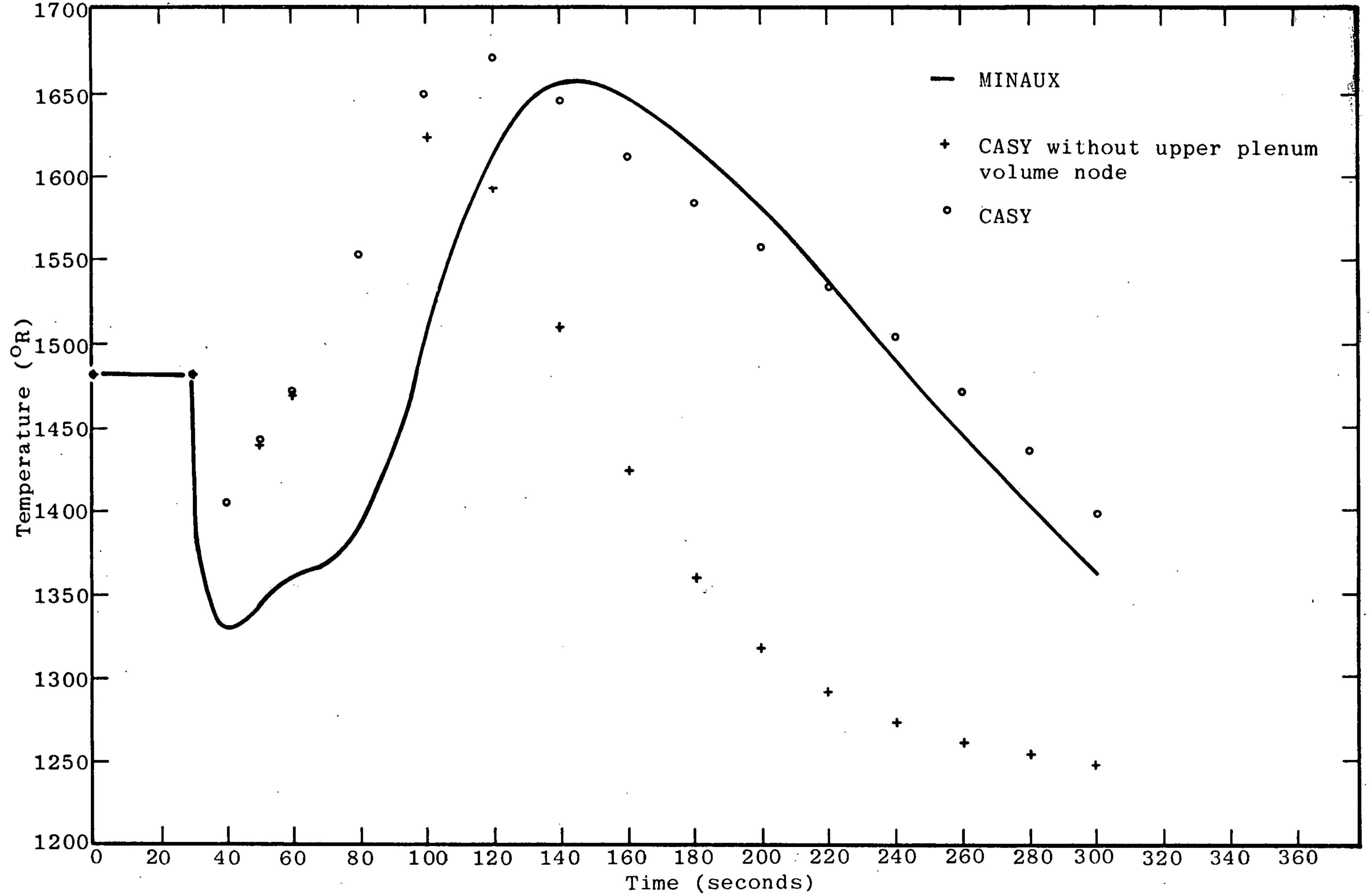

Figure 7.2-3. Comparison of MINAUX and CASY Showing Lower Plenum Helium Temperature in Response to a Scram Signal at 30 Seconds.

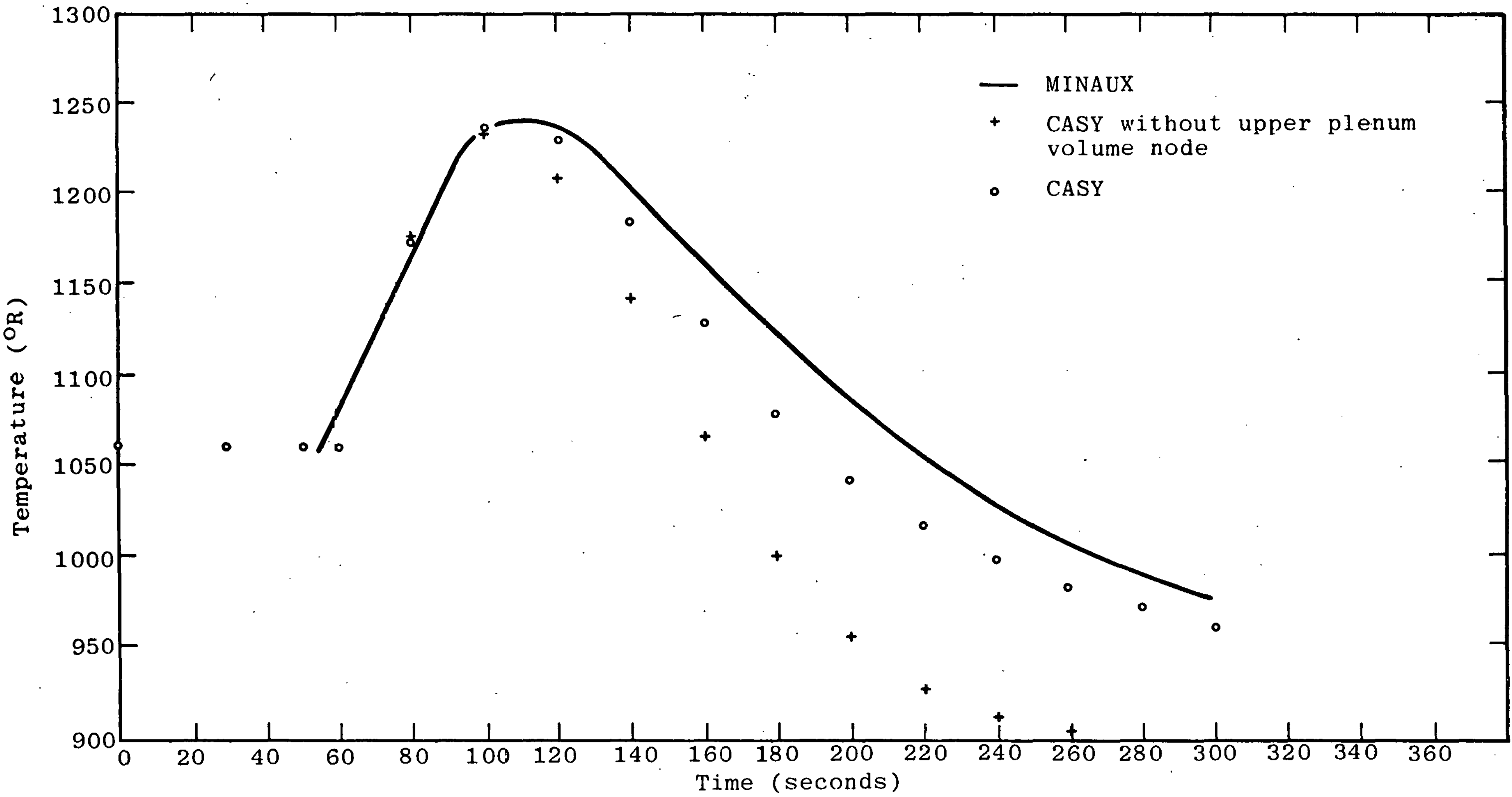

Figure 7.2-4. Comparison Between MINAUX and CASY Showing the Outlet Helium Temperature from the CAHE in Response to a Scram Signal at 30 Seconds.

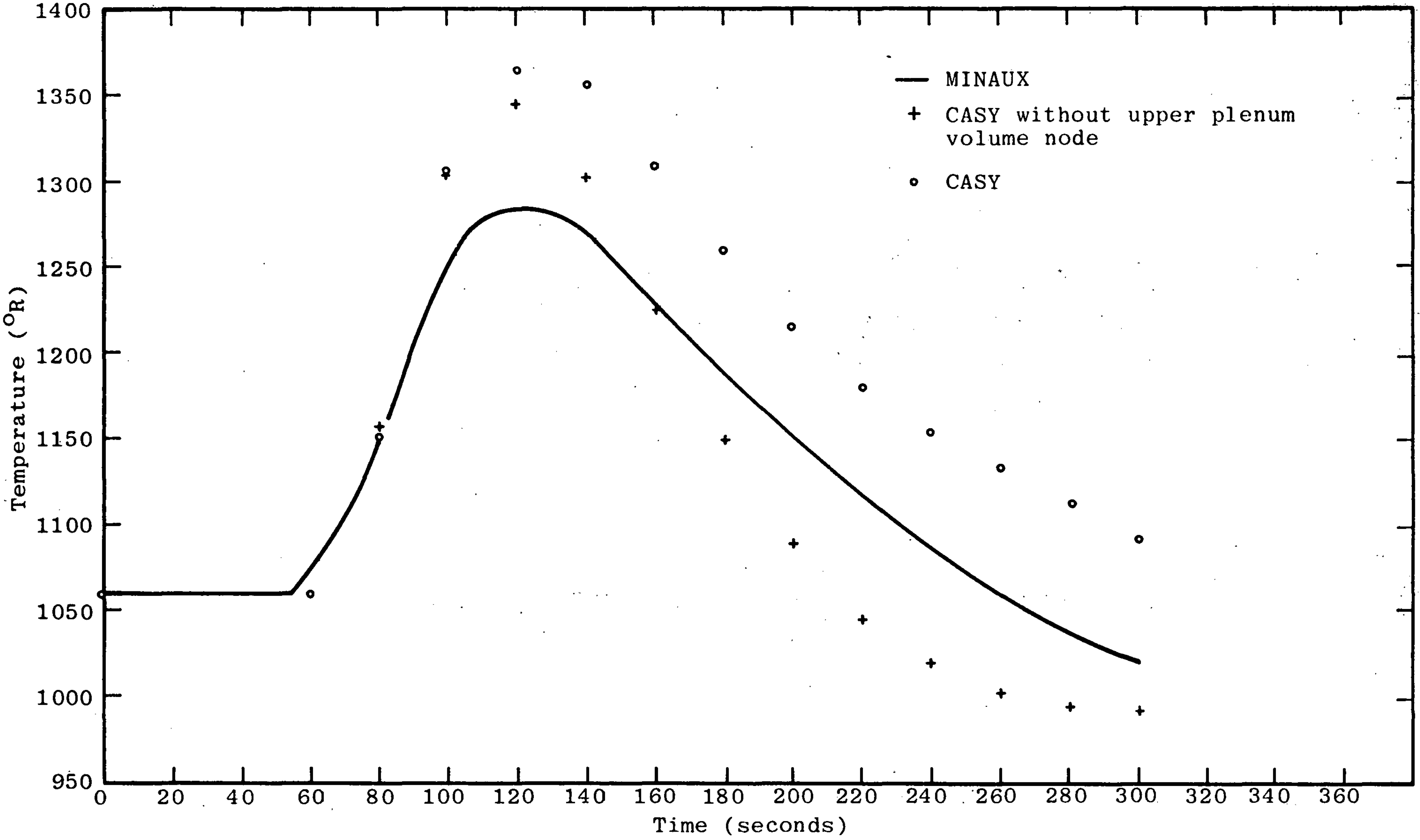

Figure 7.2-5. Comparison Between MINAUX and CASY Showing Outlet Water Temperature from the CAHE in Response to a Scram Signal at 30 Seconds.

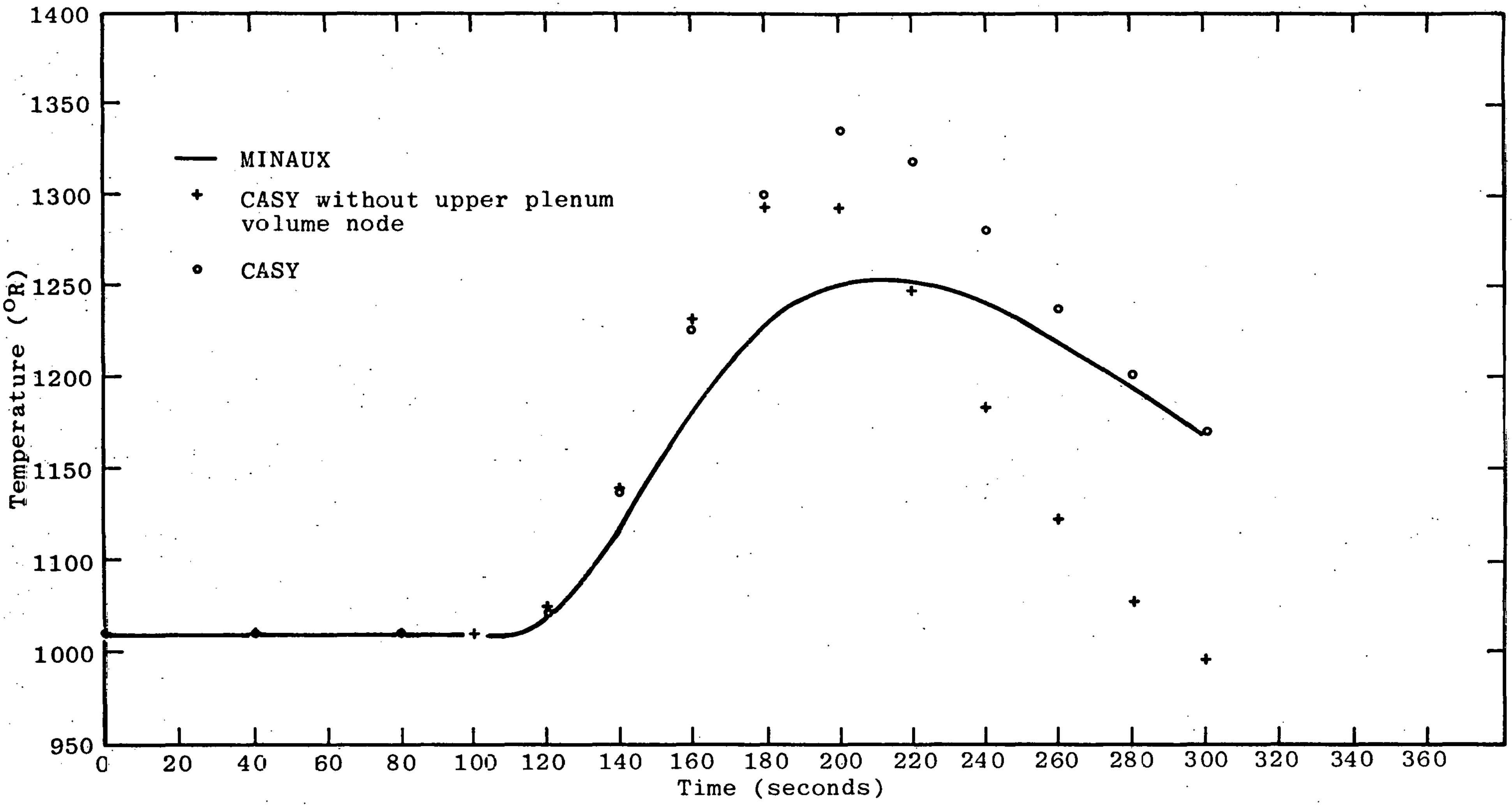

Figure 7.2-6. Comparison Between MINAUX and CASY Showing Outlet Water Temperature from the Hot Pipe in Response to a Scram Signal at 30 Seconds.

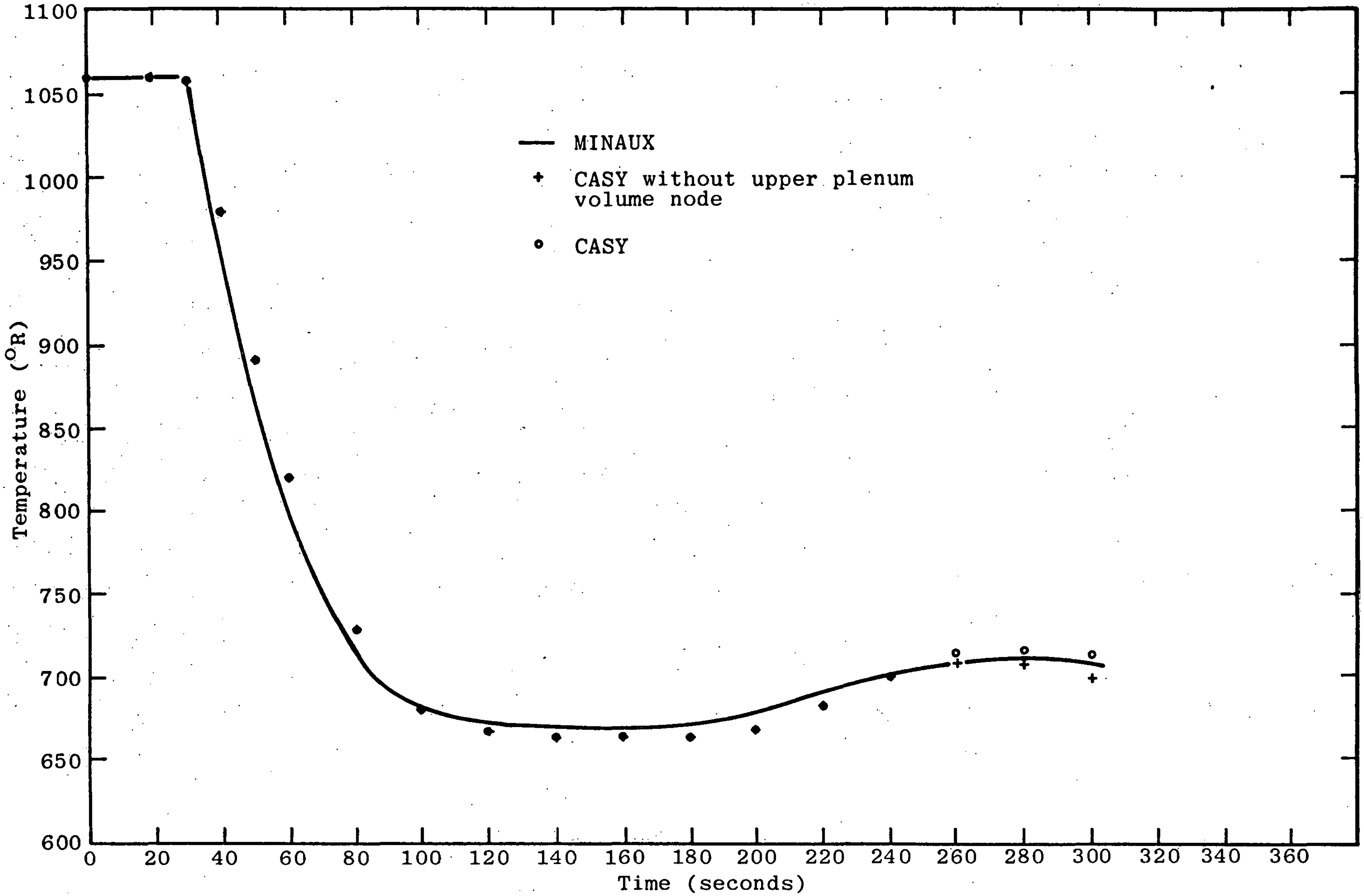

Figure 7.2-7. Comparison Between MINAUX and CASY Showing Outlet Water Temperature from the Air Blast Heat Exchanger in Response to a Scram Signal at 30 Seconds.

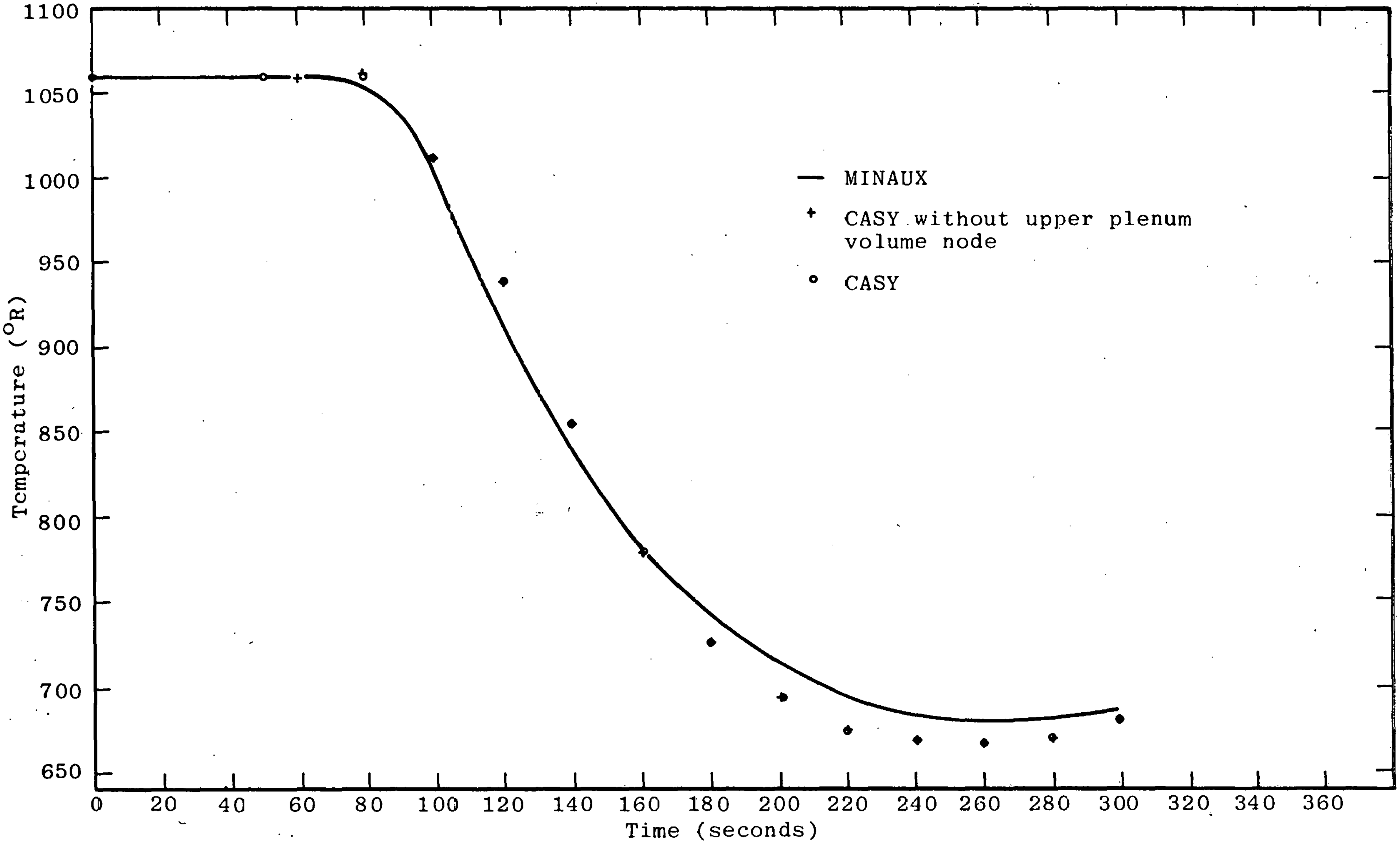

Figure 7.2-8. Comparison Between MINAUX and CASY Showing Outlet Water Temperature from the Cold Pipe in Response to a Scram Signal at 30 Seconds.

The three controllers in CASY are to establish the speed demand for the auxiliary circulator, the large pump, and the small pump valve position. These are shown schematically on Figures 7.3-2, 7.3.3 and 7.3-4.

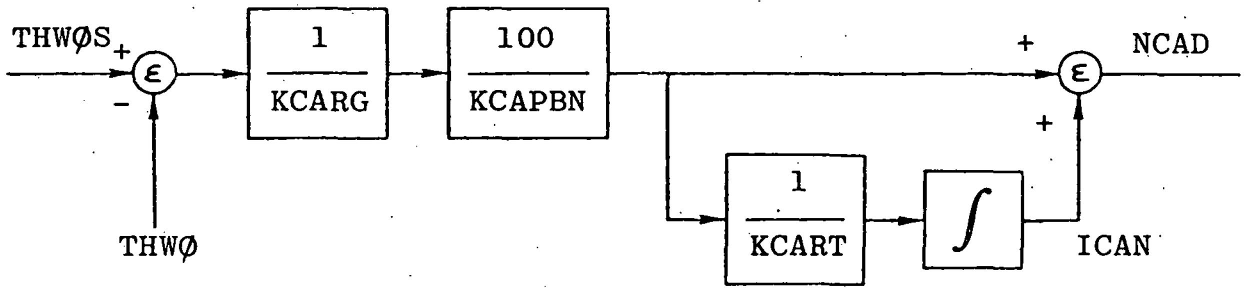

Figure 7.3-2. Circulator Speed Control Schematic

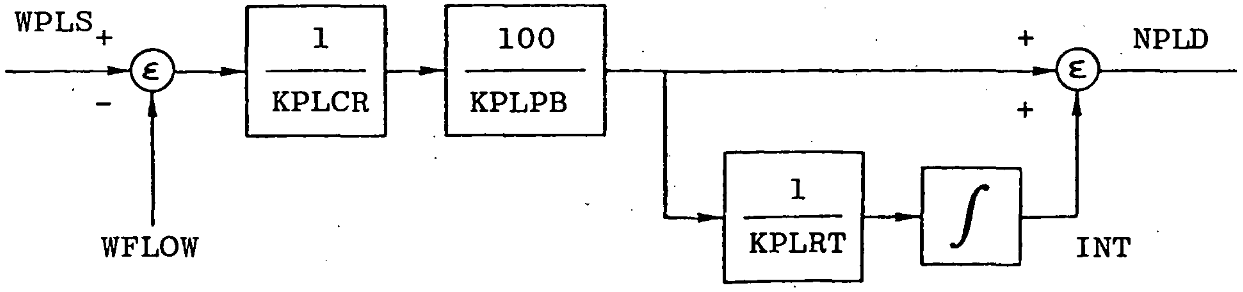

Figure 7.3-3. Large Pump Speed Control Schematic

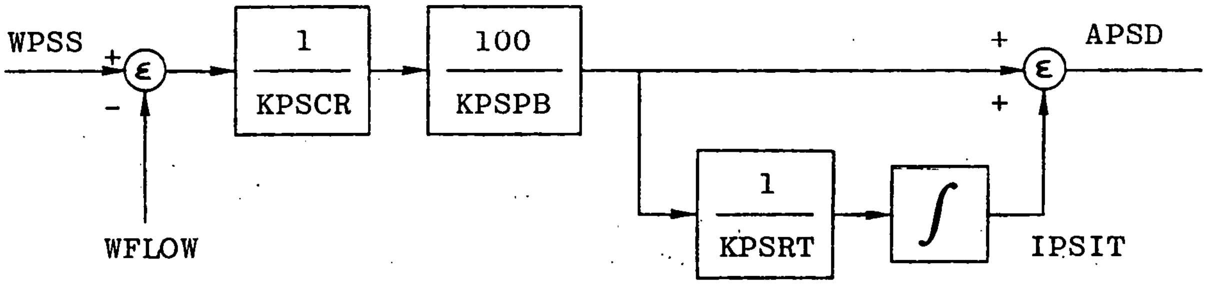

Figure 7.3-4. Small Pump Valve Control Schematic

These are programmed in CASY as shown on Figures 7.3-5, 7.3-6 and 7.3-7.

```
*  *  *  TEMPORARY CIRC SPEED CONTROL ON TEMPERATUREW ERROR

         OCAERR=THWOS-THWO
*  *  *   IF ERROR IS POSITIVE NCAD IS POSITIVE
*  *  *  THAT RESULTS IN IF WATER TEMP IS LOWER THAN
*  *  *  DESIRED, THEN TURN UP CIRC SPEED
*  *  *   ALSO THERE IS NO LIMIT ON CIRC SPEED
         PROPN=100./KCAPBN*OCAERR/KCARG
         DICAN=PROPN/KCART
         ICAN=INTGRL(IICAN,DICAN)
         NCAD=PROPN+ICAN
         DNCAA=(NCAD-NCAA)/1.
         NCAA=INTGRL(INCAA,DNCAA)
*        TCCHOA=THH01
*        TCCHOA=(1.-SCAV)*ITUPH + SCAV*THH01
         TCCHOA=AFGEN(TINLET,TIME)
         DTCAHA=(THH01-TCAHOA)/KCATAU
         TCAHOA=INTGRL(ITCAHA,DTCAHA)

*        GCAA=KCAR*144.*PNSS/TCAHOA/KUNGR*NCAA

         GCAA=GCAAS

         GRETOT=KCCN *GCCA+KCAN *GCAA
```

Figure 7.3-5. Circulator Speed Controller Listing

```
*      TEMPORARY CACWS FLOW CONTROL AND ACTUATOR MODELS

*      PROP=100./KPLPB*(WPLS-WFLOW)/KPLCR
*      DINT=PROP/KPLRT
*      INT=INTGRL(IINT,DINT)
*      NPLD=PROP+INT
*      DNPL=(NPLD-NPL)/20.
*      NPL=INTGRL(INPL,DNPL)
*
```

Figure 7.3-6. Large Pump Speed Controller Listing

```
*
*      PROPS=100./KPSPB*(WPSS-WFLOW)/KPSCR
*      DIPSIT=PROPS/KPSRT
*      IPSIT=INTGRL(IIPSIT,DIPSIT)
*      APSD=PROPS+IPSIT
*      DAPS=(APSD-APS)/4.
*      APS=LIMINT(IAPS,0.0,1.0,DAPS)
```

Figure 7.3-7. Small Pump Controller Listing

8. PROGRAM LISTINGS

8.1 CASY SIMULATION CODE

This section contains a listing of the CASY simulation code as it existed on September 30, 1977.

```
LNP!
      1:TITLE    GCFR CASY
      2:ADDMAP MAP*CASY.
      3:
      4:
      5:*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
      6:*  *  NOMENCLATURE GUIDELINES FOR CASY-SEE SECTION 3 OF REPORT    *
      7:*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
      8:
      9:
     10:*  *  FIRST LETTER DESIGNATION - TYPE OF VARIABLE
     11:
     12:*          A   NORMALIZED VALVE AREA                           (ND)
     13:*          B   RATE OF THERMAL EXPANSION OR CONTRACTION        (FT**3/SEC)
     14:*          D   RATE OF CHANGE WRT TIME                         (PER SEC)
     15:*          E   EFFICIENCY (ND)
     16:*          G   GAS FLOW RATE                                    (LBS/SEC)
     17:*          I   INITIAL VALUE OF STATE
     18:*          J   INTERMEDIATE VARIABLE
     19:*          K   RESERVED FOR CONSTANTS
     20:*          L   VALVE LIFT (ND) OR TANK LEVEL (FT)
     21:*          N   ROTATIONAL SPEED (RPM) OR NUMBER (ND)
     22:*          O   INTERMEDIATE VARIABLE
     23:*          P   PRESSURE (PSIA) OR PRESSURE DIFFERENTIAL (PSID)
     24:*          Q   RATE OF HEAT TRANSFER (BTU/SEC)
     25:*          R   DENSITY (LB/FT**3)
     26:*          T   TEMPERATURE (DEG F)
     27:*          W   WATER FLOW RATE (LBS/SEC)
     28:*          X   TORQUE (FT-LBS)
     29:
     30:*  *  SECOND AND THIRD LETTER DESIGNATIONS - COMPONENT ID
     31:
     32:*          A-   AIR BLAST HEAT EXCHANGER
     33:*          AA   AIR SIDE
     34:*          AM   TUBE AND FINS
     35:*          AW   WATER SIDE
     36:*          BP   CORE BYPASS
     37:*          CA   CIRCULATOR AUXILIARY
     38:*          CC   CIRCULATOR
     39:*          CM   CIRCULATOR MOTOR
     40:*          CG   CONTROL GUIDE
     41:*          CS   CORE SUPPORT
     42:*          H-   CAHE HEAT EXCHANGER
     43:*          HH   HELIUM SIDE
     44:*          HM   TUBE METAL
     45:*          HW   WATER SIDE
     46:*          LP   LOWER PLENUM
     47:*          LR   LOWER REFLECTOR
     48:*          PC   PIPE FROM AIR BLAST HX AND CAHE HX (COLD LEG)
     49:*          PH   PIPE FROM CAHE HX TO AIR BLAST HX (HOT LEG)
     50:*          PL   PUMP (LARGE)
     51:*          PR   PRESSURIZER
     52:*          PS   PUMP (SMALL)
     53:*          RE   CORE (NUCLEAR REACTOR)
     54:*          RF   REACTOR FUEL
     55:*          RM   REACTOR MODERATOR
     56:*          SR   SIDE REFLECTOR
     57:*          SP   SUPPORT POSTS
     58:*          UN   UNIVERSAL (CONVERSION FACTOR OR CONSTANT)
     59:*          UP   UPPER PLENUM
     60:*          UR   UPPER REFLECTOR
     61:**********************************************************************
```

```


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  CONSTANTS, TABLES, AND MACROS USED BY MORE THAN ONE      *  *
*  *  COMPONENT MODEL HENCE CONTAINED IN MISCELLANEOUS         *  *
*  *  SECTION OF ALL                                           *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *



CONST    KUNACP=0.2407     , KUNGR =386.      , KUNHCV=.746
CONST    KUNWCP=1.0227     , KUNHCP=1.242

AFGEN RFTSL=510.,62.4,560.,62.0,610.,61.2,660.,60.1,710.,58.8,760.,...
       57.3,810.,55.6,860.,53.7,910.,51.5,960.,49.0,1010.,45.9,1060.,...
       42.4,1110.,37.3
AFGEN PARTRT=510.,-.0122,610.,-.0187,660.,-.0238,710.,-.0282,760.,...
       -.0323,810.,-.0366,860.,-.0412,910.,-.0463,960.,-.0560,1010.,...
       -.0665,1110.,-.0856
AFGEN FSPH=560.,.998,660.,1.00,710.,1.01,760.,1.03,810.,1.05,...
           860.,1.08,910.,1.12,960.,1.19,1010.,1.31,1060.,1.51
AFGEN FVIS=560.,1.649,610.,1.051,660.,0.738,710.,0.569,760.,0.454, ...
         810.,0.378,860.,0.328,910.,0.288,960.,0.256,1010.,0.230, ...
         1060.,0.209,1110.,.197
AFGEN FCON=560.,0.364,610.,0.384,660.,0.394,710.,0.396,760.,0.395,...
            810.,0.391,860.,0.381,910.,0.367,960.,0.349,1010.,0.325,...
            1060.,0.292,1110.,0.280

AFGEN HSATP=58.,259.,118.,311.,220.,364.,382.,419.,...
             621.,476.,962.,537.,1431.,603.,2060.,679.,...
             2895.,784.
AFGEN HSATT=550.,58.,600.,108.,650.,158.,700.,208.,  ...
         750.,259.,800.,311.,850.,364.,900.,419.,950.,476.,...
            1000.,537.,1050.,603.,1100.,679.,1150.,784.

MACRO TGO,TWO,DTM,DTW,QGM,QWM,RW,BW=SPCFHX(TGI,TWI,ITM,TM,ITW,TW,...
     MCAP,VOL,WTG1,WTG2,WTW1,WTW2,JGCP,WFLOW,JC,JHTW)
*   SEE SECTION 6.2 OF REPORT
*  SINGLE PHASE COUNTER FLOW HEAT EXCHANGER WITH INCOMPRESSABLE
*  FLUID ON W SIDE AND NEGLIGIBLE FLUID THERMAL CAPACITY ON G SIDE
*  TGO=GAS EXIT TEMP, QGM=ENERGY TRANSFER GAS TO METAL
*  RW=AVERAGE NODAL DENSITY, TW=AVERAGE NODAL TEMP,
*  QWM=HEAT TRANSFER WATER TO METAL, TWO=WATER EXIT TEMP
      RW=AFGEN(RFTSL,TW)
      TGO=(TGI*(1.-WTG1*JC)+JC*TM)/(1.+WTG2*JC)
      QGM=JGCP*(TGI-TGO)
      TWO=(TW-WTW1*TWI)/WTW2
      QWM=JHTW*(TW-TM)
      DTM=(QWM+QGM)/MCAP
      TM=INTGRL(ITM,DTM)
      DTW=(WFLOW*(TWI-TWO)-QWM/KUNWCP)/VOL/RW
      BW=DTW*VOL*AFGEN(PARTRT,TW)
      TW=INTGRL(ITW,DTW)
ENDMAC
```

```


MACRO DTF,RF,JPRT=PIPE1(FLO,TFI,VOL,MCAP,TF,ITF)
*   SEE SECTION 6.1 OF REPORT
*   PIPE THERMAL NODE WITH COMBINED METAL AND FLUID THERMAL CAPACITANCE
      RF=AFGEN(RFTSL,TF)
      DTF=FLO*(TFI-TF)/(MCAP/KUNWCP+VOL*RF)
      JPRT=VOL*DTF*AFGEN(PARTRT,TF)
      TF=INTGRL(ITF,DTF)
ENDMAC



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  HOT LEG COMPONENT CONSTANTS, TABLES, AND MACROS            *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

CONST     KPHVT =40.7         , KPHCT =1466.0      , KPHN  =10.



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  COLD LEG COMPONENT CONSTANTS, TABLES, AND MACROS           *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

CONST     KPCVT =40.7         , KPCCT =1466.0      , KPCN  =10.



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  AIR BLAST HX COMPONENT CONSTANTS, TABLES, AND MACROS       *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

CONST     KAWRX =5316.        , KAMR  =1.08        , KAAR  =29.52
CONST     KAWWR =42.78        , KAAG  =761.1       , KAWA  =1975.
CONST     KAAA  =2438.         , KAATR =598.        , KAMTR =679.
CONST     KAWTR =760.         , KAAAU =.2831       , KAABU =.7169
CONST     KAAAK =.1777        , KAABK =.8223       , KAMAK =1.1546
CONST     KAMBK =.1546        , KAMCT = 1039.6      , KAWVT =33.33
CONST     KAWN  =10.          , KAWW1 =0.5         , KAAW1=0.5
CONST     KAWVI =3.           , KAWVO =3.          , KAMCI =100.
CONST     KAMCO =100.



MACRO TG,JAIR,JWAT=HTCOE(WFLOW,GFLRAT,JCGP,TG1,TG2,TMET,TWAT)
*   SEE APPENDIX C OF REPORT
      TG=(TG1+TG2)/2
PROCED RAIR=RESX(GFLRAT)
       RAIR=KAAR*GFLRAT*(KAAAU+KAABU*(TG/KAATR))**.681/...
       (KAAAK+KAABK*TG/KAATR)
ENDPRO
      RMET=KAMR/(KAMAK-KAMBK*TMET/KAMTR)
      CON=AFGEN(FCON,TWAT)
      VIS=AFGEN(FVIS,TWAT)
      SPH=AFGEN(FSPH,TWAT)
      RWAT=KAWRX/(CON*(WFLOW*3600./VIS)**.8*...
          (SPH*VIS/CON)**.333)
      JAIR=KAAA/KAWN/(0.5*RMET+RAIR)/JCGP
      JWAT=KAWA/KAWN/(0.5*RMET*KAWA/KAAA+RWAT)
ENDMAC
```

```



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  CAHE COMPONENT CONSTANTS, TABLES, AND MACROS              *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


CONST    KHHRX =1.614E5    , KHWRX =1.48E4      , KHMRX =28.14
CONST    KHMCT =418.       , KHMCI =58.35       , KHMCO =58.35
CONST    KHWVT =10.8       , KHWVI =3.91        , KHWVO =3.91
CONST    KHMCIO=208.       , KHWMI =.8267       , KHWMO =.8267
CONST    KHWN  =6.0        , KHHW1 =0.5         , KHWW1 =0.5
CONST    KHHVK =6.388E-4   , KHHVKE=0.687       , KHHCK =1.062E-3
CONST    KHHCKE=0.701      , KHMAK =6.25        , KHMBK =0.0055
CONST    KHHA  =1141.      , KHWA  =888.5

MACRO TG,JHEL,JWAT=HTKOE(WFLOW,HFLOW,JG,T1,T2,TM,TW)
*   SEE APPENDIX C OF REPORT
      TG=(T1+T2)/2
PROCED RHE=RESY(HFLOW)
      HSPH=1.242
      HVIS=KHHVK*TG**KHHVKE
      HCON=KHHCK*TG**KHHCKE
      RHE=KHHRX/(HCON*(HFLOW*3600./HVIS)**.8*...
            (HSPH*HVIS/HCON)**.333)
ENDPRO
      RMET=KHMRX/(KHMAK+KHMBK*(TM-460.))
      CON=AFGEN(FCON,TW)
      VIS=AFGEN(FVIS,TW)
      SPH=AFGEN(FSPH,TW)
      RWAT=KHWRX/(CON*(WFLOW*3600./VIS)**.8*...
         (SPH*VIS/CON)**.333)
      JWAT=(KHWA/KHWN)/(.5*RMET*KHWA/KHHA+RWAT)
      JHEL=(KHHA/KHWN/JG)/(.5*RMET+RHE)
ENDMAC


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  PUMP AND PROCESS-FLOW COMPONENT CONSTANTS, TABLES, AND    *  *
*  *  MACROS                                                    *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

CONST    KAWSQ =.9031      , KHWSQ =.9016       , KAWISQ=.6803
CONST    KPHSQ =.2268      , KPCSQ =.3300       , KHWISQ=.6800


MACRO W,DWDPO=MOPTV(KV,AV,SV,J0,J1,J2,WR,DELP)
*   SEE SECTION 4.1 OF REPORT
*   GENERAL PURPOSE PUMP MACRO FOR REPRESENTING CONSTANT OR VARIABLE
*   SPEED PUMP WITH THROTTLE OR ISOLATION VALVE OPTIONAL.  REQUIRES
*   THAT USER SPECIFY RECIRCULATION FLOW AS INPUT.  USER MUST SPECIFY
*   PUMP CHARACTERISTIC AS SECOND ORDER POLYNOMIAL.
      JV=KV*KV*AV*AV
      IF(SV.EQ.0.) JV=1
*   IF ISOLATION VALVE IS OPEN, THROTTLE VALVE SETTING IS IMMATERIAL
*  AS IT DROPS OUT. SETTING JV=1. RESULTS IN AINV=-1/J2 AS APPROP.
      AINV=-JV/(SV-J2*JV)
      B=(J1+2.*WR*J2)
      BAINV=B*AINV
      CPART=WR*(J1+J2*WR)+J0
      DELPMX=-B*BAINV/4.+CPART
      IF(DELPMX-DELP) 1,1,2
```

```
   1 W=0.
    DWDPO=0.
    GO TO 3
   2 C=CPART-DELP
    W=-BAINV/2.+SQRT(BAINV*BAINV/4.-C*AINV)
    DWDPO=AINV/(2.*W+B*AINV)
   3 CONTINUE
ENDMAC


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  CORE COMPONENT CONSTANTS, TABLES, AND MACROS  *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *



*   CONSTANTS --- CORE

CONST    KRENN =30834.
CONST    KRFV1 =5.54054E-4 , KRFV2 =2.45467E-4 , KRFV3 =2.45467E-4
CONST    KRFV4 =2.45467E-4 , KRFV5 =2.45467E-4 , KRFV6 =4.51359E-4
CONST    KRCV1 =2.00803E-4 , KRCV2 =8.89634E-5 , KRCV3 =8.89634E-5
CONST    KRCV4 =8.89634E-5 , KRCV5 =8.89634E-5 , KRCV6 =1.63584E-4
CONST    KREA1 =0.13599    , KREA2 =0.06025    , KREA3 =0.06025
CONST    KREA4 =0.06025    , KREA5 =0.06025    , KREA6 =0.11079
CONST    KREL1 =1.475      , KREL2 =0.817      , KREL3 =0.817
CONST    KREL4 =0.817      , KREL5 =0.817      , KREL6 =1.475
CONST    KREPF1=0.0271     , KREPF2=0.2021     , KREPF3=0.2710
CONST    KREPO =829.5      , KREPF =0.95       , KREGF =0.95
CONST    KREPF4=0.2710     , KREPF5=0.2021     , KREPF6=0.0271
CONST    KCCN  =3.         , KCAN  =2.         , KCAR  =0.2471
CONST   KHHVI6=344.

*  *  *  *  TEMPERARY LAG ON CIRC TEMPERATURE  *  *  *  *
CONST    KCATAU=1.

MACRO JCG,JCF=CORHT(G,TC,TF,TG,A,L)
PROCED JCG,JCF=CORHT1(G)
    REY=3.055E8*G*TG**-.687
    IF(REY.LT.2300.)REY=2300.
    H=8.28E-4*TG**.701*REY**.8/3600.
    KC=1.693E-3+1.208E-6*TC
    RC=.02305/(KC*L)
    RCG=1./(H*A)+RC/2.
    JCG=1./RCG
    KF=57.78*.886*(1./(18.2+.0271*TF/1.8)+5.5E-13*(TF/1.8)**3)/3600.
    KH=2.95E-7*((TF+TC)/2.)**0.701
    RCF=.03229/(KF*L)+.0036/(KH*L)+RC/2.
    JCF=1./RCF
ENDPRO
ENDMAC

```

```
MACRO DTC,DTF,TGO,TGA=CRNODE(JGC,JCF,VF,VC,TGI,G,QRF,ITF,TF,ITC,TC)
*     SINGLE NODE FOR REACTOR EQUIVALENT FUEL CHANNEL MODEL
      JL=JGC/(G*KUNHCP)
      JW=1.-1./(1.-EXP(-JL))+1./JL
      TGO=(TGI*(1.-JL*JW)+JL*TC)/(1.+JL*(1.-JW))
      TGA=JW*TGI+(1.-JW)*TGO
      QGC=KUNHCP*G*(TGO-TGI)
      CF=0.5559*(52.492+0.03953*TF-1.512E-5*TF**2+2.203E-9*TF**3)
      CC=0.1196*(218.378+0.6541*TC-4.504E-4*TC**2+1.143E-7*TC**3)
      CAPF=VF*CF
      CAPC=VC*CC
      QFC=JCF*(TF-TC)
      DTF=(QRF-QFC)/CAPF
      TF=INTGRL(ITF,DTF)
      DTC=(QFC-QGC)/CAPC
      TC=INTGRL(ITC,DTC)
ENDMAC




INITIAL


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  HOT LEG COMPONENT INCON AND PARAM SECTION                *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


INCON    ITPH1 =1060.      , ITPH2 =1060.      , ITPH3 =1060.
INCON    ITPH4 =1060.      , ITPH5 =1060.      , ITPH6 =1060.
INCON    ITPH7 =1060.      , ITPH8 =1060.      , ITPH9 =1060.
INCON ITPH10=1060.
INCON    ITPHM =1060.

      KPHC=KPHCT/KPHN
      KPHV=KPHVT/KPHN

      TPH1=ITPH1
      TPH2=ITPH2
      TPH3=ITPH3
      TPH4=ITPH4
      TPH5=ITPH5
      TPH6=ITPH6
      TPH7=ITPH7
      TPH8=ITPH8
      TPH9=ITPH9
      TPH10=ITPH10
      TPHM=ITPHM



```

```
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  COLD LEG COMPONENT INCON AND PARAM SECTION                 *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


INCON    ITPC1 =1060.       , ITPC2 =1060.        , ITPC3 =1060.
INCON    ITPC4 =1060.       , ITPC5 =1060.        , ITPC6 =1060.
INCON    ITPC7 =1060.       , ITPC8 =1060.        , ITPC9 =1060.
INCON ITPC10=1060.
INCON    ITPCOM=1060.

      KPCC=KPCCT/KPCN
      KPCV=KPCVT/KPCN

      TPC1=ITPC1
      TPC2=ITPC2
      TPC3=ITPC3
      TPC4=ITPC4
      TPC5=ITPC5
      TPC6=ITPC6
      TPC7=ITPC7
      TPC8=ITPC8
      TPC9=ITPC9
      TPC10=ITPC10
      TPCOM=ITPCOM



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  AIR BLAST HX COMPONENT INCON AND PARAM SECTION           *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


INCON    ITAW0 =1060.       , ITAW1 =1060.        , ITAWI=1060.
INCON    ITAW2 =1060.       , ITAW3 =1060.        , ITAW4=1060.
INCON    ITAW5 =1060.       , ITAW6 =1060.        , ITAW7=1060.
INCON    ITAW8 =1060.       , ITAW9 =1060.        , ITAW10=1060.
INCON    ITAM1 =1060.
INCON    ITAM2 =1060.       , ITAM3 =1060.        , ITAM4=1060.
INCON    ITAM5 =1060.       , ITAM6 =1060.        , ITAM7=1060.
INCON    ITAM8 =1060.       , ITAM9 =1060.        , ITAM10=1060.
PARAM    TAA1 =1060.       , TAA2 =1060.       , TAA3 =1060.
PARAM    TAA4 =1060.       , TAA5 =1060.       , TAA6 =1060.
PARAM    TAA7 =1060.       , TAA8 =1060.       , TAA9 =1060.
PARAM    TAA10=1060.
```

```

      TAWI=ITAWI
      TAWO=ITAWO
      TAW1=ITAW1
      TAW2=ITAW2
      TAW3=ITAW3
      TAW4=ITAW4
      TAW5=ITAW5
      TAW6=ITAW6
      TAW7=ITAW7
      TAW8=ITAW8
      TAW9=ITAW9
      TAW10=ITAW10
      TAM1=ITAM1
      TAM2=ITAM2
      TAM3=ITAM3
      TAM4=ITAM4
      TAM5=ITAM5
      TAM6=ITAM6
      TAM7=ITAM7
      TAM8=ITAM8
      TAM9=ITAM9
      TAM10=ITAM10

      KAAW2=1.-KAAW1
      KAWW2=1.-KAWW1
      KAMC= KAMCT/KAWN
      KAWV= KAWVT/KAWN


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  CAHE COMPONENT INCON AND PARAM SECTION                   *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


INCON    ITHWO =1060.      , ITHW1 =1060.      , ITHWI=1060.
INCON    ITHW2 =1060.      , ITHW3 =1060.      , ITHW4=1060.
INCON    ITHW5 =1060.      , ITHW6 =1060.
INCON    ITHM1 =1060.
INCON    ITHM2 =1060.      , ITHM3 =1060.      , ITHM4=1060.
INCON    ITHM5 =1060.      , ITHM6 =1060.      , ITHHI6=1060.
PARAM    THH1 =1060.     , THH2 =1060.     , THH3 =1060.
PARAM    THH4 =1060.     , THH5 =1060.     , THH6 =1060.


      THWO=ITHWO
      THWI=ITHWI
      THW1=ITHW1
      THW2=ITHW2
      THW3=ITHW3
      THW4=ITHW4
      THW5=ITHW5
      THW6=ITHW6
      THM1=ITHM1
      THM2=ITHM2
      THM3=ITHM3
      THM4=ITHM4
      THM5=ITHM5
      THM6=ITHM6
      THMIO=ITHMIO
      THHI6=ITHHI6

```

```
      KHHW2=1.-KHHW1
      KHWW2=1.-KHWW1
      KHMC= KHMCT/KHWN
      KHWV= KHWVT/KHWN



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  PUMP AND PROCESS-FLOW COMPONENT INCON AND PARAM SECTION  *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


INCON    IVPRW = .201657+03, ITPRW = .538657+03, IPPRG = .209573+04
INCON    IPLOAD= .126990+03, INPL  = .455178+04, IINT  = .455553+04
INCON    IAPS  =0.6731     , IIPSIT=0.6731
PARAM    WFLOW = 0.0001


      VPRW=IVPRW
      TPRW=ITPRW
      PPRG=IPPRG
      PLOAD=IPLOAD
      NPL=INPL
      INT=IINT
      APS=IAPS
      IPSIT=IIPSIT



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  CORE COMPONENT INCON AND PARAM SECTION                   *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


*   INITIAL CONDITIONS --- CORE
INCON    ITRF1 = .115745+04, ITRF2 = .245830+04, ITRF3 = .300611+04
INCON    ITRF4 = .310270+04, ITRF5 = .274210+04, ITRF6 = .156610+04
INCON    ITRC1 = .109587+04, ITRC2 = .137460+04, ITRC3 = .154961+04
INCON    ITRC4 = .165473+04, ITRC5 = .166634+04, ITRC6 = .149256+04
INCON    ITUPH = .107490+04, ITLPH = .148027+04

PARAM    TREH1 = .108106+04, TREH2 = .112910+04, TREH3 = .122578+04
PARAM    TREH4 = .133564+04, TREH5 = .143072+04, TREH6 = .147537+04

INCON    ITCAHA=1074.9

INCON    IICAN=0.01       , INCAA=0.01

*   PARAMETERS --- CORE

PARAM  TSTART = 120.0
PARAM  TFLAG = 1.0

```

```
*   INITIAL CALCULATIONS --- CORE
      TLPH=ITLPH
      TUPH=ITUPH
      TRF1=ITRF1
      TRF2=ITRF2
      TRF3=ITRF3
      TRF4=ITRF4
      TRF5=ITRF5
      TRF6=ITRF6
      TRC1=ITRC1
      TRC2=ITRC2
      TRC3=ITRC3
      TRC4=ITRC4
      TRC5=ITRC5
      TRC6=ITRC6
*     JUPV=700.0+562.0*KCAN
*     JLPV=5201.0+344.0*KCAN
      JUPV=12400.
      JLPV=6031.
      KREQT=3412800.*KREPO/3600.

      TGPM=TUPH
      TCAHOA=ITCAHA

      ICAN=IICAN
      NCAA=INCAA
      MNSS=PNSS*144./KUNGR*(JUPV/TUPH+JLPV/TLPH)


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  USER CONTROL SECTION-- TIME INDEPENDENT PART *  *  *  *  *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


*    CACWS PUMP CONTROL PARAMETERS (TEMPORARY)
PARAM    KPLPB =  1.       , KPLRT = 1.
PARAM    KPLJ0 =3.28       , KPLJ1 =.0985      , KPLJ2 =1.344
PARAM    KPLCR =50.
PARAM    WPLR  =0.0        , SPL   =1.0        , WPLS  =5.17
CONST    KPL   =2.5        , KPLN  =5000.      , WPLSO =5.17

PARAM    NPS   =5500.      , KPSPB =10.        , KPSRT =10.
PARAM    KPSJ0 =.2481      , KPSJ1 =7.622E-4   , KPSJ2 =1.126E-3
PARAM    KPSCR =10.
PARAM    WPSR  =0.0        , SPS   =1.         , WPSS  =5.17
CONST    KPS   =.40        , KPSN  =5000.

PARAM    WPRI  =0.         , WPRO  =0.         , GPRI  =0.
PARAM    GPRO  =0.         , QPR   =0.         , TPRI  =530.
PARAM    KPRV  =400.

*     AIR BLAST HX PARAMETERS
PARAM    GAA   =0.001      , TAAI10=559.

*     TEMPERATURE SENSOR LAGS
PARAM    KTAU  =10.

*     CORE PARAMETERS
PARAM    GCAAS =0.001   , GCCA  =518.8
PARAM    KGPC  =1.        , FNSS  =1280.
PARAM    PRCD=1.00       , DUMMY =1.00

```

```

AFGEN POWER=0.0,1.00,30.0,1.00,30.5,0.152,33.6,0.107, ...
        36.6,0.092,45.8,0.070,61.,0.055,100.8,0.042, ...
        296.,0.029,500.0,0.010

AFGEN HEFLOW=0.0,518.8,30.0,518.8,37.8,71.0,45.6,25.33, ...
          53.4,14.0,61.2,4.33,500.0,2.0

AFGEN AHEFLO=0.0,0.0001,  60.0,0.0001,  61.2,6.60,62.6,8.00,...
                    68.8,15.70, 76.6,21.35, 84.1,25.40,92.1,27.70,...
                   100.1,29.1,108.1,29.1,115.6,30.30,117.3,30.36,...
            125.3,30.63,131.1,30.70,148.3,30.95,156.3,31.04,...
            187.3,31.35,210.3,31.60,241.3,31.98,272.3,32.36,...
           500.0,33.0

AFGEN TINLET=0.0,1074.0,30.0,1074.0,37.8,1064.0, ...
            45.6,1055.0,53.4,1048.0,61.2,832.0,500.,1074.0

*  *  *  CIRC SPEED CONTROL TEMP PARAMETERS
PARAM    KCARG =500.         , KCAPBN= 10.        , KCART =1.

*  *  *  SCAV IS SWITCH TO OPEN AUXILIARY HELIUM VALVE.
*  *  *  SCAV=0.0 IMPLIES THAT THE VALVE IS CLOSED AND
*  *  *           HELIUM TEMPERATURE TO CAHE IS FIXED AT
*  *  *           TLPHO.
*  *  *  SCAV=1.0 IMPLIES THAT THE VALVE IS OPEN AND HELIUM
*  *  *           TEMPERATURE TO CAHE IS SET TO TLPH WHICH
*  *  *           IS A VARIABLE.
*  *  *  SCAV NOT USED AT PRESENT

PARAM    SCAV  =0.0        , TLPHO =1060.

PARAM    TSCRAM=30.         , THWOSS=1085.       , THWOS =1060.

DYNAMIC


NOSORT


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  TIME DEPENDENT INPUT SECTION                              *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


      GCCA=AFGEN(HEFLOW,TIME)
      IF(TIME.GT.60.0)GCCA=.00001
      PRCD=AFGEN(POWER,TIME)
      DUMMY=PRCD
      GCAAS=AFGEN(AHEFLO,TIME)
      IF(TIME.GE.TSCRAM)WFLOW=42.78
      IF(TIME.GE.TSCRAM)GAA=760.5
      IF (TIME.GT.TSCRAM+30.0)THWOS=THWOSS

SORT






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```
*   *   *   *   *   *   *   *   *   PIPE THERMAL MODELS   *   *   *   *   *   *   *   *
*   *   *   *   *   *   *   *   *   SECTION 6.1           *   *   *   *   *   *   *   *







*      HOT LINE MODEL

      DTPH1,RPH1,BPH1=PIPE1(WFLOW,THWO,KPHV,KPHC,TPH1,ITPH1)
      DTPH2,RPH2,BPH2=PIPE1(WFLOW,TPH1,KPHV,KPHC,TPH2,ITPH2)
      DTPH3,RPH3,BPH3=PIPE1(WFLOW,TPH2,KPHV,KPHC,TPH3,ITPH3)
      DTPH4,RPH4,BPH4=PIPE1(WFLOW,TPH3,KPHV,KPHC,TPH4,ITPH4)
      DTPH5,RPH5,BPH5=PIPE1(WFLOW,TPH4,KPHV,KPHC,TPH5,ITPH5)
      DTPH6,RPH6,BPH6=PIPE1(WFLOW,TPH5,KPHV,KPHC,TPH6,ITPH6)
      DTPH7,RPH7,BPH7=PIPE1(WFLOW,TPH6,KPHV,KPHC,TPH7,ITPH7)
      DTPH8,RPH8,BPH8=PIPE1(WFLOW,TPH7,KPHV,KPHC,TPH8,ITPH8)
      DTPH9,RPH9,BPH9=PIPE1(WFLOW,TPH8,KPHV,KPHC,TPH9,ITPH9)
      DTPH10,RPH10,BPH10=PIPE1(WFLOW,TPH9,KPHV,KPHC,TPH10,ITPH10)

      TPHO=TPH10

      RPHAV=(RPH1+RPH2+RPH3+RPH4+RPH5+RPH6+RPH7+RPH8+RPH9+RPH10)/KPHN
      BPHT=BPH1+BPH2+BPH3+BPH4+BPH5+BPH6+BPH7+BPH8+BPH9+BPH10



*      COLD LINE MODEL

      DTPC1,RPC1,BPC1=PIPE1(WFLOW,TAWO,KPCV,KPCC,TPC1,ITPC1)
      DTPC2,RPC2,BPC2=PIPE1(WFLOW,TPC1,KPCV,KPCC,TPC2,ITPC2)
      DTPC3,RPC3,BPC3=PIPE1(WFLOW,TPC2,KPCV,KPCC,TPC3,ITPC3)
      DTPC4,RPC4,BPC4=PIPE1(WFLOW,TPC3,KPCV,KPCC,TPC4,ITPC4)
      DTPC5,RPC5,BPC5=PIPE1(WFLOW,TPC4,KPCV,KPCC,TPC5,ITPC5)
      DTPC6,RPC6,BPC6=PIPE1(WFLOW,TPC5,KPCV,KPCC,TPC6,ITPC6)
      DTPC7,RPC7,BPC7=PIPE1(WFLOW,TPC6,KPCV,KPCC,TPC7,ITPC7)
      DTPC8,RPC8,BPC8=PIPE1(WFLOW,TPC7,KPCV,KPCC,TPC8,ITPC8)
      DTPC9,RPC9,BPC9=PIPE1(WFLOW,TPC8,KPCV,KPCC,TPC9,ITPC9)
      DTPC10,RPC10,BPC10=PIPE1(WFLOW,TPC9,KPCV,KPCC,TPC10,ITPC10)

      TPCO-TPC10

      RPCAV=(RPC1+RPC2+RPC3+RPC4+RPC5+RPC6+RPC7+RPC8+RPC9+RPC10)/KPCN
      BPCT=BPC1+BPC2+BPC3+BPC4+BPC5+BPC6+BPC7+BPC8+BPC9+BPC10




*   *   *   *   *   *   *   AIR BLAST HEAT EXCHANGER MODEL   *   *   *   *   *   *
*   *   *   *   *   *   *          SECTION 6.4               *   *   *   *   *   *







```

```
DTAWI,RAWI,BAWI=PIPE1(WFLOW,TPHO,KAWVI,KAMCI,TAWI,ITAWI)
DTAWO,RAWO,BAWO=PIPE1(WFLOW,TAWO10,KAWVO,KAMCO,TAWO,ITAWO)



TAA10,JAAM10,JAWM10=HTCOE(WFLOW,JAAGR,JAACP,TAAI10,TAAO10,...
TAM10,TAW10)
TAA9,JAAM9,JAWM9=HTCOE(WFLOW,JAAGR,JAACP,TAAO10,TAAO9,TAM9,TAW9)
TAA8,JAAM8,JAWM8=HTCOE(WFLOW,JAAGR,JAACP,TAAO9,TAAO8,TAM8,TAW8)
TAA7,JAAM7,JAWM7=HTCOE(WFLOW,JAAGR,JAACP,TAAO8,TAAO7,TAM7,TAW7)
TAA6,JAAM6,JAWM6=HTCOE(WFLOW,JAAGR,JAACP,TAAO7,TAAO6,TAM6,TAW6)
TAA5,JAAM5,JAWM5=HTCOE(WFLOW,JAAGR,JAACP,TAAO6,TAAO5,TAM5,TAW5)
TAA4,JAAM4,JAWM4=HTCOE(WFLOW,JAAGR,JAACP,TAAO5,TAAO4,TAM4,TAW4)
TAA3,JAAM3,JAWM3=HTCOE(WFLOW,JAAGR,JAACP,TAAO4,TAAO3,TAM3,TAW3)
TAA2,JAAM2,JAWM2=HTCOE(WFLOW,JAAGR,JAACP,TAAO3,TAAO2,TAM2,TAW2)
TAA1,JAAM1,JAWM1=HTCOE(WFLOW,JAAGR,JAACP,TAAO2,TAAO1,TAM1,TAW1)


JAACP=GAA*KUNACP
JAAGR=(GAA/KAAG)**-.681
TAAO10,TAWO10,DTAM10,DTAW10,QAAM10,QAWM10,RAW10,BAW10=SPCFHX(...
 TAAI10,TAWO9,ITAM10,TAM10,ITAW10,TAW10,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM10,JAWM10)
TAAO9,TAWO9,DTAM9,DTAW9,QAAM9,QAWM9,RAW9,BAW9=SPCFHX(TAAO10,...
 TAWO8,ITAM9,TAM9,ITAW9,TAW9,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM9,JAWM9)
TAAO8,TAWO8,DTAM8,DTAW8,QAAM8,QAWM8,RAW8,BAW8=SPCFHX(TAAO9,...
 TAWO7,ITAM8,TAM8,ITAW8,TAW8,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM8,JAWM8)
TAAO7,TAWO7,DTAM7,DTAW7,QAAM7,QAWM7,RAW7,BAW7=SPCFHX(TAAO8,...
 TAWO6,ITAM7,TAM7,ITAW7,TAW7,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM7,JAWM7)
TAAO6,TAWO6,DTAM6,DTAW6,QAAM6,QAWM6,RAW6,BAW6=SPCFHX(TAAO7,...
 TAWO5,ITAM6,TAM6,ITAW6,TAW6,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM6,JAWM6)
TAAO5,TAWO5,DTAM5,DTAW5,QAAM5,QAWM5,RAW5,BAW5=SPCFHX(TAAO6,...
 TAWO4,ITAM5,TAM5,ITAW5,TAW5,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM5,JAWM5)
TAAO4,TAWO4,DTAM4,DTAW4,QAAM4,QAWM4,RAW4,BAW4=SPCFHX(TAAO5,...
 TAWO3,ITAM4,TAM4,ITAW4,TAW4,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM4,JAWM4)
TAAO3,TAWO3,DTAM3,DTAW3,QAAM3,QAWM3,RAW3,BAW3=SPCFHX(TAAO4,...
 TAWO2,ITAM3,TAM3,ITAW3,TAW3,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM3,JAWM3)
TAAO2,TAWO2,DTAM2,DTAW2,QAAM2,QAWM2,RAW2,BAW2=SPCFHX(TAAO3,...
 TAWO1,ITAM2,TAM2,ITAW2,TAW2,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM2,JAWM2)
TAAO1,TAWO1,DTAM1,DTAW1,QAAM1,QAWM1,RAW1,BAW1=SPCFHX(TAAO2,...
 TAWI,ITAM1,TAM1,ITAW1,TAW1,KAMC,KAWV,KAAW1,KAAW2,...
 KAWW1,KAWW2,JAACP,WFLOW,JAAM1,JAWM1)



RAWAV=(RAW1+RAW2+RAW3+RAW4+RAW5+RAW6+RAW7+RAW8+RAW9+RAW10)/KAWN

BAWT=BAWI+BAW1+BAW2+BAW3+BAW4+BAW5+BAW6+BAW7+BAW8+...
     BAW9+BAW10+BAWO



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```
*   *   *   *   *  CORE AUXILIARY HEAT EXCHANGER MODEL  *   *   *   *   *   *
*   *   *   *   *              SECTION 6.3              *   *   *   *






*      CAHE INLET AND EXIT WATER HEADER MODELS

      DTHWI,RHWI,BHWI=PIPE1(WFLOW,TPCO,KHWVI,KHMCI,THWI,ITHWI)
      DTHWO,RHWO,BHWO=PIPE1(WFLOW,THWO6,KHWVO,KHMCO,THWO,ITHWO)

*     CAHE HEATED ZONE MODEL

      MHHI6=144.*PNSS*KHHVI6/(KUNGR*THHI6)
      DTHHI6=GCAA*KUNHCP*(TLPH-THHI6)/(KUNHCV*MHHI6)
      THHI6=INTGRL(ITHHI6,DTHHI6)


      THH6,JHHM6,JHWM6=HTKOE(WFLOW,GCAA,JHHCP,THHI6,THHO6,THM6,THW6)
      THH5,JHHM5,JHWM5=HTKOE(WFLOW,GCAA,JHHCP,THHO6,THHO5,THM5,THW5)
      THH4,JHHM4,JHWM4=HTKOE(WFLOW,GCAA,JHHCP,THHO5,THHO4,THM4,THW4)
      THH3,JHHM3,JHWM3=HTKOE(WFLOW,GCAA,JHHCP,THHO4,THHO3,THM3,THW3)
      THH2,JHHM2,JHWM2=HTKOE(WFLOW,GCAA,JHHCP,THHO3,THHO2,THM2,THW2)
      THH1,JHHM1,JHWM1=HTKOE(WFLOW,GCAA,JHHCP,THHO2,THHO1,THM1,THW1)



      JHHCP=GCAA*KUNHCP
      THHO6,THWO6,DTHM6,DTHW6,QHHM6,QHWM6,RHW6,BHW6=SPCFHX(THHI6,...
        THWO5,ITHM6,THM6,ITHW6,THW6,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM6,JHWM6)
      THHO5,THWO5,DTHM5,DTHW5,QHHM5,QHWM5,RHW5,BHW5=SPCFHX(THHO6,...
        THWO4,ITHM5,THM5,ITHW5,THW5,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM5,JHWM5)
      THHO4,THWO4,DTHM4,DTHW4,QHHM4,QHWM4,RHW4,BHW4=SPCFHX(THHO5,...
        THWO3,ITHM4,THM4,ITHW4,THW4,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM4,JHWM4)
      THHO3,THWO3,DTHM3,DTHW3,QHHM3,QHWM3,RHW3,BHW3=SPCFHX(THHO4,...
        THWO2,ITHM3,THM3,ITHW3,THW3,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM3,JHWM3)
      THHO2,THWO2,DTHM2,DTHW2,QHHM2,QHWM2,RHW2,BHW2=SPCFHX(THHO3,...
        THWO1,ITHM2,THM2,ITHW2,THW2,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM2,JHWM2)
      THHO1,THWO1,DTHM1,DTHW1,QHHM1,QHWM1,RHW1,BHW1=SPCFHX(THHO2,...
        THWI,ITHM1,THM1,ITHW1,THW1,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM1,JHWM1)

      BHWT=BHWI+BHW1+BHW2+BHW3+BHW4+BHW5+BHW6+BHWO

      RHWAV=(RHW1+RHW2+RHW3+RHW4+RHW5+RHW6)/KHWN



```

```
*  *  *  *  *  *  *  CACWS PROCESS-FLOW MODEL  *  *  *  *  *  *
*  *  *  *  *  *  *           SECTION 4.         *  *  *  *  *  *


*      JPL0=KPLJ0*RPC1*(NPL/KPLN)**2
*      JPL1=KPLJ1*(NPL/KPLN)
*      JPL2=-KPLJ2/RPC1
*
*
*      JPS0=KPSJ0*RPC1*(NPS/KPSN)**2
*      JPS1=KPSJ1*(NPS/KPSN)
*      JPS2=-KPSJ2/RPC1
*
*      JAWPL=1./SQRT(KPHSQ/RPHAV+KPCSQ/RPCAV+KAWSQ/RAWAV+KHWSQ/RHWAV+...
*            KHWISQ/RHWI+KAWISQ/RAWI)
*      RPUMP=RPC1
*PROCED WFLOW,WPL,WPS,PLOAD=PRFLO(JAWPL,RPUMP,APL,SPL,WPLR,JPL0,JPL1,...
*       JPL2,NPL,APS,SPS,WPSR,JPS0,JPS1,JPS2,NPS)
*    4 IF(PLOAD)1,1,2
*    1 WFLOW=0.
*      WFLOPD=0.
*      GO TO 3
*    2 WFLOW=JAWPL*SQRT(PLOAD)
*      WFLOPD=0.5*WFLOW/PLOAD
*    3 CONTINUE
*      JPL=KPL*SQRT(RPUMP)
*      JPS=KPS*SQRT(RPUMP)
*      WPL,WPLPD=MOPTV(JPL,APL,SPL,JPL0,JPL1,JPL2,WPLR,PLOAD)
*      WPS,WPSPD=MOPTV(JPS,APS,SPS,JPS0,JPS1,JPS2,WPSR,PLOAD)
*      ERR=WPL+WPS-WFLOW
*      PLOAD=PLOAD-ERR/(WPLPD+WPSPD-WFLOPD)
*      IF(ERR*ERR.GT.0.01)GO TO 4
*ENDPRO

*  *   PRESSURIZER MODEL

*      TPRG=TPRW
*      JPRRP=DTPRW*AFGEN(PARTRT,TPRW)*VPRW
*      RPRW=AFGEN(RFTSL,TPRW)
*      WPR=BPHT+BAWT+BPCT+BHWT
*      THWX=TPC9
*      DTPRW=(WPRI*(TPRI-TPRW)-QPR/KUNWCP+(THWX-TPRW)*LIMIT(0.0,...
*      .1E6,-WPR))/RPRW/VPRW
*      TPRW=INTGRL(ITPRW,DTPRW)
*      DVPRW=(WPRI-WPRO-WPR-JPRRP)/RPRW
*      VPRW=INTGRL(IVPRW,DVPRW)
*      DPPRG=((GPRI-GPRO)*KUNGR/144.*TPRG+PPRG*DVPRW)/(KPRV-VPRW)
*      PPRG=INTGRL(IPPRG,DPPRG)



```

```
*  *  *  *  *  *  *  CORE MODEL  *  *  *  *  *  *  *  *  *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


*  *  *  TEMPORARY CIRC SPEED CONTROL ON TEMPERATUREW ERROR

      OCAERR=THWOS-THWO
*  *  *  IF ERROR IS POSITIVE NCAD IS POSITIVE
*  *  *  THAT RESULTS IN IF WATER TEMP IS LOWER THAN
*  *  *  DESIRED, THEN TURN UP CIRC SPEED
*  *  *   ALSO THERE IS NO LIMIT ON CIRC SPEED
      PROPN=100./KCAPBN*OCAERR/KCARG
      DICAN=PROPN/KCART
      ICAN=INTGRL(IICAN,DICAN)
      NCAD=PROPN+ICAN
      DNCAA=(NCAD-NCAA)/1.
      NCAA=INTGRL(INCAA,DNCAA)
*     TCCHOA=THHO1
*     TCCHOA=(1.-SCAV)*ITUPH + SCAV*THHO1
      TCCHOA=AFGEN(TINLET,TIME)
      DTCAHA=(THHO1-TCAHOA)/KCATAU
      TCAHOA=INTGRL(ITCAHA,DTCAHA)

*     GCAA=KCAR*144.*PNSS/TCAHOA/KUNGR*NCAA

      GCAA=GCAAS

      GRETOT=KCCN *GCCA+KCAN *GCAA

* UPPER AND LOWER PLENUM TIME CONSTANTS
      PNSS=KUNGR*MNSS/(144.*(JUPV/TUPH+JLPV/TLPH))
      MUPH=PNSS*JUPV*144./(KUNGR*TUPH)
*     DTUPH=(KUNHCP*(KCCN *GCCA*(TCCHOA-TUPH)+KCAN *GCAA*(TCAHOA-...
*       TUPH))+JGPK*(TGPM-TUPH))/(KUNHCV*MUPH)
*     TUPH=INTGRL(ITUPH,DTUPH)
      TUPH=TCCHOA*(1.-SCAV)+TCAHOA*SCAV
      DTGPM=JGPK*(TUPH-TGPM)/KGPC
      TGPM=INTGRL(ITGPM,DTGPM)
      MLPH=PNSS*JLPV*144./(KUNGR*TLPH)
      DTLPH=(KUNHCP*(KRENN*GREH*(TREH06-TLPH)+GBPH*(TBPH-TLPH)))/...
       (KUNHCV*MLPH)
      TLPH=INTGRL(ITLPH,DTLPH)

      GREH=GRETOT*KREGF/KRENN
      GBPH=GRETOT*(1.-KREGF)
      TBPH=TUPH+QBPH/KUNHCP/GBPH


      JRECK1,JRCFK1=CORHT(GREH,TRC1,TRF1,TREH1,KREA1,KREL1)
      JRECK2,JRCFK2=CORHT(GREH,TRC2,TRF2,TREH2,KREA2,KREL2)
      JRECK3,JRCFK3=CORHT(GREH,TRC3,TRF3,TREH3,KREA3,KREL3)
      JRECK4,JRCFK4=CORHT(GREH,TRC4,TRF4,TREH4,KREA4,KREL4)
      JRECK5,JRCFK5=CORHT(GREH,TRC5,TRF5,TREH5,KREA5,KREL5)
      JRECK6,JRCFK6=CORHT(GREH,TRC6,TRF6,TREH6,KREA6,KREL6)

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```
      DTRC1,DTRF1,TREHO1,TREH1=CRNODE(JRECK1,JRCFK1,KRFV1,KRCV1,TUFH,...
        GREH,QRF1,ITRF1,TRF1,ITRC1,TRC1)
      DTRC2,DTRF2,TREHO2,TREH2=CRNODE(JRECK2,JRCFK2,KRFV2,KRCV2,...
        TREHO1,GREH,QRF2,ITRF2,TRF2,ITRC2,TRC2)
      DTRC3,DTRF3,TREHO3,TREH3=CRNODE(JRECK3,JRCFK3,KRFV3,KRCV3,...
        TREHO2,GREH,QRF3,ITRF3,TRF3,ITRC3,TRC3)
      DTRC4,DTRF4,TREHO4,TREH4=CRNODE(JRECK4,JRCFK4,KRFV4,KRCV4,...
        TREHO3,GREH,QRF4,ITRF4,TRF4,ITRC4,TRC4)
      DTRC5,DTRF5,TREHO5,TREH5=CRNODE(JRECK5,JRCFK5,KRFV5,KRCV5,...
        TREHO4,GREH,QRF5,ITRF5,TRF5,ITRC5,TRC5)
      DTRC6,DTRF6,TREHO6,TREH6=CRNODE(JRECK6,JRCFK6,KRFV6,KRCV6,...
        TREHO5,GREH,QRF6,ITRF6,TRF6,ITRC6,TRC6)

* CORE DECAY HEAT GENERATION

PROCED    TSEC = DUMT(TSTART,TIME,TFLAG)
      TSEC = TSTART + TIME
      IF(TFLAG .GT. 0.0) TSEC = TSTART
ENDPRO

*  *  *  POWER DECAY WAS ESTABLISHED FROM A MINAUX RUN ON
*  *  *  AUGUST 12, 1977.
*PROCED  DECAY = FDPOW(TSEC)
**  TEMPORARILY USE SHURES DATA FOR THERMAL REACTOR FISSION PRODUCT DECAY
*STORAG  T(5),C(4),D(4)
*TABLE  T(1-5) = 0.0,0.1,10.0,150.0,4.0E+5,  C(1-4) = 0.07,0.0603,...
*  0.0765,0.1301,  D(1-4) = 0.0,0.0639,0.1807,0.2834
*INTGER  INDEX
*     IF(TSEC.LT.1.E-10) GO TO 30
*     DO 10 INDEX=1,4
*     IF(TSEC.LT.T(INDEX+1)) GO TO 20
*  10 CONTINUE
*  20 FPDK = C(INDEX) * TSEC**(-D(INDEX))
*     UDK=0.00129*EXP(-TSEC/2034.)
*     NDK=0.00112*EXP(-TSEC/292900.)
*     GO TO 40
*  30 FPDK = C(1)
*     UDK=0.00129
*     NDK=0.00112
*  40 DECAY=FPDK+UDK+NDK
*ENDPRO

      QRF1=KREPF1*KREQT*KREPF*PRCD/KRENN
      QRF2=KREPF2*KREQT*KREPF*PRCD/KRENN
      QRF3=KREPF3*KREQT*KREPF*PRCD/KRENN
      QRF4=KREPF4*KREQT*KREPF*PRCD/KRENN
      QRF5=KREPF5*KREQT*KREPF*PRCD/KRENN
      QRF6=KREPF6*KREQT*KREPF*PRCD/KRENN
      QBPH=KREQT*(1.-KREPF)*PRCD




*  *  *  *  *  *  MISCELLANEOUS  *  *  *  *  *  *  *  *  *






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```
*     TEMPORARY CACWS FLOW CONTROL AND ACTUATOR MODELS

*     PROP=100./KPLPB*(WPLS-WFLOW)/KPLCR
*     DINT=PROP/KPLRT
*     INT=INTGRL(IINT,DINT)
*     NPLD=PROP+INT
*     DNPL=(NPLD-NPL)/20.
*     NPL=INTGRL(INPL,DNPL)
*
*
*     PROPS=100./KPSPB*(WPSS-WFLOW)/KPSCR
*     DIPSIT=PROPS/KPSRT
*     IPSIT=INTGRL(IIPSIT,DIPSIT)
*     APSD=PROPS+IPSIT
*     DAPS=(APSD-APS)/4.
*     APS=LIMINT(IAPS,0.0,1.0,DAPS)

*      COLD TEMPERATURE MEASUREMENT (KTAU SEC LAG)

      DTPCOM=(TPC10-TPCOM)/KTAU
      TPCOM=INTGRL(ITPCOM,DTPCOM)

*     CAHE EXIT TEMPERATURE MEASUREMENT (KTAU SEC LAG)

      DTPHM=(TPH1-TPHM)/KTAU
      TPHM=INTGRL(ITPHM,DTPHM)

*      VARIABLES CACULATED FOR OUTPUT PURPOSES ONLY

      QHWMT=QHWM1+QHWM2+QHWM3+QHWM4+QHWM5+QHWM6
      QHHMT=QHHM1+QHHM2+QHHM3+QHHM4+QHHM5+QHHM6
      QAWMT=QAWM1+QAWM2+QAWM3+QAWM4+QAWM5+QAWM6+QAWM7+QAWM8+...
           QAWM9+QAWM10
      QAAMT=QAAM1+QAAM2+QAAM3+QAAM4+QAAM5+QAAM6+QAAM7+QAAM8+...
           QAAM9+QAAM10
      MARGIN=AFGEN(HSATP,PPRG)-AFGEN(HSATT,THW06)

      POWFLO=PRCD/GRETOT

      EAE=DEBUG(1,0.0)
      D1=DEBUG(1,30.0)
      D2=DEBUG(1,60.0)
TERMINAL
      EAE1=DEBUG(1,TIME)
TIMER DELT=.01,FINTIM=500.,DELPR=5.,DELGR=5.,TWARN=25.
/     WRITE(12,73   )TPH1,TPH2,TPH3,TPH4,TPH5,TPH6,TPH7,TPH8,TPH9,
/    1TPH10,
/    1TPHM
/73   FORMAT('*  *  *  HOT LINE INITIAL CONDITIONS',/,
/    1'INCON    ITPH1 =',E11.6,', ITPH2 =',E11.6,', ITPH3 =',E11.6,/,
/    1'INCON    ITPH4 =',E11.6,', ITPH5 =',E11.6,', ITPH6 =',E11.6,/,
/    1'INCON    ITPH7 =',E11.6,', ITPH8 =',E11.6,', ITPH9 =',E11.6,/,
/    1'INCON    ITPH10=',E11.6,/,
/    1'INCON    ITPHM =',E11.6,//)
```

```
      WRITE(12,72  )TPC1,TPC2,TPC3,TPC4,TPC5,TPC6,TPC7,TPC8,TPC9,
     1TPC10,
     1TPCOM
72    FORMAT('*  *  *  COLD LINE INITIAL CONDITIONS',/,
     1'INCON    ITPC1 =',E11.6,',  ITPC2 =',E11.6,',  ITPC3 =',E11.6,/,
     1'INCON    ITPC4 =',E11.6,',  ITPC5 =',E11.6,',  ITPC6 =',E11.6,/,
     1'INCON    ITPC7 =',E11.6,',  ITPC8 =',E11.6,',  ITPC9 =',E11.6,/,
     1'INCON    ITPC10=',E11.6,/,
     1'INCON    ITPCOM=',E11.6,//)


      WRITE(12,70  )TAWO,TAWI,TAW1,TAW2,TAW3,TAW4,TAW5,TAW6,TAW7,
     1TAW8,TAW9,TAW10,TAM1,TAM2,TAM3,TAM4,TAM5,TAM6,TAM7,TAM8,
     1TAM9,TAM10,TAA1,TAA2,TAA3,TAA4,TAA5,TAA6,TAA7,TAA8,TAA9,TAA10
70    FORMAT('*  *  *  AIR BLAST HX INITIAL CONDITIONS',/,
     1'INCON    ITAWO =',E11.6,',  ITAWI =',E11.6,',  ITAW1 =',E11.6,/,
     1'INCON    ITAW2 =',E11.6,',  ITAW3 =',E11.6,',  ITAW4 =',E11.6,/,
     1'INCON    ITAW5 =',E11.6,',  ITAW6 =',E11.6,',  ITAW7 =',E11.6,/,
     1'INCON    ITAW8 =',E11.6,',  ITAW9 =',E11.6,',  ITAW10=',E11.6,/,
     1'INCON    ITAM1 =',E11.6,',  ITAM2 =',E11.6,',  ITAM3 =',E11.6,/,
     1'INCON    ITAM4 =',E11.6,',  ITAM5 =',E11.6,',  ITAM6 =',E11.6,/,
     1'INCON    ITAM7 =',E11.6,',  ITAM8 =',E11.6,',  ITAM9 =',E11.6,/,
     1'INCON    ITAM10=',E11.6,/,
     1'PARAM    TAA1  =',E11.6,',  TAA2  =',E11.6,',  TAA3  =',E11.6,/,
     1'PARAM    TAA4  =',E11.6,',  TAA5  =',E11.6,',  TAA6  =',E11.6,/,
     1'PARAM    TAA7  =',E11.6,',  TAA8  =',E11.6,',  TAA9  =',E11.6,/,
     1'PARAM    TAA10 =',E11.6,//)


      WRITE(12,71  )THWI,THW1,THW2,THW3,THW4,THW5,THW6,THM1,THM2,
     1THM3,THM4,THM5,THM6,THWO,THMIO,THH1,THH2,THH3,THH4,THH5,THH6
71    FORMAT('*  *  *  CAHE INITIAL CONDITIONS',/,
     1'INCON    ITHWI =',E11.6,',  ITHW1 =',E11.6,',  ITHW2 =',E11.6,/,
     1'INCON    ITHW3 =',E11.6,',  ITHW4 =',E11.6,',  ITHW5 =',E11.6,/,
     1'INCON    ITHW6 =',E11.6,',  ITHM1 =',E11.6,',  ITHM2 =',E11.6,/,
     1'INCON    ITHM3 =',E11.6,',  ITHM4 =',E11.6,',  ITHM5 =',E11.6,/,
     1'INCON    ITHM6 =',E11.6,',  ITHWO =',E11.6,',  ITHMIO=',E11.6,/,
     1'PARAM    THH1  =',E11.6,',  THH2  =',E11.6,',  THH3  =',E11.6,/,
     1'PARAM    THH4  =',E11.6,',  THH5  =',E11.6,',  THH6  =',E11.6,//)


      WRITE(12,74)VPRW,TPRW,PPRG,PLOAD,NPL,INT,APS,IPSIT,WFLOW
 74   FORMAT('*  *  *  PUMP AND PROCESS-FLOW INITIAL CONDITIONS',/,
     1'INCON    IVPRW =',E11.6,',  ITPRW =',E11.6,',  IPPRG =',E11.6,/,
     1'INCON    IPLOAD=',E11.6,',  INPL  =',E11.6,',  IINT  =',E11.6,/,
     1'INCON    IAPS  =',E11.6,',  IIPSIT=',E11.6,/,
     1'PARAM    WFLOW =',E11.6,//)


93    FORMAT('*  *  *  CORE INITIAL CONDITIONS',/,
     1'INCON    ITRF1 =',E11.6,',  ITRF2 =',E11.6,',  ITRF3 =',E11.6,/,
     1'INCON    ITRF4 =',E11.6,',  ITRF5 =',E11.6,',  ITRF6 =',E11.6,/,
     1'INCON    ITRC1 =',E11.6,',  ITRC2 =',E11.6,',  ITRC3 =',E11.6,/,
     1'INCON    ITRC4 =',E11.6,',  ITRC5 =',E11.6,',  ITRC6 =',E11.6,/,
     1'INCON    ITUPH =',E11.6,',  ITLPH =',E11.6,/,
     1'INCON    ITCAHA=',E11.6,',  IICAN =',E11.6,',  INCAA =',E11.6,//,
     1'PARAM    TREH1 =',E11.6,',  TREH2 =',E11.6,',  TREH3 =',E11.6,/,
```

```
/     1'PARAM    TREH4 =',E11.6,', TREH5 =',E11.6,', TREH6 =',E11.6,//)
/      WRITE(12,93) TRF1,TRF2,TRF3,TRF4,TRF5,TRF6,TRC1,TRC2,TRC3,
/     1TRC4,TRC5,TRC6,TUPH,TLPH,TCAHOA,ICAN,NCAA,TREH1,TREH2,TREH3,
/     1TREH4,TREH5,TREH6
/      WRITE(12,95)TIME,DUMMY
/ 95    FORMAT('*  *  *  TIME AT END OF RUN=',E11.6,' , DUMMY VARIABLE='
/     1,E11.6//)

PRINT TPCO,THWO,TPHO,TAWO,THHO1,WFLOW,MARGIN,PPRG, ...
       PNSS,GCAA,GRETOT,GCCA,PRCD,POWFLO, ...
       OCAERR,PROPN,ICAN,DNCAA,NCAA, ...
       TRC1,TRF1,TREH1,TREHO1,THHO1, ...
       TRC2,TRF2,TREH2,TREHO2,THHO2, ...
       TRC3,TRF3,TREH3,TREHO3,THHO3, ...
       TRC4,TRF4,TREH4,TREHO4,THHO4, ...
       TRC5,TRF5,TREH5,TREHO5,THHO5, ...
       TRC6,TRF6,TREH6,TREHO6,THHO6, ...
       THHI6,THM6, ...
       TLPH,TUPH
*      QAAM1,QAAM2,QAAM3,QAAM4,QAAM5,QAAM6,QAAM7,QAAM8,QAAM9,QAAM10,...
*      QAAMT, ...
*      QAWM1,QAWM2,QAWM3,QAWM4,QAWM5,QAWM6,QAWM7,QAWM8,QAWM9,QAWM10,...
*      QAWMT, ...
*      QHHM1,QHHM2,QHHM3,QHHM4,QHHM5,QHHM6,QHHMT, ...
*      QHWM1,QHWM2,QHWM3,QHWM4,QHWM5,QHWM6,QHWMT
PREPAR TPCO,THWO,TPHO,TAWO,THHO1,WFLOW,MARGIN,PPRG, ...
       TRC1,TRF1,TREH1,TREHO1,THHO1, ...
       PNSS,GCAA,GCCA,PRCD,POWFLO, ...
       OCAERR,PROPN,ICAN,DNCAA,NCAA, ...
*      TRC2,TRF2,TREH2,TREHO2,THHO2, ...
*      TRC3,TRF3,TREH3,TREHO3,THHO3, ...
*      TRC4,TRF4,TREH4,TREHO4,THHO4, ...
*      TRC5,TRF5,TREH5,TREHO5,THHO5, ...
*      TRC6,TRF6,TREH6,TREHO6,THHO6, ...
        THHO2,THHO3,THHO4,THHO5,THHO6, ...
       TLPH,TUPH
*      QAAM1,QAAM2,QAAM3,QAAM4,QAAM5,QAAM6,QAAM7,QAAM8,QAAM9,QAAM10,...
*      QAAMT, ...
*      QAWM1,QAWM2,QAWM3,QAWM4,QAWM5,QAWM6,QAWM7,QAWM8,QAWM9,QAWM10,...
*      QAWMT, ...
*      QHHM1,QHHM2,QHHM3,QHHM4,QHHM5,QHHM6,QHHMT, ...
*      QHWM1,QHWM2,QHWM3,QHWM4,QHWM5,QHWM6,QHWMT
GRAPH TIME,TPCO,THWO,TPHO,...
         TAWO,THHO1
GRAPH TIME,WFLOW,PPRG
GRAPH TIME,MARGIN
GRAPH TIME,TLPH,TUPH
*GRAPH TIME,THHO1,THHO2,THHO3,THHO4,THHO5,THHO6
*GRAPH TIME,TREHO1,TREHO2,TREHO3,TREHO4,TREHO5,TREHO6
*GRAPH TIME,TRC1,TRC2,TRC3,TRC4,TRC5,TRC6
*GRAPH TIME,TRF1,TRF2,TRF3,TRF4,TRF5,TRF6
*GRAPH TIME,TREH1,TREH2,TREH3,TREH4,TREH5,TREH6
GRAPH TIME,OCAERR,PROPN,ICAN,NCAA
GRAPH TIME,GCAA,GCCA,PNSS,PRCD,POWFLO

INTEG WSEIG
*STEADY EIGEN,DELSS=.001
END
STOP
```

8.2 CAWS SIMULATION CODE

This section contains a listing of the CAWS simulation code as it existed on September 30, 1977.

```
TITLE    GCFR CAWS
ADDMAP MAP*CAWS.


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  NOMENCLATURE GUIDELINES FOR ECSTRA-SEE SECTION 3 OF REPORT  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


*  *  FIRST LETTER DESIGNATION - TYPE OF VARIABLE

*         A   NORMALIZED VALVE AREA                          (ND)
*         B   RATE OF THERMAL EXPANSION OR CONTRACTION       (FT**3/SEC)
*         D   RATE OF CHANGE WRT TIME                        (PER SEC)
*         E   EFFICIENCY (ND)
*         G   GAS FLOW RATE                                   (LBS/SEC)
*         I   INITIAL VALUE OF STATE
*         J   INTERMEDIATE VARIABLE
*         K   RESERVED FOR CONSTANTS
*         L   VALVE LIFT (ND) OR TANK LEVEL (FT)
*         N   ROTATIONAL SPEED (RPM) OR NUMBER (ND)
*         O   INTERMEDIATE VARIABLE
*         P   PRESSURE (PSIA) OR PRESSURE DIFFERENTIAL (PSID)
*         Q   RATE OF HEAT TRANSFER (BTU/SEC)
*         R   DENSITY (LB/FT**3)
*         T   TEMPERATURE (DEG F)
*         W   WATER FLOW RATE (LBS/SEC)
*         X   TORQUE (FT-LBS)

*  *  SECOND AND THIRD LETTER DESIGNATIONS - COMPONENT ID

*         A-   AIR BLAST HEAT EXCHANGER
*         AA   AIR SIDE
*         AM   TUBE AND FINS
*         AW   WATER SIDE
*         BP   CORE BYPASS
*         CA   CIRCULATOR AUXILIARY
*         CC   CIRCULATOR
*         CM   CIRCULATOR MOTOR
*         CG   CONTROL GUIDE
*         CS   CORE SUPPORT
*         H-   CAHE HEAT EXCHANGER
*         HH   HELIUM SIDE
*         HM   TUBE METAL
*         HW   WATER SIDE
*         LP   LOWER PLENUM
*         LR   LOWER REFLECTOR
*         PC   PIPE FROM AIR BLAST HX AND CAHE HX (COLD LEG)
*         PH   PIPE FROM CAHE HX TO AIR BLAST HX (HOT LEG)
*         PL   PUMP (LARGE)
*         PR   PRESSURIZER
*         PS   PUMP (SMALL)
*         RE   CORE (NUCLEAR REACTOR)
*         RF   REACTOR FUEL
*         RM   REACTOR MODERATOR
*         SR   SIDE REFLECTOR
*         SP   SUPPORT POSTS
*         UN   UNIVERSAL (CONVERSION FACTOR OR CONSTANT)
*         UP   UPPER PLENUM
*         UR   UPPER REFLECTOR
***********************************************************************
```

```


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  CONSTANTS, TABLES, AND MACROS USED BY MORE THAN ONE      *  *
*  *  COMPONENT MODEL HENCE CONTAINED IN MISCELLANEOUS         *  *
*  *  SECTION OF ALL                                           *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *



CONST    KUNACP=0.2407       , KUNGR =2.6785    , KUNHCV=.746
CONST    KUNWCP=1.0227     , KUNHCP=1.242

AFGEN RFTSL=510.,62.4,560.,62.0,610.,61.2,660.,60.1,710.,58.8,760.,...
       57.3,810.,55.6,860.,53.7,910.,51.5,960.,49.0,1010.,45.9,1060.,...
       42.4,1110.,37.3
AFGEN PARTRT=510.,-.0122,610.,-.0187,660.,-.0238,710.,-.0282,760.,...
       -.0323,810.,-.0366,860.,-.0412,910.,-.0463,960.,-.0560,1010.,...
       -.0665,1110.,-.0856
AFGEN FSPH=560.,.998,660.,1.00,710.,1.01,760.,1.03,810.,1.05,...
           860.,1.08,910.,1.12,960.,1.19,1010.,1.31,1060.,1.51
AFGEN FVIS=560.,1.649,610.,1.051,660.,0.738,710.,0.569,760.,0.454, ...
         810.,0.378,860.,0.328,910.,0.288,960.,0.256,1010.,0.230, ...
         1060.,0.209
AFGEN FCON=560.,0.364,610.,0.384,660.,0.394,710.,0.396,760.,0.395,...
            810.,0.391,860.,0.381,910.,0.367,960.,0.349,1010.,0.325,...
            1060.,0.292

AFGEN HSATP=58.,259.,118.,311.,220.,364.,382.,419.,...
             621.,476.,962.,537.,1431.,603.,2060.,679.,...
             2895.,784.
AFGEN HSATT=550.,58.,600.,108.,650.,158.,700.,208.,  ...
         750.,259.,800.,311.,850.,364.,900.,419.,950.,476.,...
            1000.,537.,1050.,603.,1100.,679.,1150.,784.

MACRO TGO,TWO,DTM,DTW,QGM,QWM,RW,BW=SPCFHX(TGI,TWI,ITM,TM,ITW,TW,...
     MCAP,VOL,WTG1,WTG2,WTW1,WTW2,JGCP,WFLOW,JC,JHTW)
*   SEE SECTION 6.2 OF REPORT
*  SINGLE PHASE COUNTER FLOW HEAT EXCHANGER WITH INCOMPRESSABLE
*  FLUID ON W SIDE AND NEGLIGIBLE FLUID THERMAL CAPACITY ON G SIDE
*  TGO=GAS EXIT TEMP, QGM=ENERGY TRANSFER GAS TO METAL
*  RW=AVERAGE NODAL DENSITY, TW=AVERAGE NODAL TEMP.
*  QWM=HEAT TRANSFER WATER TO METAL, TWO=WATER EXIT TEMP
      RW=AFGEN(RFTSL,TW)
      TGO=(TGI*(1.-WTG1*JC)+JC*TM)/(1.+WTG2*JC)
      QGM=JGCP*(TGI-TGO)
      TWO=(TW-WTW1*TWI)/WTW2
      QWM=JHTW*(TW-TM)
      DTM=(QWM+QGM)/MCAP
      TM=INTGRL(ITM,DTM)
      DTW=(WFLOW*(TWI-TWO)-QWM/KUNWCP)/VOL/RW
      BW=DTW*VOL*AFGEN(PARTRT,TW)
      TW=INTGRL(ITW,DTW)
ENDMAC


```

```
MACRO DTF,RF,JPRT=PIPE1(FLO,TFI,VOL,MCAP,TF,ITF)
*   SEE SECTION 6.1 OF REPORT
*   PIPE THERMAL NODE WITH COMBINED METAL AND FLUID THERMAL CAPACITANCE
      RF=AFGEN(RFTSL,TF)
      DTF=FLO*(TFI-TF)/(MCAP/KUNWCP+VOL*RF)
      JPRT=VOL*DTF*AFGEN(PARTRT,TF)
      TF=INTGRL(ITF,DTF)
ENDMAC



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  HOT LEG COMPONENT CONSTANTS, TABLES, AND MACROS          *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

CONST    KPHVT =40.7        , KPHCT =1466.0      , KPHN  =10.



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  COLD LEG COMPONENT CONSTANTS, TABLES, AND MACROS         *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

CONST    KPCVT =40.7        , KPCCT =1466.0      , KPCN  =10.



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  AIR BLAST HX COMPONENT CONSTANTS, TABLES, AND MACROS     *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

CONST    KAWRX =5316.       , KAMR  =1.08        , KAAR  =29.52
CONST    KAWWR =42.78       , KAAG  =761.1       , KAWA  =1975.
CONST    KAAA  =2438.        , KAATR =598.        , KAMTR =679.
CONST    KAWTR =760.        , KAAAU =.2831       , KAABU =.7169
CONST    KAAAK =.1777       , KAABK =.8223       , KAMAK =1.1546
CONST    KAMBK =.1546       , KAMCT = 331.7      , KAWVT =33.33
CONST    KAWN  =10.         , KAWW1 =0.5         , KAAW1=0.5
CONST    KAWVI =3.          , KAWVO =3.          , KAMCI =100.
CONST    KAMCO =100.



MACRO TG,JAIR,JWAT=HTCOE(WFLOW,GFLRAT,JCGP,TG1,TG2,TMET,TWAT)
*   SEE APPENDIX C OF REPORT
      TG=(TG1+TG2)/2
PROCED RAIR=RESX(GFLRAT)
       RAIR=KAAR*GFLRAT*(KAAAU+KAABU*(TG/KAATR))**.681/...
       (KAAAK+KAABK*TG/KAATR)
ENDPRO
      RMET=KAMR/(KAMAK-KAMBK*TMET/KAMTR)
      CON=AFGEN(FCON,TWAT)
      VIS=AFGEN(FVIS,TWAT)
      SPH=AFGEN(FSPH,TWAT)
      RWAT=KAWRX/(CON*(WFLOW*3600./VIS)**.8*...
         (SPH*VIS/CON)**.333)
      JAIR=KAAA/KAWN/(0.5*RMET+RAIR)/JCGP
      JWAT=KAWA/KAWN/(0.5*RMET*KAWA/KAAA+RWAT)
ENDMAC
```

```



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  CAHE COMPONENT CONSTANTS, TABLES, AND MACROS              *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *



CONST    KHHRX =1.614E5    , KHWRX =1.48E4     , KHMRX =28.14
CONST    KHMCT =418.       , KHMCI =58.35      , KHMCO =58.35
CONST    KHWVT =10.8       , KHWVI =3.91       , KHWVO =3.91
CONST    KHMCIO=208.       , KHWMI =.8267      , KHWMO =.8267
CONST    KHWN  =6.0        , KHHW1 =0.5        , KHWW1 =0.5
CONST    KHHVK =6.388E-4   , KHHVKE=0.687      , KHHCK =1.062E-3
CONST    KHHCKE=0.701      , KHMAK =6.25       , KHMBK =0.0055
CONST    KHHA  =1141.      , KHWA  =888.5


MACRO TG,JHEL,JWAT=HTKOE(WFLOW,HFLOW,JG,T1,T2,TM,TW)
*   SEE APPENDIX C OF REPORT
      TG=(T1+T2)/2
PROCED RHE=RESY(HFLOW)
      HSPH=1.242
      HVIS=KHHVK*TG**KHHVKE
      HCON=KHHCK*TG**KHHCKE
      RHE=KHHRX/(HCON*(HFLOW*3600./HVIS)**.8*...
           (HSPH*HVIS/HCON)**.333)
ENDPRO
      RMET=KHMRX/(KHMAK+KHMBK*(TM-460.))
      CON=AFGEN(FCON,TW)
      VIS=AFGEN(FVIS,TW)
      SPH=AFGEN(FSPH,TW)
      RWAT=KHWRX/(CON*(WFLOW*3600./VIS)**.8*...
         (SPH*VIS/CON)**.333)
      JWAT=(KHWA/KHWN)/(.5*RMET*KHWA/KHHA+RWAT)
      JHEL=(KHHA/KHWN/JG)/(.5*RMET+RHE)
ENDMAC


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  PUMP AND PROCESS-FLOW COMPONENT CONSTANTS, TABLES, AND   *  *
*  *  MACROS                                                   *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

CONST    KAWSQ =.9031      , KHWSQ =.9016      , KAWISQ=.6803
CONST    KPHSQ =.2268      , KPCSQ =.3300      , KHWISQ=.6800


```

```
MACRO W,DWDPO=MOPTV(KV,AV,SV,J0,J1,J2,WR,DELP)
*   SEE SECTION 4.1 OF REPORT
*   GENERAL PURPOSE PUMP MACRO FOR REPRESENTING CONSTANT OR VARIABLE
*   SPEED PUMP WITH THROTTLE OR ISOLATION VALVE OPTIONAL.  REQUIRES
*   THAT USER SPECIFY RECIRCULATION FLOW AS INPUT.  USER MUST SPECIFY
*   PUMP CHARACTERISTIC AS SECOND ORDER POLYNOMIAL.
      JV=KV*KV*AV*AV
      IF(SV.EQ.0.) JV=1
*   IF ISOLATION VALVE IS OPEN (SV=0.0) FULL PUMP FLOW IS THROUGH
*   THE ISOLATION VALVE, AND THROTTLE VALVE SETTING IS IMMATERIAL
*   AS IT DROPS OUT SETTING JV=1 WHICH RESULTS IN AINV=-1/J2 AS APPROP.
      AINV=-JV/(SV-J2*JV)
      B=(J1+2.*WR*J2)
      BAINV=B*AINV
      CPART=WR*(J1+J2*WR)+J0
      DELPMX=-B*BAINV/4.+CPART
      IF(DELPMX-DELP) 1,1,2
    1 W=0.
      DWDPO=0.
      GO TO 3
    2 C=CPART-DELP
      W=-BAINV/2.+SQRT(BAINV*BAINV/4.-C*AINV)
*     IF(AINV.LT.0.0001)GO TO 3
      DWDPO=AINV/(2.*W+B*AINV)
    3 CONTINUE
ENDMAC




INITIAL


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  HOT LEG COMPONENT INCON AND PARAM SECTION               *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


INCON    ITPH1 = .166079+04, ITPH2 = .166079+04, ITPH3 = .166079+04
INCON    ITPH4 = .166079+04, ITPH5 = .166079+04, ITPH6 = .166079+04
INCON    ITPH7 = .166079+04, ITPH8 = .166079+04, ITPH9 = .166079+04
INCON    ITPH10= .166079+04
INCON    ITPHM = .166079+04

      KPHC=KPHCT/KPHN
      KPHV=KPHVT/KPHN

      TPH1=ITPH1
      TPH2=ITPH2
      TPH3=ITPH3
      TPH4=ITPH4
      TPH5=ITPH5
      TPH6=ITPH6
      TPH7=ITPH7
      TPH8=ITPH8
      TPH9=ITPH9
      TPH10=ITPH10
      TPHM=ITPHM



```

```
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  COLD LEG COMPONENT INCON AND PARAM SECTION               *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


INCON    ITPC1 = .113749+04, ITPC2 = .113749+04, ITPC3 = .113749+04
INCON    ITPC4 = .113749+04, ITPC5 = .113749+04, ITPC6 = .113749+04
INCON    ITPC7 = .113749+04, ITPC8 = .113749+04, ITPC9 = .113749+04
INCON    ITPC10= .113749+04
INCON    ITPCOM= .113749+04
      KPCC=KPCCT/KPCN
      KPCV=KPCVT/KPCN

      TPC1=ITPC1
      TPC2=ITPC2
      TPC3=ITPC3
      TPC4=ITPC4
      TPC5=ITPC5
      TPC6=ITPC6
      TPC7=ITPC7
      TPC8=ITPC8
      TPC9=ITPC9
      TPC10=ITPC10
      TPCOM=ITPCOM



```

```
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  AIR BLAST HX COMPONENT INCON AND PARAM SECTION            *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


INCON    ITAW0 = .113749+04, ITAWI = .166079+04, ITAW1 = .164037+04
INCON    ITAW2 = .159815+04, ITAW3 = .155317+04, ITAW4 = .150542+04
INCON    ITAW5 = .145495+04, ITAW6 = .140185+04, ITAW7 = .134631+04
INCON    ITAW8 = .128857+04, ITAW9 = .122903+04, ITAW10= .116817+04
INCON    ITAM1 = .163354+04, ITAM2 = .159088+04, ITAM3 = .154546+04
INCON    ITAM4 = .149728+04, ITAM5 = .144638+04, ITAM6 = .139289+04
INCON    ITAM7 = .133699+04, ITAM8 = .127895+04, ITAM9 = .121918+04
INCON    ITAM10= .115819+04
PARAM    TAA1  = .135261+04, TAA2  = .128599+04, TAA3  = .121500+04
PARAM    TAA4  = .113965+04, TAA5  = .105999+04, TAA6  = .976195+03
PARAM    TAA7  = .888535+03, TAA8  = .797429+03, TAA9  = .703461+03
PARAM    TAA10 = .607424+03

      TAWI=ITAWI
      TAW0=ITAW0
      TAW1=ITAW1
      TAW2=ITAW2
      TAW3=ITAW3
      TAW4=ITAW4
      TAW5=ITAW5
      TAW6=ITAW6
      TAW7=ITAW7
      TAW8=ITAW8
      TAW9=ITAW9
      TAW10=ITAW10
      TAM1=ITAM1
      TAM2=ITAM2
      TAM3=ITAM3
      TAM4=ITAM4
      TAM5=ITAM5
      TAM6=ITAM6
      TAM7=ITAM7
      TAM8=ITAM8
      TAM9=ITAM9
      TAM10=ITAM10

      KAAW2=1.-KAAW1
      KAWW2=1.-KAWW1
      KAMC= KAMCT/KAWN
      KAWV= KAWVT/KAWN


```

```
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  CAHE COMPONENT INCON AND PARAM SECTION                   *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


INCON    ITHWI = .113749+04, ITHW1 = .116689+04, ITHW2 = .123020+04
INCON    ITHW3 = .130329+04, ITHW4 = .138783+04, ITHW5 = .148581+04
INCON    ITHW6 = .159960+04, ITHM1 = .119535+04, ITHM2 = .126298+04
INCON    ITHM3 = .134112+04, ITHM4 = .143156+04, ITHM5 = .153647+04
INCON    ITHM6 = .165842+04, ITHWO = .166078+04, ITHMIO= .000000
PARAM    THH1  = .135508+04, THH2  = .144544+04, THH3  = .154976+04
PARAM    THH4  = .167042+04, THH5  = .181026+04, THH6  = .197268+04


      THWO=ITHWO
      THWI=ITHWI
      THW1=ITHW1
      THW2=ITHW2
      THW3=ITHW3
      THW4=ITHW4
      THW5=ITHW5
      THW6=ITHW6
      THM1=ITHM1
      THM2=ITHM2
      THM3=ITHM3
      THM4=ITHM4
      THM5=ITHM5
      THM6=ITHM6
      THMIO=ITHMIO

      KHHW2=1.-KHHW1
      KHWW2=1.-KHWW1
      KHMC= KHMCT/KHWN
      KHWV= KHWVT/KHWN



*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  PUMP AND PROCESS-FLOW COMPONENT INCON AND PARAM SECTION  *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


INCON    IVPRW = .201652+03, ITPRW = .538666+03, IPPRG = .209568+04
INCON    IPLOAD= .269699+01, INPL  = .455178+04, IINT  = .455553+04
INCON    IAPS  = .729776+00, IIPSIT= .729851+00
PARAM    WFLOW = .519897+01


      VPRW=IVPRW
      TPRW=ITPRW
      PPRG=IPPRG
      PLOAD=IPLOAD
      NPL=INPL
      INT=IINT
      APS=IAPS
      IPSIT=IIPSIT



```

```
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  USER CONTROL SECTION-- TIME INDEPENDENT PART *  *  *  *  *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


*    CACWS PUMP CONTROL PARAMETERS (TEMPORARY)
PARAM    KPLFB =  1.       , KPLRT = 1.
PARAM    KPLJ0 =3.28       , KPLJ1 =.0985       , KPLJ2 =1.344
PARAM    KPLCR =50.
PARAM    WPLR  =0.0        , SPL   =1.0         , WPLS  =0.0
CONST    KPL   =2.5        , KPLN  =5000.       , WPLS0 =0.0

PARAM    NPS   =5500.      , KPSPB =10.         , KPSRT =10.
PARAM    KPSJ0 =.2481      , KPSJ1 =7.622E-4    , KPSJ2 =1.126E-3
PARAM    KPSCR =10.
PARAM    WPSR  =0.0        , SPS   =1.          , WPSS  =5.2
CONST    KPS   =.40        , KPSN  =5000.

PARAM    WPRI  =0.         , WPRO  =0.          , GPRI  =0.
PARAM    GPRO  =0.         , QPR   =0.          , TPRI  =530.
PARAM    KPRV  =400.

*     AIR BLAST HX PARAMETERS
PARAM    GAA   =14.0        , TAAI10=559.

*     TEMPERATURE SENSOR LAGS
PARAM    KTAU  =10.

*     CORE PARAMETERS
PARAM    GCAA  = 3.0    , TLPH  =2060.


DYNAMIC


NOSORT


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  TIME DEPENDENT INPUT SECTION                             *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *



SORT
```

```
*   *   *   *   *   *   *   *   *   PIPE THERMAL MODELS   *   *   *   *   *   *   *   *
*   *   *   *   *   *   *   *   *   SECTION 6.1           *   *   *   *   *   *   *   *







*      HOT LINE MODEL

       DTPH1,RPH1,BPH1=PIPE1(WFLOW,THWO,KPHV,KPHC,TPH1,ITPH1)
       DTPH2,RPH2,BPH2=PIPE1(WFLOW,TPH1,KPHV,KPHC,TPH2,ITPH2)
       DTPH3,RPH3,BPH3=PIPE1(WFLOW,TPH2,KPHV,KPHC,TPH3,ITPH3)
       DTPH4,RPH4,BPH4=PIPE1(WFLOW,TPH3,KPHV,KPHC,TPH4,ITPH4)
       DTPH5,RPH5,BPH5=PIPE1(WFLOW,TPH4,KPHV,KPHC,TPH5,ITPH5)
       DTPH6,RPH6,BPH6=PIPE1(WFLOW,TPH5,KPHV,KPHC,TPH6,ITPH6)
       DTPH7,RPH7,BPH7=PIPE1(WFLOW,TPH6,KPHV,KPHC,TPH7,ITPH7)
       DTPH8,RPH8,BPH8=PIPE1(WFLOW,TPH7,KPHV,KPHC,TPH8,ITPH8)
       DTPH9,RPH9,BPH9=PIPE1(WFLOW,TPH8,KPHV,KPHC,TPH9,ITPH9)
       DTPH10,RPH10,BPH10=PIPE1(WFLOW,TPH9,KPHV,KPHC,TPH10,ITPH10)

       TPHO=TPH10

       RPHAV=(RPH1+RPH2+RPH3+RPH4+RPH5+RPH6+RPH7+RPH8+RPH9+RPH10)/KPHN
       BPHT=BPH1+BPH2+BPH3+BPH4+BPH5+BPH6+BPH7+BPH8+BPH9+BPH10



*      COLD LINE MODEL

       DTPC1,RPC1,BPC1=PIPE1(WFLOW,TAWO,KPCV,KPCC,TPC1,ITPC1)
       DTPC2,RPC2,BPC2=PIPE1(WFLOW,TPC1,KPCV,KPCC,TPC2,ITPC2)
       DTPC3,RPC3,BPC3=PIPE1(WFLOW,TPC2,KPCV,KPCC,TPC3,ITPC3)
       DTPC4,RPC4,BPC4=PIPE1(WFLOW,TPC3,KPCV,KPCC,TPC4,ITPC4)
       DTPC5,RPC5,BPC5=PIPE1(WFLOW,TPC4,KPCV,KPCC,TPC5,ITPC5)
       DTPC6,RPC6,BPC6=PIPE1(WFLOW,TPC5,KPCV,KPCC,TPC6,ITPC6)
       DTPC7,RPC7,BPC7=PIPE1(WFLOW,TPC6,KPCV,KPCC,TPC7,ITPC7)
       DTPC8,RPC8,BPC8=PIPE1(WFLOW,TPC7,KPCV,KPCC,TPC8,ITPC8)
       DTPC9,RPC9,BPC9=PIPE1(WFLOW,TPC8,KPCV,KPCC,TPC9,ITPC9)
       DTPC10,RPC10,BPC10=PIPE1(WFLOW,TPC9,KPCV,KPCC,TPC10,ITPC10)

       TPCO=TPC10

       RPCAV=(RPC1+RPC2+RPC3+RPC4+RPC5+RPC6+RPC7+RPC8+RPC9+RPC10)/KPCN
       BPCT=BPC1+BPC2+BPC3+BPC4+BPC5+BPC6+BPC7+BPC8+BPC9+BPC10




```

```
*    *    *    *    *    *    *  AIR BLAST HEAT EXCHANGER MODEL  *    *    *    *    *    *
*    *    *    *    *    *    *          SECTION 6.4              *    *    *    *    *    *







        DTAWI,RAWI,BAWI=PIPE1(WFLOW,TPHO,KAWVI,KAMCI,TAWI,ITAWI)
        DTAWO,RAWO,BAWO=PIPE1(WFLOW,TAWO10,KAWVO,KAMCO,TAWO,ITAWO)



        TAA10,JAAM10,JAWM10=HTCOE(WFLOW,JAAGR,JAACP,TAAI10,TAAO10,...
        TAM10,TAW10)
        TAA9,JAAM9,JAWM9=HTCOE(WFLOW,JAAGR,JAACP,TAAO10,TAAO9,TAM9,TAW9)
        TAA8,JAAM8,JAWM8=HTCOE(WFLOW,JAAGR,JAACP,TAAO9,TAAO8,TAM8,TAW8)
        TAA7,JAAM7,JAWM7=HTCOE(WFLOW,JAAGR,JAACP,TAAO8,TAAO7,TAM7,TAW7)
        TAA6,JAAM6,JAWM6=HTCOE(WFLOW,JAAGR,JAACP,TAAO7,TAAO6,TAM6,TAW6)
        TAA5,JAAM5,JAWM5=HTCOE(WFLOW,JAAGR,JAACP,TAAO6,TAAO5,TAM5,TAW5)
        TAA4,JAAM4,JAWM4=HTCOE(WFLOW,JAAGR,JAACP,TAAO5,TAAO4,TAM4,TAW4)
        TAA3,JAAM3,JAWM3=HTCOE(WFLOW,JAAGR,JAACP,TAAO4,TAAO3,TAM3,TAW3)
        TAA2,JAAM2,JAWM2=HTCOE(WFLOW,JAAGR,JAACP,TAAO3,TAAO2,TAM2,TAW2)
        TAA1,JAAM1,JAWM1=HTCOE(WFLOW,JAAGR,JAACP,TAAO2,TAAO1,TAM1,TAW1)


        JAACP=GAA*KUNACP
        JAAGR=(GAA/KAAG)**-.681
        TAAO10,TAWO10,DTAM10,DTAW10,QAAM10,QAWM10,RAW10,BAW10=SPCFHX(...
         TAAI10,TAWO9,ITAM10,TAM10,ITAW10,TAW10,KAMC,KAWV,KAAW1,KAAW2,...
         KAWW1,KAWW2,JAACP,WFLOW,JAAM10,JAWM10)
        TAAO9,TAWO9,DTAM9,DTAW9,QAAM9,QAWM9,RAW9,BAW9=SPCFHX(TAAO10,...
         TAWO8,ITAM9,TAM9,ITAW9,TAW9,KAMC,KAWV,KAAW1,KAAW2,...
         KAWW1,KAWW2,JAACP,WFLOW,JAAM9,JAWM9)
        TAAO8,TAWO8,DTAM8,DTAW8,QAAM8,QAWM8,RAW8,BAW8=SPCFHX(TAAO9,...
         TAWO7,ITAM8,TAM8,ITAW8,TAW8,KAMC,KAWV,KAAW1,KAAW2,...
         KAWW1,KAWW2,JAACP,WFLOW,JAAM8,JAWM8)
        TAAO7,TAWO7,DTAM7,DTAW7,QAAM7,QAWM7,RAW7,BAW7=SPCFHX(TAAO8,...
         TAWO6,ITAM7,TAM7,ITAW7,TAW7,KAMC,KAWV,KAAW1,KAAW2,...
         KAWW1,KAWW2,JAACP,WFLOW,JAAM7,JAWM7)
        TAAO6,TAWO6,DTAM6,DTAW6,QAAM6,QAWM6,RAW6,BAW6=SPCFHX(TAAO7,...
         TAWO5,ITAM6,TAM6,ITAW6,TAW6,KAMC,KAWV,KAAW1,KAAW2,...
         KAWW1,KAWW2,JAACP,WFLOW,JAAM6,JAWM6)
        TAAO5,TAWO5,DTAM5,DTAW5,QAAM5,QAWM5,RAW5,BAW5=SPCFHX(TAAO6,...
         TAWO4,ITAM5,TAM5,ITAW5,TAW5,KAMC,KAWV,KAAW1,KAAW2,...
         KAWW1,KAWW2,JAACP,WFLOW,JAAM5,JAWM5)
        TAAO4,TAWO4,DTAM4,DTAW4,QAAM4,QAWM4,RAW4,BAW4=SPCFHX(TAAO5,...
         TAWO3,ITAM4,TAM4,ITAW4,TAW4,KAMC,KAWV,KAAW1,KAAW2,...
         KAWW1,KAWW2,JAACP,WFLOW,JAAM4,JAWM4)
        TAAO3,TAWO3,DTAM3,DTAW3,QAAM3,QAWM3,RAW3,BAW3=SPCFHX(TAAO4,...
         TAWO2,ITAM3,TAM3,ITAW3,TAW3,KAMC,KAWV,KAAW1,KAAW2,...
         KAWW1,KAWW2,JAACP,WFLOW,JAAM3,JAWM3)
        TAAO2,TAWO2,DTAM2,DTAW2,QAAM2,QAWM2,RAW2,BAW2=SPCFHX(TAAO3,...
         TAWO1,ITAM2,TAM2,ITAW2,TAW2,KAMC,KAWV,KAAW1,KAAW2,...
         KAWW1,KAWW2,JAACP,WFLOW,JAAM2,JAWM2)
        TAAO1,TAWO1,DTAM1,DTAW1,QAAM1,QAWM1,RAW1,BAW1=SPCFHX(TAAO2,...
         TAWI,ITAM1,TAM1,ITAW1,TAW1,KAMC,KAWV,KAAW1,KAAW2,...
         KAWW1,KAWW2,JAACP,WFLOW,JAAM1,JAWM1)
```

```
      RAWAV=(RAW1+RAW2+RAW3+RAW4+RAW5+RAW6+RAW7+RAW8+RAW9+RAW10)/KAWN

      BAWT=BAWI+BAW1+BAW2+BAW3+BAW4+BAW5+BAW6+BAW7+BAW8+...
           BAW9+BAW10+BAWO



*  *  *  *  *  CORE AUXILIARY HEAT EXCHANGER MODEL  *  *  *  *  *  *
*  *  *  *  *             SECTION 6.3              *  *  *  *



*      CAHE INLET AND EXIT WATER HEADER MODELS

      DTHWI,RHWI,BHWI=PIPE1(WFLOW,TPCO,KHWVI,KHMCI,THWI,ITHWI)
      DTHWO,RHWO,BHWO=PIPE1(WFLOW,THWO6,KHWVO,KHMCO,THWO,ITHWO)

*     CAHE HEATED ZONE MODEL

      THHI6=TLPH


      THH6,JHHM6,JHWM6=HTKOE(WFLOW,GCAA,JHHCP,THHI6,THHO6,THM6,THW6)
      THH5,JHHM5,JHWM5=HTKOE(WFLOW,GCAA,JHHCP,THHO6,THHO5,THM5,THW5)
      THH4,JHHM4,JHWM4=HTKOE(WFLOW,GCAA,JHHCP,THHO5,THHO4,THM4,THW4)
      THH3,JHHM3,JHWM3=HTKOE(WFLOW,GCAA,JHHCP,THHO4,THHO3,THM3,THW3)
      THH2,JHHM2,JHWM2=HTKOE(WFLOW,GCAA,JHHCP,THHO3,THHO2,THM2,THW2)
      THH1,JHHM1,JHWM1=HTKOE(WFLOW,GCAA,JHHCP,THHO2,THHO1,THM1,THW1)



      JHHCP=GCAA*KUNHCP
      THHO6,THWO6,DTHM6,DTHW6,QHHM6,QHWM6,RHW6,BHW6=SPCFHX(THHI6,...
        THWO5,ITHM6,THM6,ITHW6,THW6,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM6,JHWM6)
      THHO5,THWO5,DTHM5,DTHW5,QHHM5,QHWM5,RHW5,BHW5=SPCFHX(THHO6,...
        THWO4,ITHM5,THM5,ITHW5,THW5,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM5,JHWM5)
      THHO4,THWO4,DTHM4,DTHW4,QHHM4,QHWM4,RHW4,BHW4=SPCFHX(THHO5,...
        THWO3,ITHM4,THM4,ITHW4,THW4,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM4,JHWM4)
      THHO3,THWO3,DTHM3,DTHW3,QHHM3,QHWM3,RHW3,BHW3=SPCFHX(THHO4,...
        THWO2,ITHM3,THM3,ITHW3,THW3,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM3,JHWM3)
      THHO2,THWO2,DTHM2,DTHW2,QHHM2,QHWM2,RHW2,BHW2=SPCFHX(THHO3,...
        THWO1,ITHM2,THM2,ITHW2,THW2,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM2,JHWM2)
      THHO1,THWO1,DTHM1,DTHW1,QHHM1,QHWM1,RHW1,BHW1=SPCFHX(THHO2,...
        THWI,ITHM1,THM1,ITHW1,THW1,KHMC,KHWV,KHHW1,KHHW2,...
        KHWW1,KHWW2,JHHCP,WFLOW,JHHM1,JHWM1)

      BHWT=BHWI+BHW1+BHW2+BHW3+BHW4+BHW5+BHW6+BHWO

      RHWAV=(RHW1+RHW2+RHW3+RHW4+RHW5+RHW6)/KHWN

      QHWMT=QHWM1+QHWM2+QHWM3+QHWM4+QHWM5+QHWM6
      QHHMT=QHHM1+QHHM2+QHHM3+QHHM4+QHHM5+QHHM6




```

```
*  *  *  *  *  *  *  CACWS PROCESS-FLOW MODEL  *  *  *  *  *  *
*  *  *  *  *  *  *         SECTION 4.         *  *  *  *  *  *







*     JPL0=KPLJ0*RPC1*(NPL/KPLN)**2
*     JPL1=KPLJ1*(NPL/KPLN)
*     JPL2=-KPLJ2/RPC1
*

      JPS0=KPSJ0*RPC1*(NPS/KPSN)**2
      JPS1=KPSJ1*(NPS/KPSN)
      JPS2=-KPSJ2/RPC1

      JAWPL=1./SQRT(KPHSQ/RPHAV+KPCSQ/RPCAV+KAWSQ/RAWAV+KHWSQ/RHWAV+...
            KHWISQ/RHWI+KAWISQ/RAWI)
      RPUMP=RPC1
PROCED WFLOW,WPL,WPS,PLOAD=PRFLO(JAWPL,RPUMP,APL,SPL,WPLR,JPL0,JPL1,...
       JPL2,NPL,APS,SPS,WPSR,JPS0,JPS1,JPS2,NPS)
    4 IF(PLOAD)1,1,2
    1 WFLOW=0.
      WFLOPD=0.
      GO TO 3
    2 WFLOW=JAWPL*SQRT(PLOAD)
      WFLOPD=0.5*WFLOW/PLOAD
    3 CONTINUE
      JPL=KPL*SQRT(RPUMP)
      JPS=KPS*SQRT(RPUMP)
*     WPL,WPLPD=MOPTV(JPL,APL,SPL,JPL0,JPL1,JPL2,WPLR,PLOAD)
      WPS,WPSPD=MOPTV(JPS,APS,SPS,JPS0,JPS1,JPS2,WPSR,PLOAD)
      ERR=WPL+WPS-WFLOW
      PLOAD=PLOAD-ERR/(WPLPD+WPSPD-WFLOPD)
      IF(ERR*ERR.GT.0.01)GO TO 4
ENDPRO

*  *  PRESSURIZER MODEL

      TPRG=TPRW
      JPRRP=DTPRW*AFGEN(PARTRT,TPRW)*VPRW
      RPRW=AFGEN(RFTSL,TPRW)
      WPR=BPHT+BAWT+BPCT+BHWT
      THWX=TPC9
      DTPRW=(WPRI*(TPRI-TPRW)-QPR/KUNWCP+(THWX-TPRW)*LIMIT(0.0,...
      .1E6,-WPR))/RPRW/VPRW
      TPRW=INTGRL(ITPRW,DTPRW)
      DVPRW=(WPRI-WPRO-WPR-JPRRP)/RPRW
      VPRW=INTGRL(IVPRW,DVPRW)
      DPPRG=((GPRI-GPRO)*KUNGR*TPRG+PPRG*DVPRW)/(KPRV-VPRW)
      PPRG=INTGRL(IPPRG,DPPRG)


```

```
*  *  *  *  *  *  MISCELLANEOUS  *  *  *  *  *  *  *  *  *


*  *  TEMPORARY CACWS FLOW CONTROL AND ACTUATOR MODELS

*     PROP=100./KPLPB*(WPLS-WFLOW)/KPLCR
*     DINT=PROP/KPLRT
*     INT=INTGRL(IINT,DINT)
*     NPLD=PROP+INT
*     DNPL=(NPLD-NPL)/20.
*     NPL=INTGRL(INPL,DNPL)


      PROPS=100./KPSPB*(WPSS-WFLOW)/KPSCR
      DIPSIT=PROPS/KPSRT
      IPSIT=INTGRL(IIPSIT,DIPSIT)
      APSD=PROPS+IPSIT
      DAPS=(APSD-APS)/4.
      APS=LIMINT(IAPS,0.0,1.0,DAPS)

*      COLD TEMPERATURE MEASUREMENT (KTAU SEC LAG)

      DTPCOM=(TPC10-TPCOM)/KTAU
      TPCOM=INTGRL(ITPCOM,DTPCOM)

*     CAHE EXIT TEMPERATURE MEASUREMENT (KTAU SEC LAG)

      DTPHM=(TPH1-TPHM)/KTAU
      TPHM=INTGRL(ITPHM,DTPHM)

*      VARIABLES CACULATED FOR OUTPUT PURPOSES ONLY

      QHWMT=QHWM1+QHWM2+QHWM3+QHWM4+QHWM5+QHWM6
      QHHMT=QHHM1+QHHM2+QHHM3+QHHM4+QHHM5+QHHM6
      QAWMT=QAWM1+QAWM2+QAWM3+QAWM4+QAWM5+QAWM6+QAWM7+QAWM8+...
           QAWM9+QAWM10
      QAAMT=QAAM1+QAAM2+QAAM3+QAAM4+QAAM5+QAAM6+QAAM7+QAAM8+...
           QAAM9+QAAM10
      MARGIN=AFGEN(HSATP,PPRG)-AFGEN(HSATT,THWO6)


      EAE=DEBUG(1,0.0)
*     EA1=DEBUG(1,0.1)
*     EA2=DEBUG(1,0.2)
*     EA3=DEBUG(1,0.3)
*     EA4=DEBUG(1,0.4)
*     EA5=DEBUG(1,0.5)
*     EA6=DEBUG(1,0.6)
*     EA7=DEBUG(1,0.7)
*     EA8=DEBUG(1,0.8)
*     EA9=DEBUG(1,0.9)
*     EA99=DEBUG(1,0.99)
TERMINAL
      EAE1=DEBUG(1,TIME)
TIMER DELT=.1,FINTIM=6000.,DELPR=100.,DELGR=25.,TWARN=20.
/     WRITE(12,73   )TPH1,TPH2,TPH3,TPH4,TPH5,TPH6,TPH7,TPH8,TPH9,
/    1TPH10,TPHM
/73   FORMAT('*  *  *  HOT LINE INITIAL CONDITIONS',/,
/    1'INCON    ITPH1 =',E11.6,', ITPH2 =',E11.6,', ITPH3 =',E11.6,/,
/    1'INCON    ITPH4 =',E11.6,', ITPH5 =',E11.6,', ITPH6 =',E11.6,/,
/    1'INCON    ITPH7 =',E11.6,', ITPH8 =',E11.6,', ITPH9 =',E11.6,/,
/    1'INCON    ITPH10=',E11.6,/,'INCON    ITPHM =',E11.6)
```

```
      WRITE(12,72  )TPC1,TPC2,TPC3,TPC4,TPC5,TPC6,TPC7,TPC8,TPC9,
     1TPC10,TPCOM
72    FORMAT('*  *  *  COLD LINE INITIAL CONDITIONS',/,
     1'INCON    ITPC1 =',E11.6,', ITPC2 =',E11.6,', ITPC3 =',E11.6,/,
     1'INCON    ITPC4 =',E11.6,', ITPC5 =',E11.6,', ITPC6 =',E11.6,/,
     1'INCON    ITPC7 =',E11.6,', ITPC8 =',E11.6,', ITPC9 =',E11.6,/,
     1'INCON    ITPC10=',E11.6,/,
     1'INCON    ITPCOM=',E11.6)


      WRITE(12,70  )TAW0,TAWI,TAW1,TAW2,TAW3,TAW4,TAW5,TAW6,TAW7,
     1TAW8,TAW9,TAW10,TAM1,TAM2,TAM3,TAM4,TAM5,TAM6,TAM7,TAM8,
     1TAM9,TAM10,TAA1,TAA2,TAA3,TAA4,TAA5,TAA6,TAA7,TAA8,TAA9,TAA10
70    FORMAT('*  *  *  AIR BLAST HX INITIAL CONDITIONS',/,
     1'INCON    ITAW0 =',E11.6,', ITAWI =',E11.6,', ITAW1 =',E11.6,/,
     1'INCON    ITAW2 =',E11.6,', ITAW3 =',E11.6,', ITAW4 =',E11.6,/,
     1'INCON    ITAW5 =',E11.6,', ITAW6 =',E11.6,', ITAW7 =',E11.6,/,
     1'INCON    ITAW8 =',E11.6,', ITAW9 =',E11.6,', ITAW10=',E11.6,/,
     1'INCON    ITAM1 =',E11.6,', ITAM2 =',E11.6,', ITAM3 =',E11.6,/,
     1'INCON    ITAM4 =',E11.6,', ITAM5 =',E11.6,', ITAM6 =',E11.6,/,
     1'INCON    ITAM7 =',E11.6,', ITAM8 =',E11.6,', ITAM9 =',E11.6,/,
     1'INCON    ITAM10=',E11.6,/,
     1'PARAM    TAA1  =',E11.6,', TAA2  =',E11.6,', TAA3  =',E11.6,/,
     1'PARAM    TAA4  =',E11.6,', TAA5  =',E11.6,', TAA6  =',E11.6,/,
     1'PARAM    TAA7  =',E11.6,', TAA8  =',E11.6,', TAA9  =',E11.6,/,
     1'PARAM    TAA10 =',E11.6)


      WRITE(12,71  )THWI,THW1,THW2,THW3,THW4,THW5,THW6,THM1,THM2,
     1THM3,THM4,THM5,THM6,THW0,THMIO,THH1,THH2,THH3,THH4,THH5,THH6
71    FORMAT('*  *  *  CAHE INITIAL CONDITIONS',/,
     1'INCON    ITHWI =',E11.6,', ITHW1 =',E11.6,', ITHW2 =',E11.6,/,
     1'INCON    ITHW3 =',E11.6,', ITHW4 =',E11.6,', ITHW5 =',E11.6,/,
     1'INCON    ITHW6 =',E11.6,', ITHM1 =',E11.6,', ITHM2 =',E11.6,/,
     1'INCON    ITHM3 =',E11.6,', ITHM4 =',E11.6,', ITHM5 =',E11.6,/,
     1'INCON    ITHM6 =',E11.6,', ITHW0 =',E11.6,', ITHMIO=',E11.6,/,
     1'PARAM    THH1  =',E11.6,', THH2  =',E11.6,', THH3  =',E11.6,/,
     1'PARAM    THH4  =',E11.6,', THH5  =',E11.6,', THH6  =',E11.6)


      WRITE(12,74)VPRW,TPRW,PPRG,PLOAD,NPL,INT,APS,IPSIT,WFLOW,TIME
 74   FORMAT('*  *  *  PUMP AND PROCESS-FLOW INITIAL CONDITIONS',/,
     1'INCON    IVPRW =',E11.6,', ITPRW =',E11.6,', IPPRG =',E11.6,/,
     1'INCON    IPLOAD=',E11.6,', INPL  =',E11.6,', IINT  =',E11.6,/,
     1'INCON    IAPS  =',E11.6,', IIPSIT=',E11.6,/,
     1'PARAM    WFLOW =',E11.6,/,'*  *  TIME AT END OF RUN=',E11.6,//)

```

```
PRINT TPCO,THWO6,THWO,TPHO,TAWO10,TAWO,THHO1,WFLOW,MARGIN,PPRG, ...
      QAAM1,QAAM2,QAAM3,QAAM4,QAAM5,QAAM6,QAAM7,QAAM8,QAAM9,QAAM10,...
      QAAMT, ...
      QAWM1,QAWM2,QAWM3,QAWM4,QAWM5,QAWM6,QAWM7,QAWM8,QAWM9,QAWM10,...
      QAWMT, ...
      QHHM1,QHHM2,QHHM3,QHHM4,QHHM5,QHHM6,QHHMT, ...
      QHWM1,QHWM2,QHWM3,QHWM4,QHWM5,QHWM6,QHWMT
PREPAR TPCO,THWO6,THWO,TPHO,TAWO10,TAWO,THHO1,WFLOW,MARGIN,PPRG, ...
      QAAM1,QAAM2,QAAM3,QAAM4,QAAM5,QAAM6,QAAM7,QAAM8,QAAM9,QAAM10,...
      QAAMT, ...
      QAWM1,QAWM2,QAWM3,QAWM4,QAWM5,QAWM6,QAWM7,QAWM8,QAWM9,QAWM10,...
      QAWMT, ...
      QHHM1,QHHM2,QHHM3,QHHM4,QHHM5,QHHM6,QHHMT, ...
      QHWM1,QHWM2,QHWM3,QHWM4,QHWM5,QHWM6,QHWMT, ...
      NPL,APS
GRAPH TIME,TPCO,THWO,TPHO,...
        TAWO,THHO1
GRAPH TIME,TAWO10
GRAPH TIME,WFLOW,PPRG
GRAPH TIME,THWO6
GRAPH TIME,MARGIN
GRAPH TIME,APS,NPL

INTEG WSEIG
*STEADY EIGEN,DELSS=.001
END
STOP
```

9. REFERENCES

1. "ECSTRA - Dynamic Simulation of the HTGR Auxiliary Core Cooling System," by M.R. Ringham and R.W. McNamara, GA-A14585, July 1977.

2. "Development of the Mathematical Model of the Core Auxiliary Cooling System," by W.D. Leech, R.D. Person and A.J. Spurgin, GA-D13743, November 1975.

3. "AUXTRN - A Fortran V Program for Simulating the Dynamic Performance of the GCFR Core Auxiliary Cooling System," by R.G. Perkins, GA Report No. GA-D13292, January 1975.

4. "MINGAF - A Computer Program to Evaluate the Transient Thermal-Hydraulic and Neutronic Response of a Gas-Cooled Fast Breeder Reactor (GCFR) Core," by D.R. Buttemer and B.E. Boyack, GA Report No. GA-D14282, July 1977.

5. "Gas-Cooled Fast Breeder Reactor Preliminary Safety Information Document," GA Report No. GA-10298, February 23, 1976.

6. "Control Simulation for the Gas Cooled Fast Breeder Reactor," by M.R. Ringham and R. W. McNamara, to be published.

7. "DeLaval Engineering Handbook," by H. Gartmann, McGraw-Hill, 1970.

8. "Bayonet Heat Transfer Code," by W.W. Howard, GA Internal Memo AC4359/76-7215 dated 27 January 1976.

APPENDIX A

BASIC DATA

This appendix documents the basic data used in CASY during its development. This data is preliminary since no information on detail design of the CAHE or CAAB was supplied. The data will be presented for each component following the order of the model development writeup in the main body of this report. Section A.1 documents the CACS process flow data, Section A.2 documents the primary loop process flow data, and Section A.3 documents the thermal model data.

A.1 CORE AUXILIARY SECONDARY COOLANT LOOP

There are five basic components in the secondary coolant loop. These include a large pump, a small pump, and water flow controller (including a throttle valve), water line losses, and a pressurizer.

A.1.1 Secondary Loop Process Flow

The line losses are associated with the various components in the system as shown in Figure A.1.1-1.

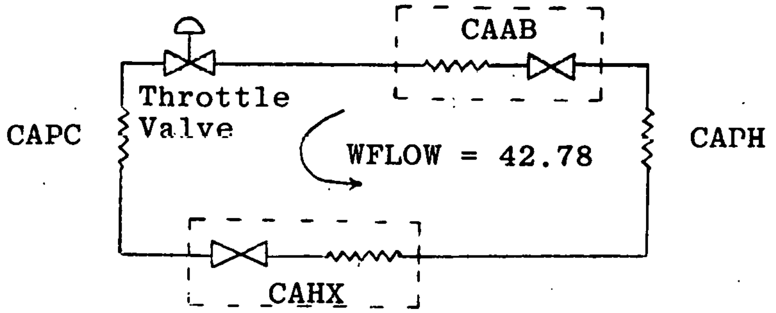

Figure A.1.1-1. Core Auxiliary Secondary Line Losses

At a flow of 42.78 lb/sec, the CAHX and CAAB modules are assumed to have a pressure drop of 30 psi plus a 30 psi pressure drop in the inlet headers. The CAPH and CAPC modules are assumed to have a 20 psi pressure drop. PLOAD then is about 160 psi. The control valve is assumed to have a pressure drop of 20 psi. These line losses are converted to effective losses by the expression

$$K^2 = \rho\Delta P/W^2$$

Assuming a density of 60 lb/ft^3 on the cold side and 51 lb/ft^3 on the hot side, then

KAWSQ = .9031	KHWSQ = .9016	KAWISQ = .6803
KPHSQ = .2268	KPCSQ = .3300	KHWISQ = .6800

Assuming a normalized valve area of ½, the valve area coefficient is

$$KPL = 42.78/(0.5)/\sqrt{\rho * 20} = 2.5$$

$$\boxed{KPL = 2.5}$$

This was found from the general expression

$$K = W_{FLOW}/A_{VALVE}/\sqrt{\rho\Delta P_{VALVE}}$$

A.1.2 Large Pump

The large pump is used during core cooling operation with the auxiliary circulator. The large pump curve coefficients were established from the total pressure drop of 160 psi or 384 feet with the design flow of 42.78 lb/sec or 320 gal/min. For a centrifugal pump, the pump curve general expression is (see for example curve 4 in Figure 6-3, Chapter 6 of Ref. 7):

$$h/384 = 1.23 + 0.0256 * Q/320 - 0.256 * Q^2/(320)^2$$

or

$$h = 472.3 + 0.03072Q - 9.6 * 10^{-4}Q^2$$

resulting in the pump coefficients

$$J_0 = 472.3/144 = 3.28$$

$$J_1 = 3.12 * 0.03072 = 0.0958$$

$$J_2 = 1.4 * 10^3 * (-9.6 * 10^{-4}) = -1.344$$

The reference speed of the pump is assumed to be 5000 RPM; therefore, KPLN = 5000. The control parameters were selected as a proportional band of 1 and a reset time of 1.

Summarizing

KPLPB = 1., KPLRT = 1.,
KPLJO = 3.28, KPLJ1 = 0.0985, KPLJ2 = 1.344
KPLCR = 50., KPLN = 5000.

A.1.3 Small Pump

The small pump is used during standby operation. For this operation, the flow is 5.2 lb/sec resulting in PLOAD ≈ 2.7. The valve area coefficient is

$$KPS = W/A/\sqrt{\rho\Delta\rho}$$

$$KPS = 5.2/(0.67)/\sqrt{\rho*10} = 0.40$$

$$\boxed{KPS = 0.40}$$

The small pump curve coefficients were established from the total pressure drop on standby of 12.7 or 29 feet with the design flow at 5.2 lb/sec or 38.9 gpm. The pump curve general expression is:

$h/29 = 1.23 + 0.0256 * Q/320 - 0.256 * Q^2/320^2$

$h = 35.72 + 2.443E-4 * Q - 8.024E-7 * Q^2$

$J_0 = 35.72/144 = .2481$

$J_1 = 2.443E-4 * 3.12 = 2.622E-4$

$J_2 = 1400 * 8.024E-7 = 1.126E-3$

Summarizing

NPS = 5500, KPSPB = 10, KPSRT = 10

KPSJ0 = 0.2481, KPSJ1 = 7.622E-4, KPSJ2 = 1.126E-3

KPSCR = 10, KPSN = 5000, KPS = 0.40

A.1.4 Pressurizer

The pressurizer was assumed to have a volume of 400 cu. ft. The initial pressure under hot conditions was set at 2100 psi. The model was developed to accommodate a gas pressurizer. Currently, the inlet and outlet gas flow is set at zero and not allowed to change.

Summarizing

WPRI = 0.0, WPRO = 0.0, GPRI = 0.0

QPR = 0.0, TPRI = 530, KPRV = 400

A.2 CIRCULATOR

Table A.2-1 is a duplication of Table 4.5-1 from Reference 5. It is considered preliminary, but was used to establish circulator coefficients from the expression

$K = G/\rho/N$

Table A.2-1

AUXILIARY-HELIUM-CIRCULATOR DESIGN DATA

(Depressurized Condition)

Type	Centrifugal
Drive	Electric motor
Fluid	Helium
Speed, rpm	4900
Inlet temperature, °F	400
Inlet pressure, psia	25.3
Outlet pressure, psia	26.7
Mass flow, lb/sec	13.3 per circulator
Efficiency, %	80.7
Tip diameter, in.	45
Tip width, in.	3.4
Eye diameter, in.	25.2
Hub diameter, in.	12
Power, hp	690

where G is the helium flow, ρ is the helium density ($\rho = P/T/R$), and N is circulator speed.

$$\rho = 25.3/(400 + 460)/2.678$$
$$= 0.01098$$

Then K = 13.3/.01098/4900 = 0.2471

$$\boxed{KCAR = 0.2471, \quad KCCN = 3, \quad KCAN = 2}$$

A.3 THERMAL MODELS

A.3.1 Pipe Data

The pipe requires three data values: the number of nodes in the pipe (KPHN); the water volume (KPHVT); and the metal thermal capacitance (KPHCT). The hot and cold pipes are assumed to be 277 ft. long with an outside diameter of 6.625 inches and an inside diameter of 5.189. Then,

$$K_C = \pi \; (OD^2 - ID^2)/4 * T_{LENGTH} * HEAT\ CAP_{STEEL} * \rho_{STEEL}$$

$$KPHCT = \pi * \left((6.625/12)^2 - (5.189/12)^2\right)/4 * 277 * .117 * 489 = 1466$$

$$K_{VOL} = \pi * ID^2/4 * T_{LENGTH}$$

$$KPHVT = \pi * (5.189/12)^2/4 * 277 = 40.7$$

$$KPHN = 10$$

The hot and cold pipes were assumed identical in size.

Summarizing

$$\boxed{\begin{array}{l} KPHCT = 1466, \ KPHVT = 40.7, \ KPHN = 10 \\ KPCCT = 1466, \ KPCVT = 40.7, \ KPCN = 10 \end{array}}$$

A list of eigenvalues for this data is given in Table A.3.1-1.

Table A.3.1-1

List of Eigenvalues

Hot Pipe		Cold Pipe*	
Real	Imaginary	Real	Imaginary
-.124	0.0	-.131	± .00675
-.112	0.0	-.123	± .0175
-.120	± .00875	-.110	± .0214
-.112	± .0122	-.0987	± .0177
-.103	± .00841	-.0917	± .00911
-.112	0.0	-.090	0.0
-.100	0.0		

*(Includes Temperature Measurement)

A series of test cases were made to justify lumping the water and metal capacitances. The results are shown on Figure A.2-1. The "best" model that could be developed using SYSL and a series of first order lumped parameter control volumes is the 145 node, separate water and metal thermal capacitances. As can be observed, the combined thermal capacitance approximation is very adequate.

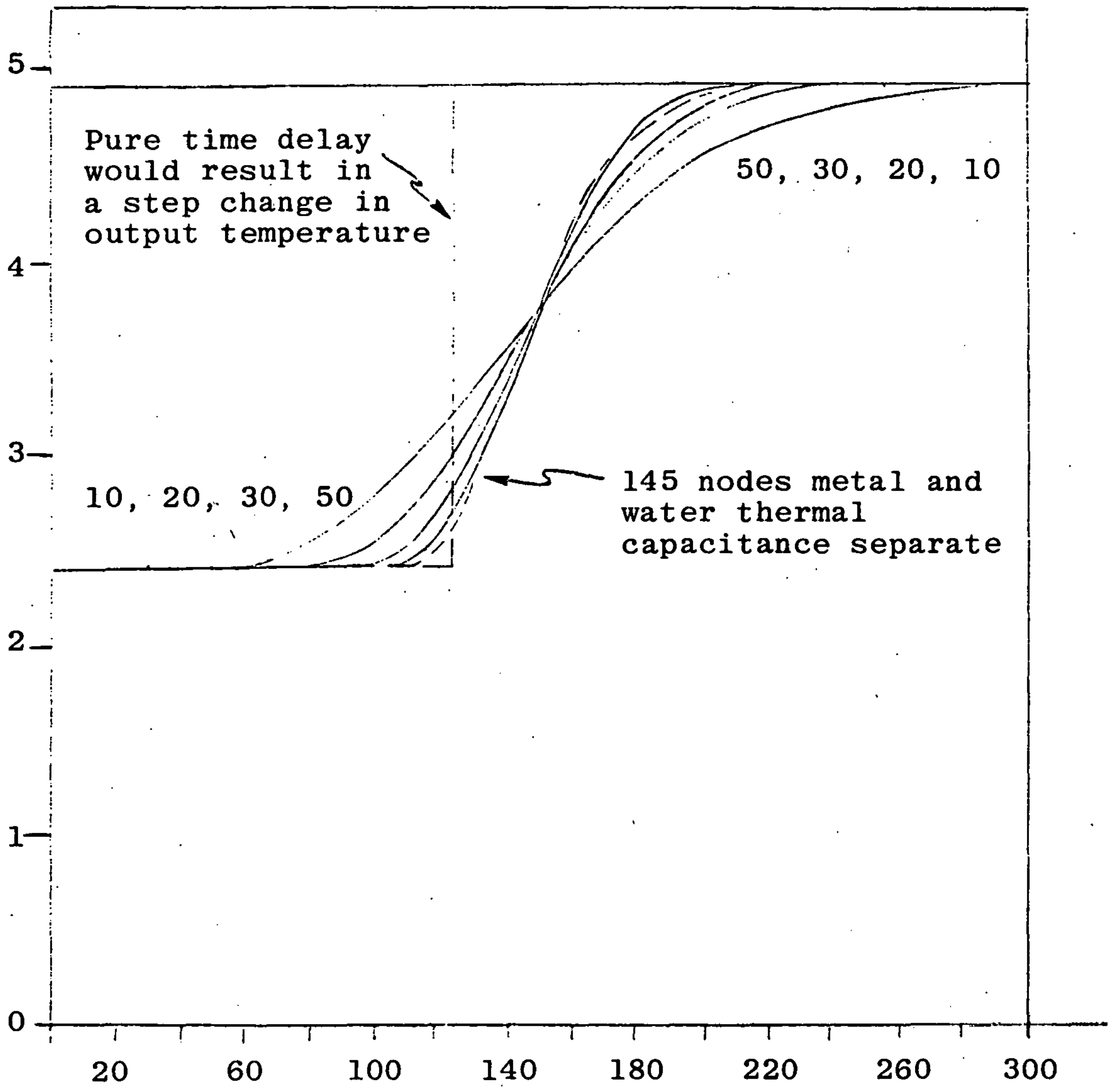

Figure A.2-1. Cold Line Model Outlet Water Temperature Response to Step Input in Inlet Water Temperature at Time Equal Zero (Metal and Water Thermal Capacitance Combined)

Note: The time scale is dependent upon the length of pipe. This data was generated for an 8.625" OD by 8" ID pipe 625 ft. long.

A.3.2 Core Auxiliary Heat Exchanger, CAHE

The design data given in Table A.3.2-1 was duplicated from Table 4.6-2 in Reference 5. This design data was used in the CAHE input data calculations. See also Reference 8.

The heat transfer from the helium to the tube metal is calculated based upon a Colburn type expression for resistance to heat flow:

$$R_H = 3600/h_H$$

where

$$h_H^{(1)} = K_H/D_{HH} * (0.023) * N_{Re}^{0.8} * N_{PR}^{1/3}$$

$$N_{Re} = \dot{m} * D_{HH}/\mu_H/A_{FH}$$

$$N_{PR} = C_{PH} * \mu_H/K_H$$

$$D_{HH} = 4 * A_{FH}/P_W$$

$$A_{FH} = \pi * \left((H_{DIA}/12)^2 - N_{TUBES} * (T_{ODIA}/12)^2\right)/4$$

$$P_w = \pi * N_{TUBES} * T_{ODIA}/12$$

$$\mu_H = 6.388 * 10^{-4} * T_H^{0.687} \quad (\mu_H = \text{viscosity of helium})$$

$$K_H = 1.062 * 10^{-3} * T_H^{0.701} \quad (K_H = \text{conductivity of helium})$$

$$C_{PH} = 1.242 \quad ;$$

then

$$R_H = 3600/.023 * D_{HH} * (D_H/A_F)^{-0.8} * (C_{PH}^{-1/3}/K_H * (\dot{m}/\mu_H)^{-0.8} * (\mu_H/K_H)^{-1/3}$$

---

(1) Note that both the constant 0.023 and exponents 0.8 and 1/3 are engineering estimates based upon detail heat exchanger design; these values could be questioned.

Table A.3.2-1

DESIGN DATA FOR AN AUXILIARY HEAT-EXCHANGER

General	
Helium frontal flow area, ft^2	24.7
Heat duty, Btu/hr	$50.4x10^6$
Logarithmic mean temperature difference, ^oF	487
Overall heat transfer coefficient, Btu/(hr)(ft^2)(^oF)	90
Heat transfer surface area, ft^2	1,140
Helium Side	
Flow rate, lb/hr	48,000
Inlet temperature, ^oF	1,414
Outlet temperature, ^oF	400
Average pressure, psia	25
Pressure drop, psi	0.25
Water Side	
Flow rate, lb/hr	154,000
Inlet temperature, ^oF	180
Outlet temperature, ^oF	500
Average pressure, psia	2,100
Pressure drop, psi	30
Tubes	
Number of tubes	60
Tube size, in.	0.75x0.083
Tube length, ft.	97
Longitudinal tube pitch, in.	1.0
Transverse tube pitch, in.	1.13
Tube bundle height, ft	1.9

Define KHHRX = $3600/.023 * D_{HH} * (D_H/A_{FH})^{-0.8}$

KHHVK = $6.388 * 10^{-4}$

KHHVKE = 0.687

KHHCK = $1.062 * 10^{-3}$

KHHCKE = 0.701

N_{TUBES} = 60 (number of tubes)

T_{ODIA} = 0.75 (tube outside diameter)

H_{DIA} = 24 (helium flow diameter; estimated)

then $P_w = \pi * 60 * 0.75/12 = 11.781$

$A_{FH} = \pi\left((24/12)^2 - 60 * (0.75/12)^2\right)/4 = 2.957$

$D_{HH} = 4 * 2.957/11.781 = 1.004$

KHHRX = $3600/0.023 * 1.004 * (1.004/2.957)^{-0.8}$

$$\boxed{\text{KHHRX} = 3.73 * 10^5}$$

The metal resistance is calculated from the expression

$$R = T_{ODIA}/12/2/K_T * \ln(T_{ODIA}/T_{IDIA}) * 3600$$

where $K_T = 6.25 * 0.0055\ (T_M - 460)$.

Define KHMRX = $T_{ODIA}/12/2 * \ln(T_{ODIA}/T_{IDIA}) * 3600 = 28.14$

KHMRX = 28.14	KHMAK = 6.25	KHMBK = 0.0055

The heat transfer from the tube metal to the water is calculated based upon a similar expression for resistance to heat flow:

$$R_w = 3600/h_w$$

where

$$h_w = K_w/D_{HW} * 0.023 * N_{Re}^{0.8} * N_{PR}^{1/3}$$

$$N_{Re} = \dot{m} * D_{HW}/\mu_w/A_{FW}$$

$$N_{PR} = C_{Pw} * \mu_w/K_w$$

$$D_{HW} = T_{IDIA}/12$$

$$A_{HW} = \pi(T_{IDIA}/12)^2/4 * N_{TUBES}$$

$$\mu_w = f(T_w)$$

$$K_w = f(T_w)$$

$$C_{Pw} = f(T_w)$$

Define

$$KHWRX = 3600/0.023 * D_{HW} * (D_{HW}/A_{FW})^{-0.8} \quad ;$$

then

$$D_{HW} = (.75 - 2 * .083)/12 = .0487$$

$$A_{FW} = \pi\left((.75 - 2 * .083)/12\right)^2/4 * 60 = .1116$$

$$KHWRX = 3600/.023 * .0487 * (.0487/.1116)^{-.8}$$

$$\boxed{KHWRX = 1.48 * 10^4}$$

The effective surface area in the heated zone was calculated using the expression

$$KHHA = \pi * (T_{ODIA}/12) * L_{TUBE} * N_{TUBES}$$

$$= \pi * (0.75/12) * 97 * 60$$

$$\boxed{\begin{array}{l} KHHA = 1142. \\ KHWA = 888. \end{array}}$$

Where $KHWA = KHHA * \left(\frac{T_{ODIA} - 2 * T_{THICKNESS}}{T_{ODIA}}\right)$

In addition, a heat balance was provided by an AUXTRAN run. The heat balance is shown in Figure A.3.2-1. The above set of calculations did not result in the same heat balance. Assuming the difference lay in the method of calculating the heat transfer resistance KHHRX, it was modified until the heat balance agreed. The final selection was

$$\boxed{KHHRX = 1.614 * 10^5}$$

The water volume (KHWVT) and metal thermal capacitance (KHMCT) were evaluated using the expressions

$$KHWVT = \pi(T_{ID}/12)^2/4 * L_{TUBE} * N_{TUBES}$$

$$KHMCT = \pi\left((T_{OD}/12)^2 - (T_{ID}/12)^2\right)/4 * L_{TUBE} * N_{TUBES}$$

$$* 496 * .117$$

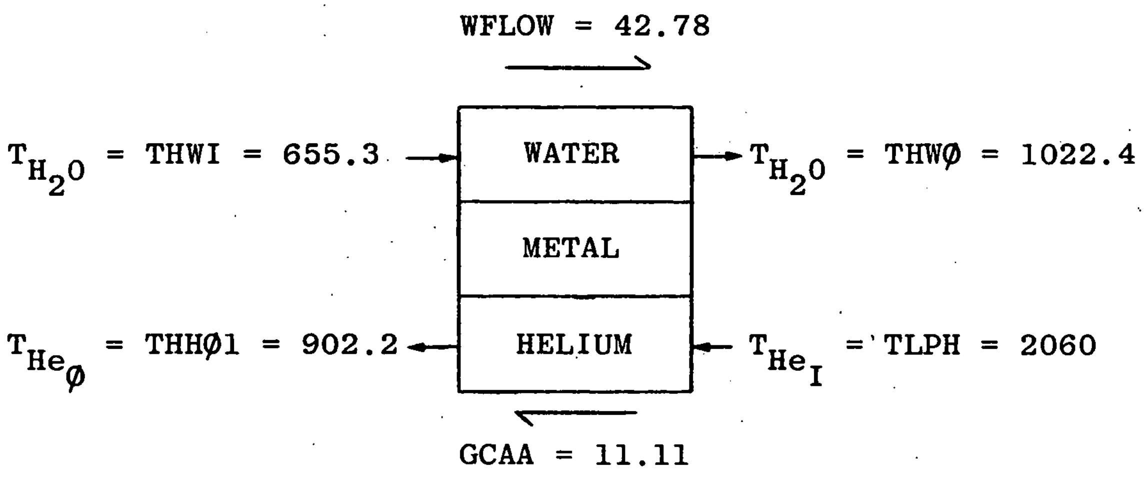

Figure A.3.2-1. CAHE Temperature Balance

$$KHWVT = \pi\left((0.75 - 2 * 0.083)/12\right)^2/4 * 97 * 60$$

$$\boxed{KHWVT = 10.8}$$

$$KHMCT = \pi\left((0.175/12)^2 - \left((0.75 - 2 * 0.083)/12\right)^2\right)/4 * 60 * 97 * 496 * .12$$

$$\boxed{KHMCT = 418.}$$

The CAHE lead-in and lead-out equivalent pipe node data was calculated assuming that there are 20 lead-in and 20 lead-out pipes with a total cross section area equal to the total tube bundle cross section area and 35 feet in length. The tube bundle cross section area is

$$A_{TB} = 60 * \pi\left((.75 - 2 * .083)/12\right)^2/4 = .1116 \text{ sq. ft.}$$

$$KHMVI = .1116 * 35 = 3.91$$

$$\boxed{KHMVI = 3.91}$$

The thermal capacitance is calculated assuming this area is divided into 20 pipes to yield an inner diameter of 1.01 and assume a thickness of 0.12.

$$KHMCI = \pi\left((1.13/12)^2 - (1.01/12)^2\right)/4 * 20 * 35 * 496 * .12 = 58.35$$

$$\boxed{KHMCI = 58.35}$$

The helium volume between the circulator and the CAHE (representative of the cold helium) was assumed to be 344 ft^3.

Summarizing

KHHRX = 1.614E5
KHWRX = 1.48E4
KHMRX = 28.14
KHMCT = 418
KHMCI = 58.35
KHMCO = 58.35
KHWVT = 10.8
KHWVI = 3.91
KHWVO = 3.91
KHMCIO = 208.
KHWMI = .8267
KHWMO = .8267
KHWN = 6.
KHHWI = 0.5
KHWWI = 0.5
KHHVK = 6.388E-4
KHHVKE = 0.687
KHHCK = 1.062E-3
KHHCKE = 0.701
KHMAK = 6.25
KHMBK = 0.0055
KHHA = 1142.
KHWA = 888.
KHHVI6 = 344.

Eigenvalues of this component with this data are given in Table A.3.2-2.

A.3.3 Core Auxiliary Air Blast Heat Exchanger, CAAB

The design data given in Table A.3.3-1 was duplicated from Table B.2, Reference 5. This design data was used in the CAAB input data calculations.

Table A.3.2-2

List of Eigenvalues

CAHE

Real	Imaginary
-1.976	0.0
-1.695	± .303
-1.249	± .286
- .981	0.0
- .552	0.0
- .521	± .116
- .343	± .163
- .131	0.0
- .0660	0.0
- .0535	0.0

Table A.3.3-1

DESIGN DATA FOR THE AUXILIARY LOOP COOLER (ALC) AND THE INTERCONNECTING PIPES (PER LOOP)

Type	Finned tube bank counter-cross flow
Thermal duty, BTU/hr	50.4×10^6
Tube outer diameter and wall thickness, in	1. x 0.095
Tube length, ft	194. (6 passes of 32 ft)
Number of tubes	48
Heat exchange area, ft^2	22000, finned tubeside
Design air flow rate, lb/hr	2740000
Design water-flow rate, lb/hr	154000
Design inlet air temperature, °F	99
Design outlet air temperature, °F	176
Design air pressure, psia	14.7
Water pressure, psia	2100
Material	Stainless Steel
Design water-inlet temperature, °F	500
Design water-outlet temperature, °F	180
Interconnecting pipe outer diameter and wall thickness, in.	
Hot leg	6.625 x 0.718
Cold leg	6.625 x 0.718
Interconnecting pipe length, ft.	
Hot leg	277
Cold leg	277
Interconnecting pipe material	
Hot leg	Carbon steel
Cold leg	Carbon steel

The thermal resistance between the tubes and air is calculated from the expression

$$R_{MA} = R_{Ref} * 3600 * (G_A/G_{ARef})^{-0.681}$$

$$* \left(\left(a_\mu' + b_\mu' * (T_A/T_{ARef})\right) / \left(a_\mu' + b_\mu' * (T_A/T_{ARef})\right)\right)$$

From reference data (see Reference 8)

$a_k' = KAAAK = 0.1777$

$b_k' = KAABK = 0.8223$

$a_\mu' = KAAAU = 0.2831$

$b_\mu' = KAABU = 0.7169$

$KAAR = R_{Ref} * 3600 = 0.00304 * 3600 = 10.9$

$$\boxed{KAAR = 10.9}$$

The metal resistance is calculated from the expression

$$R = T_{ODIA}/12/2/K_T * \ell n(T_{ODIA}/T_{IDIA})$$

with

$$K_T = \left(29.1 - 0.0059 * (T_M - 460)\right)/3600$$

$$= 0.8837 * 10^{-2} - 0.1183 * 10^{-2} (T_M/722)$$

defining $R = R_{Ref}/K_T'$

$$R_{Ref} = R(722) = (T_{ODIA}/12/2) * \ell n(T_{ODIA}/T_{IDIA})$$

$$/(0.8837 * 10^{-2} - .1183 * 10^{-2})$$

$$K'_T = R_{Ref}/R = R_{Ref} * K_T/\left(T_{ODIA}/12/2 * \ell n(T_{ODIA}/T_{IDIA})\right)$$

$$= K_T * 130.6$$

Then $R = 1.08/\left(1.1542 - 0.1542 * (T_M/722)\right)$

Define

$$\boxed{\begin{array}{c} KAMR = 1.08 \\ KAMAK = 1.1546 \\ KAMBK = 0.1546 \end{array}}$$

The heat transfer from the water to the tube metal is calculated based upon the Coburn type expression

$$R_w = 3600/h_w$$

where

$$h_w = K_w/D_{HW} * 0.023 * N_{Re}^{0.8} * N_{PR}^{1/3}$$

$$N_{Re} = \dot{m} * D_{HW}/A_{FW}/\mu_w$$

$$N_{PR} = C_{PW} * \mu_w/K_w$$

$$D_{HW} = T_{IDIA}/12$$

$$A_{FW} = \pi(T_{IDIA}/12)^2/4 * N_{TUBES}/N_{PASSES}$$

Then

$$R_w = 3600 * D_{HW}/0.023 * (D_{HW}/A_{FW})^{-0.8} * K_w/(\dot{m}/\mu_w)^{0.8}$$

$$/(C_{PW} * \mu_w/K_w)^{1/3}$$

Define $KAWRX = 3600 * D_{HW}/0.023 * (D_{HW}/A_{FW})^{-0.8}$

$$D_{HW} = (1.0 - 2 * 0.095)/12 = .0675$$

$A_{FW} = \pi(.81/12)^2/4 * 48/6 = .0286$

$$\boxed{\text{KAWRX} = 5316}$$

The effective heat transfer surface area KAAA and KAWA was calculated on the total pipe surface area.

$$\text{KAAA} = \pi * T_{ODIA}/12 * N_{TUBES} * L_{TUBES}$$

$$= \pi * 1/12 * 48 * 194 = 2438$$

$$\text{KAWA} = \text{KAAA} * \frac{T_{IDIA}}{T_{ODIA}} = 2438 * \frac{1/12 - 2 * .095/12}{1/12} = 1975.$$

$$\boxed{\begin{array}{l}\text{KAAA} = 2438. \\ \text{KAWA} = 1975.\end{array}}$$

The heat balance shown in Figure A.3.3-1 was obtained from an AUXTRAN run. A heat balance for CAAB using the above calculations did not agree. Assuming the disagreement lay in the calculation of the heat transfer resistance coefficient KAAR, it was varied to yield the same heat balance. A value of 29.52 was established.

The water volume, KAWVT, was evaluated from the expression

$$\text{KAWVT} = \pi * \left((1 - 2 * .095)/12\right)^2/4 * 194 * 48$$

$$\boxed{\text{KAWVT} = 33.33}$$

The metal thermal capacitance, KAMCT, was evaluated from the expression (which does not account for any fin capacitance)

$$K_{THERMAL\ CAP} = \pi(OD^2 - ID^2)/4 * L_{TUBE} * N_{TUBE} * \rho_{STEEL} * HEAT\ CAPACITY_{STEEL}$$

$$KAMCT = \pi * \left((1/12)^2 - \left((1-2*.095)/12\right)^2\right)/4 * 194 * 48 * 496 * .117$$

$$\boxed{KAMCT = 1039.6}$$

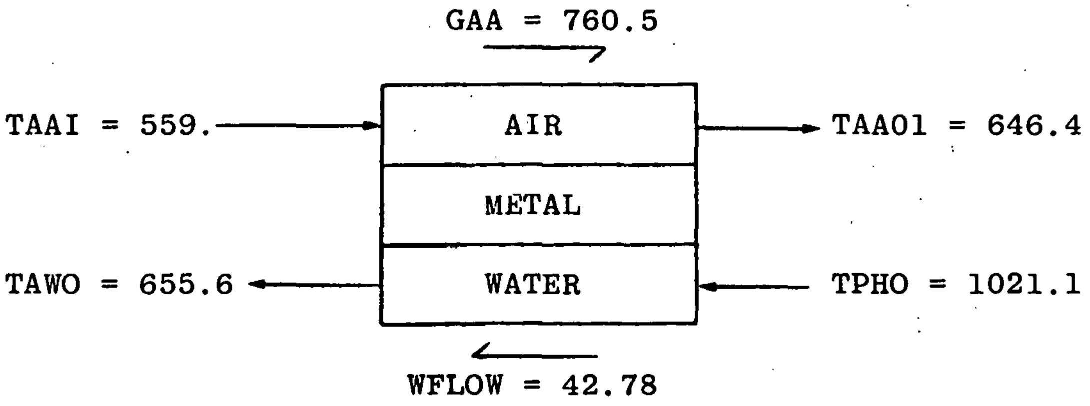

Figure A.3.3-1. CAAB Temperature Balance

Since no specific data is given for the CAAB configuration, it was assumed that the inlet and outlet pipe nodes had the following characteristics

KAWVT = 33.33

KAMCI = 100.

KAMCO = 100.

KAWVI = 3.

KAWVO = 3.

Summarizing

KAWRX = 5316 KAMR = 1.08 KAAR = 29.52
KAWWR = 42.78 KAAG = 761.1 KAWA = 1975.
KAAA = 2438 KAATR = 598. KAMTR = 679.
KAWTR = 760. KAAAU = .2831 KAABU = .7169
KAAAK = .1777 KAABK = .8223 KAMAK = 1.1546
KAMBK = .1546 KAMCT = 1039.6 KAWVT = 33.33
KAWN = 10. KAWWI = .5 KAAWI = .5
KAWVI = 3. KAWVO = 3. KAMCI = 100.
KAMCO = 100.

The eigenvalues of this component for this data were given in Table A.3.3-2.

A.3.4. Reactor

The reactor data was taken from Reference A-2. The data follows from the definitions given in the body of the report and are summarized here for completeness.

```
*   CONSTANTS --- CORE

CONST     KRENN =30834.
CONST     KRFV1 =5.54054E-4 , KRFV2 =2.45467E-4 , KRFV3 =2.45467E-4
CONST     KRFV4 =2.45467E-4 , KRFV5 =2.45467E-4 , KRFV6 =4.51359E-4
CONST     KRCV1 =2.00803E-4 , KRCV2 =8.89634E-5 , KRCV3 =8.89634E-5
CONST     KRCV4 =8.89634E-5 , KRCV5 =8.89634E-5 , KRCV6 =1.63584E-4
CONST     KREA1 =0.13599    , KREA2 =0.06025    , KREA3 =0.06025
CONST     KREA4 =0.06025    , KREA5 =0.06025    , KREA6 =0.11079
CONST     KREL1 =1.475      , KREL2 =0.817      , KREL3 =0.817
CONST     KREL4 =0.817      , KREL5 =0.817      , KREL6 =1.475
CONST     KREPF1=0.0271     , KREPF2=0.2021     , KREPF3=0.2710
CONST     KREPO =829.5      , KREPF =0.95       , KREGF =0.95
CONST     KREPF4=0.2710     , KREPF5=0.2021     , KREPF6=0.0271
CONST     KCCN  =3.         , KCAN  =2.bZ@ =0.2471
CONST    KHHVI6=344.
```

The eigenvalues of this component for this data are given in Table A.3.4-1.

Table A.3.3-2

List of Eigenvalues

CAAB

Real	Imaginary
-1.49	0.0
-1.37	± .258
-1.097	± .341
- .895	± .251
- .802	± .131
- .754	0.0
- .231	0.0
- .218	± .05
- .175	± .088
- .115	± .088
- .0712	± .054
- .0398	0.0
- .0289	0.0
- .0314	0.0

Table A.3.4-1

List of Eigenvalues

Core

Real	Imaginary
-6.04	± 1.20
-5.75	0.0
-5.38	± .011
-4.31	0.0
-1.33	0.0
-0.54	0.0
-0.47	0.0
-0.51	± 0.14
-0.42	0.0
-0.39	0.0
-0.38	0.0
-0.33	0.0

APPENDIX B

USER'S GUIDE TO CASY

CASY was programmed using the SYSL (SYstem Simulation Language) programming language. SYSL is a problem-oriented programming language designed to facilitate the digital simulation of continuous processes. SYSL has a basic set of functional blocks which together with FORTRAN statements allows the user to handle problems of considerable complexity.

Input and output is simplified by means of user-oriented control statements. These features enable the user to concentrate on the problem at hand rather than on the programming of the simulation.

SYSL has been documented in GA Report GA-D14439, and may be referred to if more detailed information is needed.

The purpose of this User Guide is not to teach SYSL programming; rather, it is to provide the basic information needed to use the program in a productive manner.

Evaluation of values for the constants necessary to run CASY are discussed in Appendix A. These values are entered into the program by defining the constants in the form (beginning in Column 1):

```
CONST KAWRX = 7.2 E4, KAMR = 1.08, KAAR = 10.4
```

These constants are defined in the program in lines about 130 to 250 (see listing in Volume II for example run).

The initial conditions of variables are selected by the user and defined in the form (beginning in Column 1):

```
INCON  ITPH1 = 700., ITPH2 = 700., ITPH3 = 700.
```

These initial conditions are defined in the program in lines about 275 to 500.

Certain PARAMs are generally more user-dependent. These parameters are collected into a user's control section of the program. These statements are defined in the program in lines about 532 to 600. An example of this section is given in Figure B-1. The various constants are defined in Tables 3.2-1 and 3.2-2 in the body of this report.

A unique feature developed for CASY was the capability of "stacking" runs. Each time CASY is run, the values of the state variables and certain parameters are written into File 12. By properly assigning a catalog file to be File 12, these final values are saved. These final values are read into the next run as the initial conditions, thus the runs are "stacked." This feature was accomplished using the SYSL statements shown in Figure B-2.

Various SYSL control parameters included on the TIMER card had the values given in Table B-1.

In general, Gear's widely spaced integration technique is used and is specified by the SYSL structure statement INTEG WSEIG.

Output from SYSL is in several forms. For CASY the print was controlled by the SYSL structure statement:

```
PRINT TPCO,THWO,TPHO,TAWO,THHO1,WFLOW,MARGIN,PPRG, ...
      PNSS,GCAA,GRETOT,GCCA,PRCD,POWFLO, ...
      OCAERR,PROPN,ICAN,DNCAA,NCAA, ...
      TRC1,TRF1,TREH1,TREHO1,THHO1, ...
      TRC2,TRF2,TREH2,TREHO2,THHO2, ...
      TRC3,TRF3,TREH3,TREHO3,THHO3, ...
      TRC4,TRF4,TREH4,TREHO4,THHO4, ...
      TRC5,TRF5,TREH5,TREHO5,THHO5, ...
      TRC6,TRF6,TREH6,TREHO6,THHO6, ...
      THHI6,THM6, ...
      TLPH,TUPH
*     QAAM1,QAAM2,QAAM3,QAAM4,QAAM5,QAAM6,QAAM7,QAAM8,QAAM9,QAAM10,...
*     QAAMT, ...
*     QAWM1,QAWM2,QAWM3,QAWM4,QAWM5,QAWM6,QAWM7,QAWM8,QAWM9,QAWM10,...
*     QAWMT, ...
*     QHHM1,QHHM2,QHHM3,QHHM4,QHHM5,QHHM6,QHHMT, ...
*     QHWM1,QHWM2,QHWM3,QHWM4,QHWM5,QHWM6,QHWMT
```

```

*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  USER CONTROL SECTION-- TIME INDEPENDENT PART *  *  *  *  *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


*     CACWS PUMP CONTROL PARAMETERS (TEMPORARY)
PARAM     KPLPB =  1.        , KPLRT = 1.
PARAM     KPLJO =3.28        , KPLJ1 =.0985       , KPLJ2 =1.344
PARAM     KPLCR =50.
PARAM     WPLR  =0.0         , SPL   =1.0         , WPLS  =5.17
CONST     KPL   =2.5         , KPLN  =5000.       , WPLSO =5.17

PARAM     NPS   =5500.       , KPSPB =10.         , KPSRT =10.
PARAM     KPSJO =.2481       , KPSJ1 =7.622E-4    , KPSJ2 =1.126E-3
PARAM     KPSCR =10.
PARAM     WPSR  =0.0         , SPS   =1.          , WPSS  =5.17
CONST     KPS   =.40         , KPSN  =5000.

PARAM     WPRI  =0.          , WPRO  =0.          , GPRI  =0.
PARAM     GPRO  =0.          , QPR   =0.          , TPRI  =530.
PARAM     KPRV  =400.

*      AIR BLAST HX PARAMETERS
PARAM     GAA   =0.001       , TAAI10=559.

*      TEMPERATURE SENSOR LAGS
PARAM     KTAU  =10.

*      CORE PARAMETERS
PARAM     GCAAS =0.001    , GCCA  =518.8
PARAM     KGPC  =1.          , PNSS  =1280.
PARAM     PRCD=1.00        , DUMMY =1.00


AFGEN POWER=0.0,1.00,30.0,1.00,30.5,0.152,33.6,0.107, ...
        36.6,0.092,45.8,0.070,61.,0.055,100.8,0.042, ...
        296.,0.029,500.0,0.010

AFGEN HEFLOW=0.0,518.8,30.0,518.8,37.8,71.0,45.6,25.33, ...
          53.4,14.0,61.2,4.33,500.0,2.0

AFGEN AHEFLO=0.0,0.0001,  60.0,0.0001,  61.2,6.60,62.6,8.00,...
                      68.8,15.70, 76.6,21.35, 84.1,25.40,92.1,27.70,...
                     100.1,29.1,108.1,29.1,115.6,30.30,117.3,30.36,...
             125.3,30.63,131.1,30.70,148.3,30.95,156.3,31.04,...
             187.3,31.35,210.3,31.60,241.3,31.98,272.3,32.36,...
            500.0,33.0

AFGEN TINLET=0.0,1074.0,30.0,1074.0,37.8,1064.0, ...
             45.6,1055.0,53.4,1048.0,61.2,832.0,500.,1074.0

*  *  *  CIRC SPEED CONTROL TEMP PARAMETERS
PARAM     KCARG =500.         , KCAPBN= 10.        , KCART =1.

*  *  *  SCAV IS SWITCH TO OPEN AUXILIARY HELIUM VALVE.
*  *  *  SCAV=0.0 IMPLIES THAT THE VALVE IS CLOSED AND
*  *  *           HELIUM TEMPERATURE TO CAHE IS FIXED AT
*  *  *           TLPHO.
*  *  *  SCAV=1.0 IMPLIES THAT THE VALVE IS OPEN AND HELIUM
*  *  *           TEMPERATURE TO CAHE IS SET TO TLPH WHICH
*  *  *           IS A VARIABLE.
*  *  *  SCAV NOT USED AT PRESENT

PARAM     SCAV  =0.0         , TLPHO =1060.

PARAM     TSCRAM=30.          , THWOSS=1085.       , THWOS =1060.

DYNAMIC


NOSORT


*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*  *  TIME DEPENDENT INPUT SECTION                               *  *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *


      GCCA=AFGEN(HEFLOW,TIME)
      IF(TIME.GT.60.0)GCCA=.00001
      PRCD=AFGEN(POWER,TIME)
      DUMMY=PRCD
      GCAAS=AFGEN(AHEFLO,TIME)
      IF(TIME.GE.TSCRAM)WFLOW=42.78
      IF(TIME.GE.TSCRAM)GAA=760.5
      IF (TIME.GT.TSCRAM+30.0)THWOS=THWOSS

```

Figure B-1. User Control Section of CASY

```
/      WRITE(12,73  )TPH1,TPH2,TPH3,TPH4,TPH5,TPH6,TPH7,TPH8,TPH9,
/     1TPH10,
/     1TPHM
/73    FORMAT('*  *  *  HOT LINE INITIAL CONDITIONS',/,
/     1'INCON     ITPH1 =',E11.6,', ITPH2 =',E11.6,', ITPH3 =',E11.6,/,
/     1'INCON     ITPH4 =',E11.6,', ITPH5 =',E11.6,', ITPH6 =',E11.6,/,
/     1'INCON     ITPH7 =',E11.6,', ITPH8 =',E11.6,', ITPH9 =',E11.6,/,
/     1'INCON     ITPH10=',E11.6,/,
/     1'INCON     ITPHM =',E11.6,//)



/      WRITE(12,72  )TPC1,TPC2,TPC3,TPC4,TPC5,TPC6,TPC7,TPC8,TPC9,
/     1TPC10,
/     1TPCOM
/72    FORMAT('*  *  *  COLD LINE INITIAL CONDITIONS',/,
/     1'INCON     ITPC1 =',E11.6,', ITPC2 =',E11.6,', ITPC3 =',E11.6,/,
/     1'INCON     ITPC4 =',E11.6,', ITPC5 =',E11.6,', ITPC6 =',E11.6,/,
/     1'INCON     ITPC7 =',E11.6,', ITPC8 =',E11.6,', ITPC9 =',E11.6,/,
/     1'INCON     ITPC10=',E11.6,/,
/     1'INCON     ITPCOM=',E11.6,//)


/      WRITE(12,70  )TAWO,TAWI,TAW1,TAW2,TAW3,TAW4,TAW5,TAW6,TAW7,
/     1TAW8,TAW9,TAW10,TAM1,TAM2,TAM3,TAM4,TAM5,TAM6,TAM7,TAM8,
/     1TAM9,TAM10,TAA1,TAA2,TAA3,TAA4,TAA5,TAA6,TAA7,TAA8,TAA9,TAA10
/70    FORMAT('*  *  *  AIR BLAST HX INITIAL CONDITIONS',/,
/     1'INCON     ITAWO =',E11.6,', ITAWI =',E11.6,', ITAW1 =',E11.6,/,
/     1'INCON     ITAW2 =',E11.6,', ITAW3 =',E11.6,', ITAW4 =',E11.6,/,
/     1'INCON     ITAW5 =',E11.6,', ITAW6 =',E11.6,', ITAW7 =',E11.6,/,
/     1'INCON     ITAW8 =',E11.6,', ITAW9 =',E11.6,', ITAW10=',E11.6,/,
/     1'INCON     ITAM1 =',E11.6,', ITAM2 =',E11.6,', ITAM3 =',E11.6,/,
/     1'INCON     ITAM4 =',E11.6,', ITAM5 =',E11.6,', ITAM6 =',E11.6,/,
/     1'INCON     ITAM7 =',E11.6,', ITAM8 =',E11.6,', ITAM9 =',E11.6,/,
/     1'INCON     ITAM10=',E11.6,/,
/     1'PARAM     TAA1  =',E11.6,', TAA2  =',E11.6,', TAA3  =',E11.6,/,
/     1'PARAM     TAA4  =',E11.6,', TAA5  =',E11.6,', TAA6  =',E11.6,/,
/     1'PARAM     TAA7  =',E11.6,', TAA8  =',E11.6,', TAA9  =',E11.6,/,
/     1'PARAM     TAA10 =',E11.6,//)


/      WRITE(12,71  )THWI,THW1,THW2,THW3,THW4,THW5,THW6,THM1,THM2,
/     1THM3,THM4,THM5,THM6,THWO,THMIO,THH1,THH2,THH3,THH4,THH5,THH6
/71    FORMAT('*  *  *  CAHE INITIAL CONDITIONS',/,
/     1'INCON     ITHWI =',E11.6,', ITHW1 =',E11.6,', ITHW2 =',E11.6,/,
/     1'INCON     ITHW3 =',E11.6,', ITHW4 =',E11.6,', ITHW5 =',E11.6,/,
/     1'INCON     ITHW6 =',E11.6,', ITHM1 =',E11.6,', ITHM2 =',E11.6,/,
/     1'INCON     ITHM3 =',E11.6,', ITHM4 =',E11.6,', ITHM5 =',E11.6,/,
/     1'INCON     ITHM6 =',E11.6,', ITHWO =',E11.6,', ITHMIO=',E11.6,/,
/     1'PARAM     THH1  =',E11.6,', THH2  =',E11.6,', THH3  =',E11.6,/,
/     1'PARAM     THH4  =',E11.6,', THH5  =',E11.6,', THH6  =',E11.6,//)


/      WRITE(12,74)VPRW,TPRW,PPRG,PLOAD,NPL,INT,APS,IPSIT,WFLOW
/ 74   FORMAT('*  *  *  PUMP AND PROCESS-FLOW INITIAL CONDITIONS',/,
/     1'INCON     IVPRW =',E11.6,', ITPRW =',E11.6,', IPPRG =',E11.6,/,
/     1'INCON     IPLOAD=',E11.6,', INPL  =',E11.6,', IINT  =',E11.6,/,
/     1'INCON     IAPS  =',E11.6,', IIPSIT=',E11.6,/,
/     1'PARAM     WFLOW =',E11.6,//)


/93    FORMAT('*  *  *  CORE INITIAL CONDITIONS',/,
/     1'INCON     ITRF1 =',E11.6,', ITRF2 =',E11.6,', ITRF3 =',E11.6,/,
/     1'INCON     ITRF4 =',E11.6,', ITRF5 =',E11.6,', ITRF6 =',E11.6,/,
/     1'INCON     ITRC1 =',E11.6,', ITRC2 =',E11.6,', ITRC3 =',E11.6,/,
/     1'INCON     ITRC4 =',E11.6,', ITRC5 =',E11.6,', ITRC6 =',E11.6,/,
/     1'INCON     ITUPH =',E11.6,', ITLPH =',E11.6,/,
/     1'INCON     ITCAHA=',E11.6,', IICAN =',E11.6,', INCAA =',E11.6,//,
/     1'PARAM     TREH1 =',E11.6,', TREH2 =',E11.6,', TREH3 =',E11.6,/,
/     1'PARAM     TREH4 =',E11.6,', TREH5 =',E11.6,', TREH6 =',E11.6,//)
/      WRITE(12,93) TRF1,TRF2,TRF3,TRF4,TRF5,TRF6,TRC1,TRC2,TRC3,
/     1TRC4,TRC5,TRC6,TUPH,TLPH,TCAHOA,ICAN,NCAA,TREH1,TREH2,TREH3,
/     1TREH4,TREH5,TREH6
/      WRITE(12,95)TIME,DUMMY
/ 95    FORMAT('*  *  *  TIME AT END OF RUN=',E11.6,' , DUMMY VARIABLE='
/     1,E11.6//)
```

Figure B-2. Listing of States Saved on File 12

Table B-1. SYSL Control Parameters

PARAMETER	VALUE	DEFINITION
DELT	0.5	Integration step size
FINTIM	1000.	Final Time (when simulation is halted)
DELPR	20.	Time between print intervals
DELGR	5.0	Time between plot values
TWARN	25.	Actual CPU time left before maximum run time is exceeded

Plots can be obtained from SYSL and can be either line printer plots, 4020 plots or CALCOMP plots. Variables to be plotted by either means must be defined in the PREPAR SYSL structure statement. An example calling for printer plots is shown:

```
PREPAR TPCO,THWO,TPHO,TAWO,THHO1,WFLOW,MARGIN,PPRG, ...
      TRC1,TRF1,TREH1,TREHO1,THHO1, ...
      PNSS,GCAA,GCCA,PRCD,POWFLO, ...
      OCAERR,PROPN,ICAN,DNCAA,NCAA, ...
*     TRC2,TRF2,TREH2,TREHO2,THHO2, ...
*     TRC3,TRF3,TREH3,TREHO3,THHO3, ...
*     TRC4,TRF4,TREH4,TREHO4,THHO4, ...
*     TRC5,TRF5,TREH5,TREHO5,THHO5, ...
*     TRC6,TRF6,TREH6,TREHO6,THHO6, ...
       THHO2,THHO3,THHO4,THHO5,THHO6, ...
      TLPH,TUPH
*     QAAM1,QAAM2,QAAM3,QAAM4,QAAM5,QAAM6,QAAM7,QAAM8,QAAM9,QAAM10,...
*     QAAMT, ...
*     QAWM1,QAWM2,QAWM3,QAWM4,QAWM5,QAWM6,QAWM7,QAWM8,QAWM9,QAWM10,...
*     QAWMT, ...
*     QHHM1,QHHM2,QHHM3,QHHM4,QHHM5,QHHM6,QHHMT, ...
*     QHWM1,QHWM2,QHWM3,QHWM4,QHWM5,QHWM6,QHWMT
GRAPH TIME,TPCO,THWO,TPHO,...
        TAWO,THHO1
GRAPH TIME,WFLOW,PPRG
GRAPH TIME,MARGIN
GRAPH TIME,TLPH,TUPH
*GRAPH TIME,THHO1,THHO2,THHO3,THHO4,THHO5,THHO6
*GRAPH TIME,TREHO1,TREHO2,TREHO3,TREHO4,TREHO5,TREHO6
*GRAPH TIME,TRC1,TRC2,TRC3,TRC4,TRC5,TRC6
*GRAPH TIME,TRF1,TRF2,TRF3,TRF4,TRF5,TRF6
*GRAPH TIME,TREH1,TREH2,TREH3,TREH4,TREH5,TREH6
GRAPH TIME,OCAERR,PROPN,ICAN,NCAA
GRAPH TIME,GCAA,GCCA,PNSS,PRCD,POWFLO
```

CASY was developed using the UNIVAC 1110 time share editor code as available at GA. Some features utilized to run CASY will be discussed. CASY is run in the batch mode and is initiated from the demand terminal using the @STRUN processor. The form of this job control instruction is (beginning in Column 1) @STRUN,RM RUN*CASY.,XX,6,200 where M is the priority of the run; XX is the user's box number; 6 is the maximum number of SUP minutes that the run will be allowed to execute; and 200 is the maximum number of pages that the run will be allowed to print. RUN*CASY. is a catalog file that contains the job control instructions for the batch run.

The data file GCFR*CASY. contains CASY coded in SYSL. It is the input data to SYSLTRAN. A listing of GCFR*CASY is given in Section 8.1 of the report. The data file MAP*CASY. listed as the second record in GCFR*CASY. contains additional job control instructions.

The file IC*CASY will contain the final values of variable written on File 12 in CASY if the job instruction @USE 12.,IC*CASY. is given. The file SIMOUT*CASY will contain the output of SYSL if the job instruction @USE 6., SIMOUT*CASY. is included before the @XQT instruction. If the output from SYSL is written on SIMOUT*CASY, it can be interrogated from the demand terminal by using the EDITOR feature. If the output is desired, it can be directed to a line printer using the demand terminal instruction @SYM,U SIMOUT*CASY.

In summary, a run is initiated when the user is satisfied that input data to the code is correct for the case being run and that the job control instruction files are correct for what the user wants to do with the output. The run is then initiated with the instruction from the demand terminal @STRUN,M RUN*CASY.,21,6,200. If the user wants to initiate job using cards, he simply duplicates the job control instructions in RUN*CASY, adds the job card to the front and submits the deck at the submittal window.

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