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A Computerized Process Control System for the ORR-PSF Irradiation Experiment Part 1: Overall View of the Control System

S. H. Merriman

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PART 1: OVERALL VIEW OF THE CONTROL SYSTEM

S. H. Merriman

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ABSTRACT

A dedicated process control computer has been implemented for regulating the metallurgical Pressure Vessel Wall Benchmark Facility (PSF) at the Oak Ridge Research Reactor. The purpose of the PSF is to provide reliable standards and methods by which to judge the radiation damage to reactor pressure vessel specimens. Benchmark data gathered from the PSF will be used to improve and standardize procedures for assessing the remaining safe operating lifetime of aging reactors.

The computer system controls the pressure vessel specimen environment in the presence of gamma heating so that in-vessel conditions are simulated. Instrumented irradiation capsules, in which the specimens are housed, contain temperature sensors and electrical heaters. The computer system regulates the amount of power delivered to the electrical heaters based on the temperature distribution within the capsules. Time-temperature profiles are recorded along with reactor conditions for later correlation with specimen metallurgical changes.

INTRODUCTION

In response to a need for accurate and universal methods of measuring radiation damage to in-service light water reactor pressure vessels, the U.S. Nuclear Regulatory Commission established the LWR-PVS Dosimetry Improvement Program.^[1] Aging light water reactor pressure vessels are accumulating significant neutron fluence exposures, with resulting changes in their steel embrittlement characteristics. Recognizing that effective, standardized procedures are needed to periodically evaluate the metallurgical condition of these pressure vessels, the NRC initiated a research program to formulate such procedures. The primary objective of the program is an improved accuracy in the prediction of the remaining safe operating lifetime for light water reactor pressure vessels currently in use.

The Metallurgical Pressure Vessel Wall Benchmark Facility (PSF) has been installed at the Oak Ridge Research Reactor to provide data to be used in establishing dosimetry and damage analysis techniques. At this facility, reactor pressure vessel specimens will be irradiated in a controlled surveillance environment for a two-year period. Following the experiment, radiation damage to the specimens will be assessed and changes in material properties will be correlated with the characteristics of the neutron radiation field. Throughout the experiment, specimen environment is to be controlled and recorded by a dedicated process control computer system.

A PDP-11T03 with a modified IP300 Input/Output Subsystem was selected to perform the process data acquisition and control functions. The RT11 foreground/background operating system was used and applications programs were written in FORTRAN IV and MACRO-11.

SECTION 1. THE ORR-PSF EXPERIMENT

SECTION 1.1 EXPERIMENT APPARATUS

To provide an environment for the reactor vessel steel specimens which would closely approximate the in-vessel attributes of light water reactors (LWRs), two instrumented irradiation capsules (IIC) were fabricated.

The larger capsule, the simulated pressure vessel capsule (SPVC), is shown in Figure 1. This capsule simulates pressure vessel conditions of a typical LWR and contains three sample sets of metallurgical specimens. Each of the three specimen assemblies is bounded front and back by heater plates containing electrical heaters. The specimen assembly/heater plate units are then separated with coolant assemblies. The coolant plates contain 24 coolant tubes and, along with the reactor pool water in contact with the capsule exterior surfaces, provide heat sinks for heat generated both from the electrical heaters and from the absorption of gamma energy in the IIC. The layered nature of the assembly was a design effort to maintain thermal isolation of the three specimen assemblies since thermally decoupled regions simplify the computations for controlling specimen environment. The three regions correspond to pressure vessel wall thickness and simulate vessel surface (0T), one-quarter thickness ($1/4 T$), and one-half thickness ($1/2 T$). The entire metallurgical specimen matrix plus instrumentation is encapsulated in a carbon steel box. The void spaces within the capsule contain a cover gas mixture of helium and neon. The helium/neon proportions were experimentally determined so that heater power demand needed to maintain steady-state capsule temperatures is minimized. Each specimen assembly is equipped with 20 embedded Chromel-Alumel thermocouples for monitoring temperature distribution.

The second capsule simulates a surveillance capsule of the type that exists in some operating LWRs. A single sample set of pressure vessel specimens bounded by heater plates makes up the simulated surveillance capsule (SSC). Heat transfer from the SSC is accomplished solely by natural convection to the reactor pool water from the capsule surfaces. Numbers and distributions

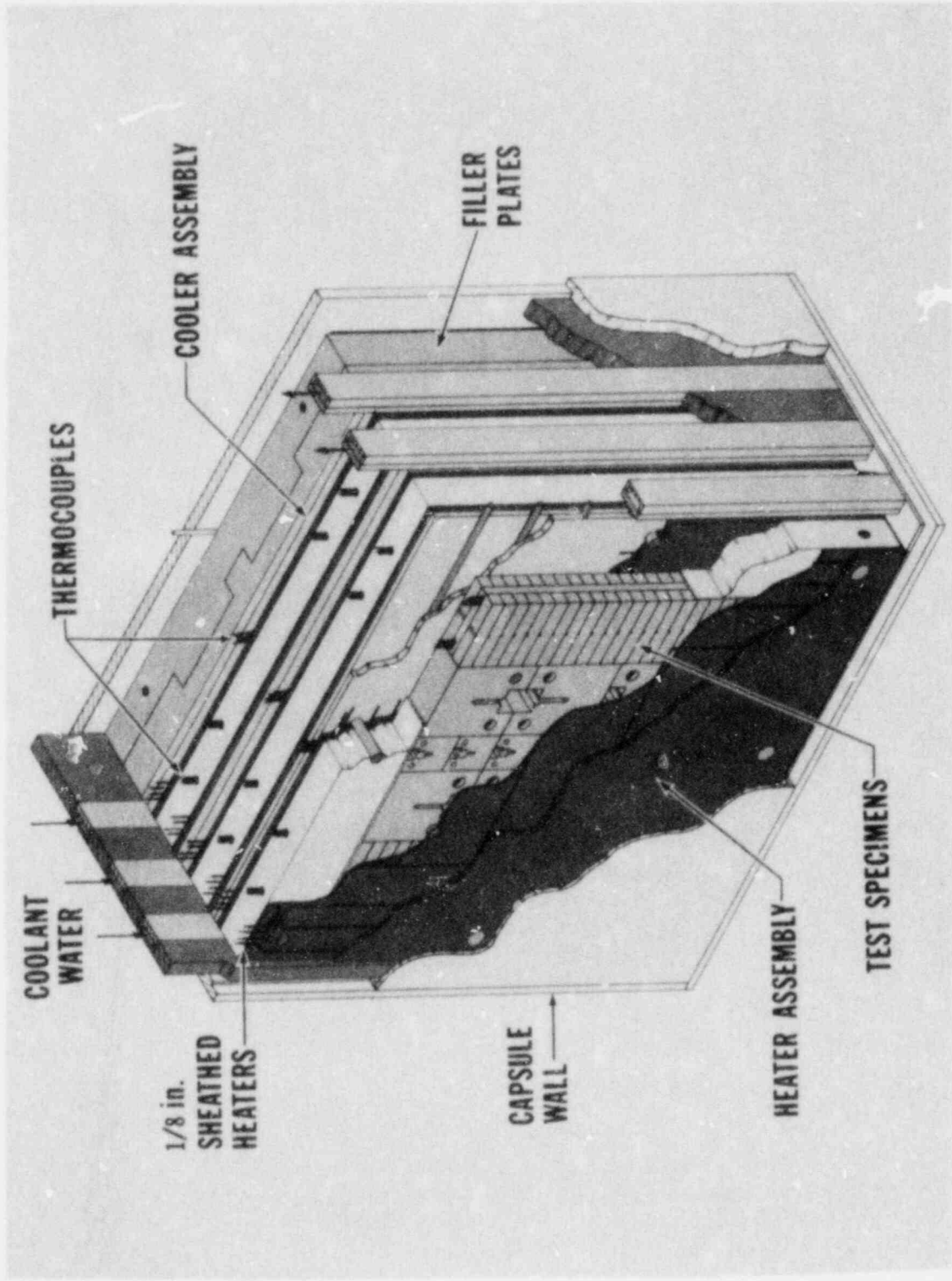


Figure 1
SIMULATED PRESSURE VESSEL CAPSULE (SPVC)

of thermocouples and heaters are the same as for one of the SPVC regions. Location of thermocouples and heaters was in accordance with required equilibrium temperatures in the presence of predicted gamma radiation.^[2]

The irradiation capsules have been installed in the ORR poolside facility as shown in Figure 2. The SSC is positioned nearest the reactor core behind a thermal shield and is followed by the SPVC. The entire experiment apparatus is retractable from the poolside facility to a position outside the high neutron flux region.

SECTION 1.2. EXPERIMENT PROCEDURES AND GOALS

For a two-year period, the IIC reactor test specimens are to be irradiated at a temperature of $288^{\circ}\text{C} \pm 10^{\circ}\text{C}$. Specimen environment will be regulated by the process control system (PCS) discussed in this report. The PCS senses and records specimen neutron spectral and temperature environment and makes feedback adjustments in the temperature environment. Capsule spectral environmental data stored by the PCS will be correlated at the end of the experiment with specimen embrittlement changes. The expected benefits from this project are better standards for determining reactor vessel radiation damage and a means of ascertaining pressure vessel damage by extrapolating from damage done to LWR surveillance capsules.

SECTION 1.3. ORR-PSF PROCESS CONTROL EQUIPMENT

Gamma radiation provides most of the heat to the capsules with the electrical heaters supplying the means of maintaining the required heat balance. The power to the heaters is regulated by variation of the voltage using a constant amperage. Voltage is controlled by variac setting and was experimentally determined through a series of pre-experiment tests (see Section 1.4). The total power delivered to the heaters is controlled by zero-crossing solid-state relays which are computer-driven. Each variac is associated with a pair of heaters -- one located on the front face and one in a corresponding position on the back face of the specimen assemblies. Each of the four specimen regions (OT, 1/4 T, 1/2 T, and SSC) has ten variacs for controlling heater power demand.

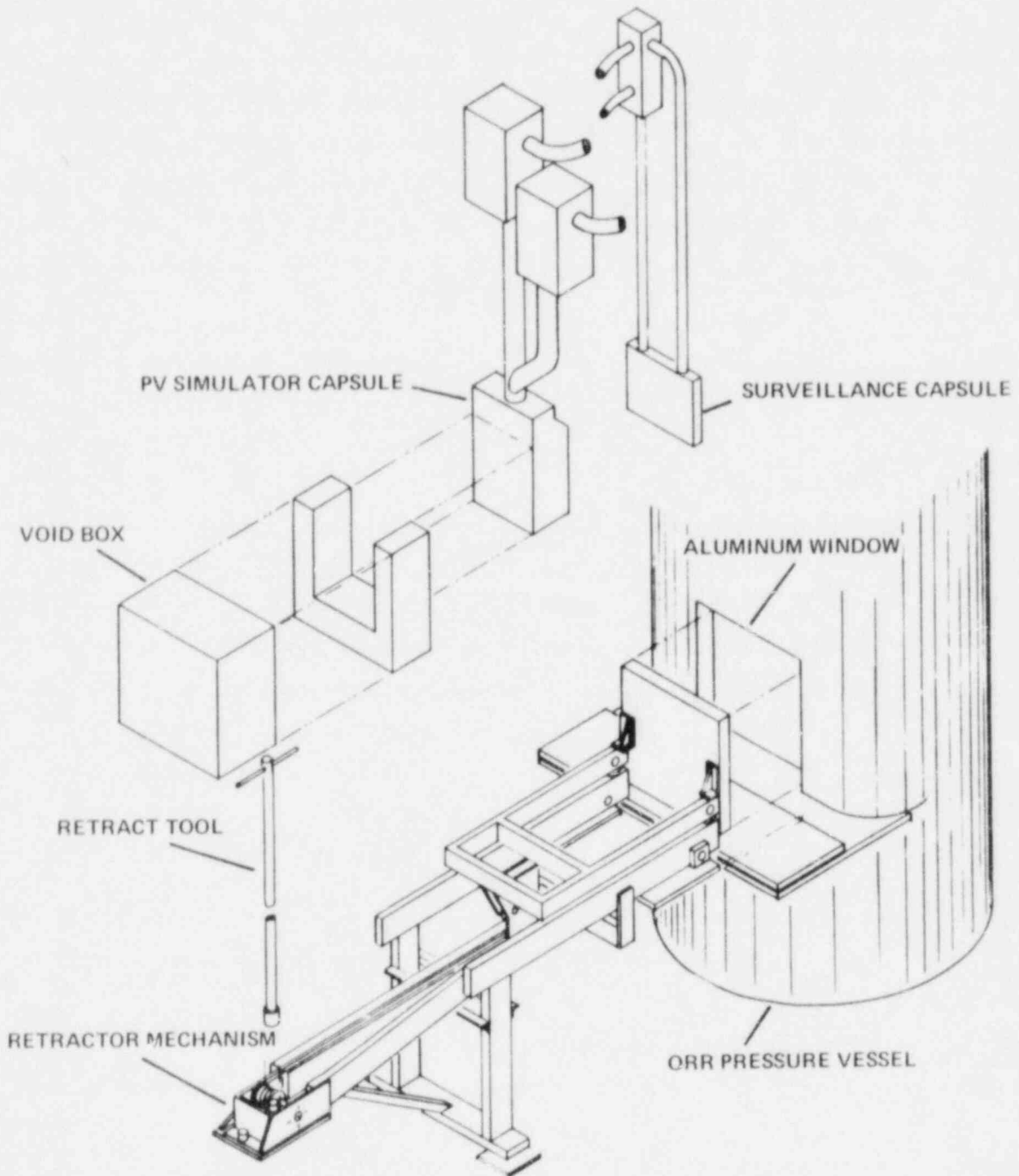


Figure 2
METALLURGICAL PRESSURE VESSEL WALL BENCHMARK FACILITY (PSF)

The solid-state relays are fired by digital single-shot output devices for discrete periods to activate the heaters. Output timing intervals are device-selectable and range from 100 milliseconds to 5 seconds. An output pulse length of 200 milliseconds was found to be optimum for minimizing heater stress and also for accommodating concurrent real-time computing functions. Assuming a 100% heater duty cycle, the process control cycle period is then 20 seconds. Heater duty cycles vary with computed heater power demands and are allowed to range between 50 and 100%. A 50% minimum is enforced to comply with heater specifications which limit heater off-time to no more than 0.5 second. Longer periods are expected to cause heater thermal cycling and possible early heater failure.

Manual or computer control of each variac is switch selectable. Manual control results in heater duty cycles of 100%. In this case, the total power delivered to a heater can be decreased only by changing the variac setpoint to reduce the voltage. This obviously results in a loss of system control ease and flexibility unless the manual mode variac settings are already known. Most noticeably, it does not allow for quick addition of electrical heating in the case of reactor power level sag and resulting gamma heating decreases. Manual control variac settings have been experimentally determined, but it has been found that reactor core configuration changes or even flux variations as a function of fuel cycle time cause these setpoints to vary somewhat. For this reason, manual control of the PSF experiment will be used sparingly. Under computer control, variac setpoints are predetermined to meet heater power demands with a nominal computed heater duty cycle of about 80%. This means that the heaters are being fired only 80% of the time to maintain the desired capsule temperatures under normal reactor operating conditions (i.e., a power level of 30 megawatts). These operating parameters allow contingency for maintaining the capsule heat balance at equilibrium even in the event of thermal perturbations caused by gamma heat variations.

A watt transducer was incorporated in the PCS instrumentation for the purpose of monitoring total heater power delivered to the capsules from all heater plates at any time. Watt transducer analog data are available to the PCS computer but are presently not used in the process control. A potential use of the watt transducer is in calibration tests of the individual variac setpoints.

Each of the four specimen regions has 22 temperature sensors. Two of the sensors interface to mechanical recorders for use in manual control of the experiment. The remaining thermocouples are monitored by the PCS computer. Thermocouple inputs are low level, differential signals. Each thermocouple input is routed to one of two isothermal boxes where it is corrected by a reference temperature. The 80 thermocouples are sampled every 40 seconds to provide system feedback for determining heater power demand changes. A sample set of four elements is taken for each thermocouple and anomalous values are eliminated. The quality of the process input signals in terms of electrical noise imposed on them is variable because of the long distances the signals must travel from the reactor pool and other environmental factors. By using software signal conditioning techniques and relying on the slow system dynamic response time, however, adequate input signal accuracy ($\pm 1.5^{\circ}\text{C}$) has been achieved. The overall dynamics of the process are such that settling errors can be minimized by incorporating delays between analog conversions.

The operating power level of the reactor is sampled every 40 seconds. When the experiment is at steady state, reactor power data are recorded every hour and are used in correlating neutron flux - spectral parameters with the capsule conditions during the experiment. Determinations of cumulative specimen radiation exposure time are made to help schedule experiment events such as SSC replacement.

Figure 3 illustrates the interaction of PCS equipment components with the ORR-PSF.

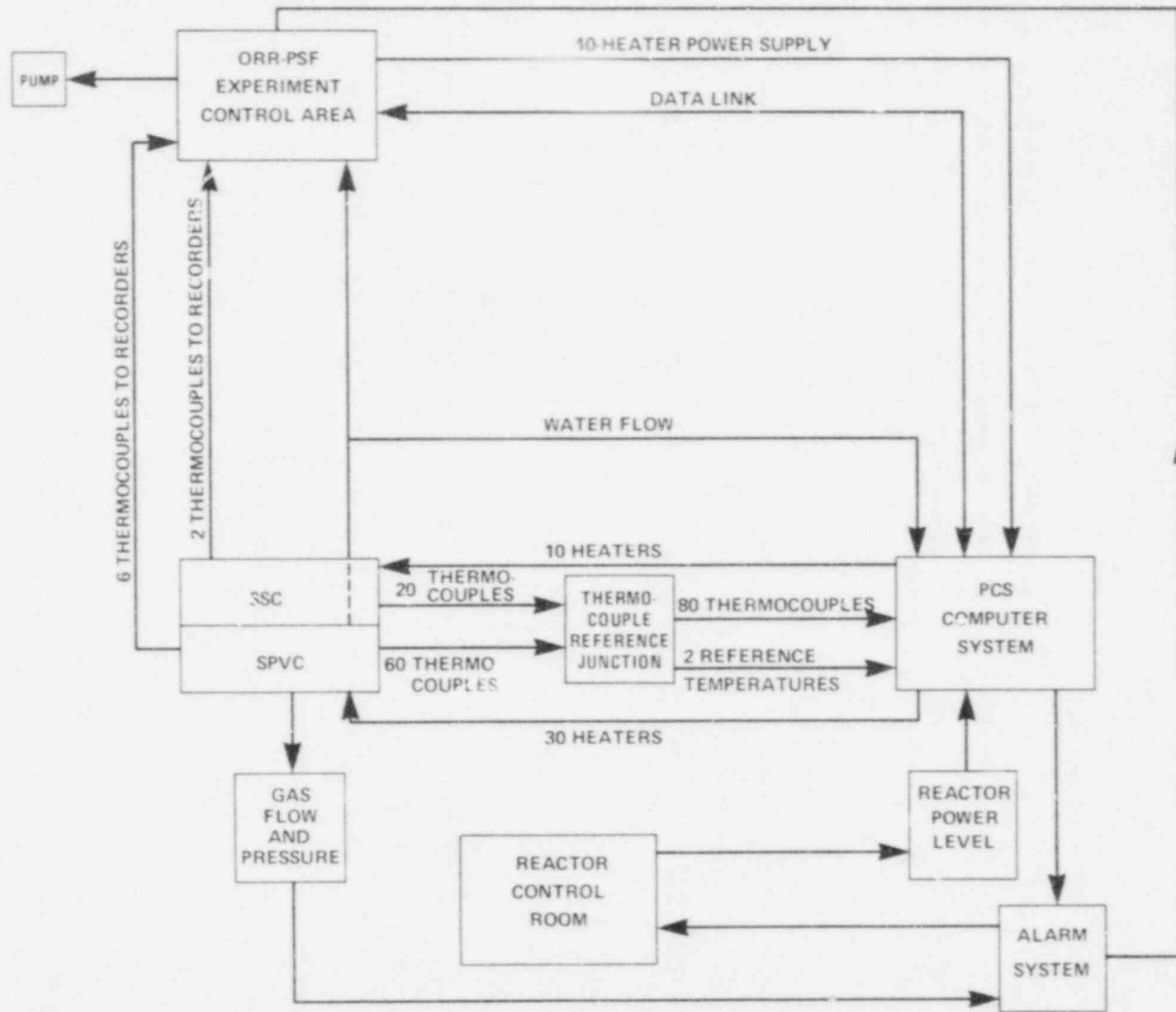


Figure 3
ORR-PSF PROCESS CONTROL SYSTEM BLOCK DIAGRAM

SECTION 1.4. PRE-EXPERIMENT DETERMINATIONS

Prior to experiment start-up, tests were made to determine system parameters and to evaluate PCS equipment capabilities given the system boundary conditions. The system parameters of most interest, because of their necessity in formulating a process control algorithm, were the process response times and capsule thermodynamic properties. A series of system characterization experiments was carried out to produce data for modeling a process control algorithm. A full discussion of the mathematical model, model testing under simulated and real-time process conditions, and finally its implementation in the PCS is presented by L. F. Miller.^[3] The characterization experiments will be discussed below.

Prior to capsule characterization tests, software was developed for handling communications between the PDP-11T03 and the Input/Output Subsystem. Also, data acquisition routines for monitoring capsule temperature distribution and heater firing routines were written to be used in initial computer and related PCS equipment testing.

Initial equipment checkout tested the integrity of the process instrumentation in its entirety from capsule to computer by simulating system input signals of known magnitude at various nodes in the system and verifying the computed results. Likewise, computer output signals were tested by checking the process for proper response. Following simulated process monitoring and control, real-time testing was done to verify that heater zones and thermocouples were coupled according to design criteria. Finally, tests were made to determine the shortest period during which minimum data acquisition and equipment control tasks could be performed. This time was found to be 200 milliseconds and was defined as the basic control loop period. Worst case heater duty cycles (50%) were used.

The intent of the capsule characterization tests was to subject the capsules to various combinations of gamma and electrical heating and to record temperature change rates as a function of heater power changes. Response time constants and heat transfer coefficients in individual

heater zones, as well as conductive heat transfer characteristics in overlapping zones, were to be determined. Because of time constraints, the characterization data were obtained with electrical heating only. Later tests of the model under actual process conditions, however, showed it to be valid for controlling capsule temperature in the presence of gamma heat.

Twenty tests were carried out, ten for each capsule. Since the three specimen regions of the SPVC were assumed to be thermally decoupled, simultaneous characterization data were accumulated for them. The test procedure was to select a variac position, compute the associated power, and initiate heater firing at a 100% duty cycle. Temperature distribution was recorded every 40 seconds while the capsule reached and maintained steady state. Heater firing was stopped and cooldown data were recorded. This was repeated for each variac in the SSC (variacs #1-10) and for the ten groups of variacs (variacs #11, 21, 31, etc.) in the SPVC. Miller's analysis of these data showed that the system is essentially linear under steady-state conditions and that a two-minute data sampling interval adequately reflects system response.^[3]

After a process control model was developed from capsule characteristic analysis, it was incorporated into the PCS software which performs data surveillance and equipment control. Extensive program structuring and testing had to be done to accommodate all real-time functions plus control algorithm computations so that both process and computer system constraints were observed. Experimentation showed that a period of at least 40 seconds was needed to gather, display, and record capsule temperature distribution; carry out error detection, alarm, and corrective measures; compute new heater power demands based on current temperature distribution; and initiate new heater firing sequences to achieve the computed demand changes. As pointed out in the previous section, one complete control cycle (i.e., firing all 40 SSRs in continuous 200-millisecond bursts to attain 100% heater power output) is 20 seconds. Therefore, the heater firing sequence is initiated twice for each computed heater demand adjustment. This introduces no discernible control law error

since best measurements show the steady-state system response period to be about 2 minutes. For computing purposes, then, the system is assumed to be a discrete-time model having 200 time frames of 200 milliseconds each. Fixed real-time computer functions occur within each discrete time interval. Scheduling of real-time activities will be discussed in Section 3.3.1.

Finally, experiments were made to verify the effectiveness of the control algorithm in modifying power demands and to prove that the digital control of the heaters was properly designed to effect needed power changes. During these tests, both capsules were heated to steady-state temperatures of 75°C and 150°C in the retracted position outside the gamma radiation field. The experiment apparatus was then positioned at the poolside facility window and the temperature distribution was determined with gamma heat alone. It was found that the total heat produced in the specimen regions by gamma radiation alone was higher than predicted by the design analysis but was sufficiently under that needed to maintain a target temperature of 288°C to allow control of the heat balance with the PCS. Final testing included allowing the capsules to approach target as the reactor achieved normal power level with heater power demand under PCS control and then maintaining them at target for various test periods.

SECTION 1.5. EXPERIMENT CONTROL CONCEPTS

Early work in defining the ORR-PSF as a linear, time-invariant system^[4] laid groundwork for the development of the discrete-time control algorithm used by the PCS. It has been determined that the system is not linear in dynamic stages but that in steady-state operation, temperature response to electrical heating is essentially linear.^[3] This, along with the fact that the process data sampling interval is considerably less than the system time constants, allows effective digital heater control. The control scheme is closed loop in nature.

SECTION 2. PCS COMPUTER EQUIPMENT

SECTION 2.1. STANDARD EQUIPMENT

As was stated earlier, a PDP-11T03 with a modified IP300 I/O Subsystem was purchased to control the ORR-PSF experiment. The computer includes the following components:

- LSI-11 CPU
- 32K words MOS RAM (MSV11-CD and MSV11-DC)
- KEV11 EIS floating point processor
- REV11-A refresh/bootstrap/terminator unit
- RKV11-DA disk controller
- RK05J-AA 2.5M-byte removable cartridge disk
- RK05F-AA 5M-byte fixed cartridge disk
- DLV11-F EIA serial line interface
- DLV11-J EIA 4-channel serial line interface
- LA36 DECwriter II with EIA interface
- KWV11-A programmable clock
- Tektronix 4010 terminal with EIA interface
- Tektronix 4631 hard copy unit

SECTION 2.2. PROCESS CONTROL INPUT/OUTPUT EQUIPMENT

The IP300 I/O subsystem is an industrial-level unit housing a variety of input/output devices. The IP300 subsystem as marketed by DEC is a stand-alone system with its own built-in microcomputer. The configuration used in the ORR-PSF application has been modified so that the IP300 operates externally to the PDP-11T03 host computer and interfaces with the computer via a LSI-11 Bus. Communications between the host and IP300 are handled by a M7958 I/O Control Module. The IOCM performs data routing and control functions between the processor on the LSI-11 Bus and I/O modules on the IP300 data Bus as shown in Figure 4.

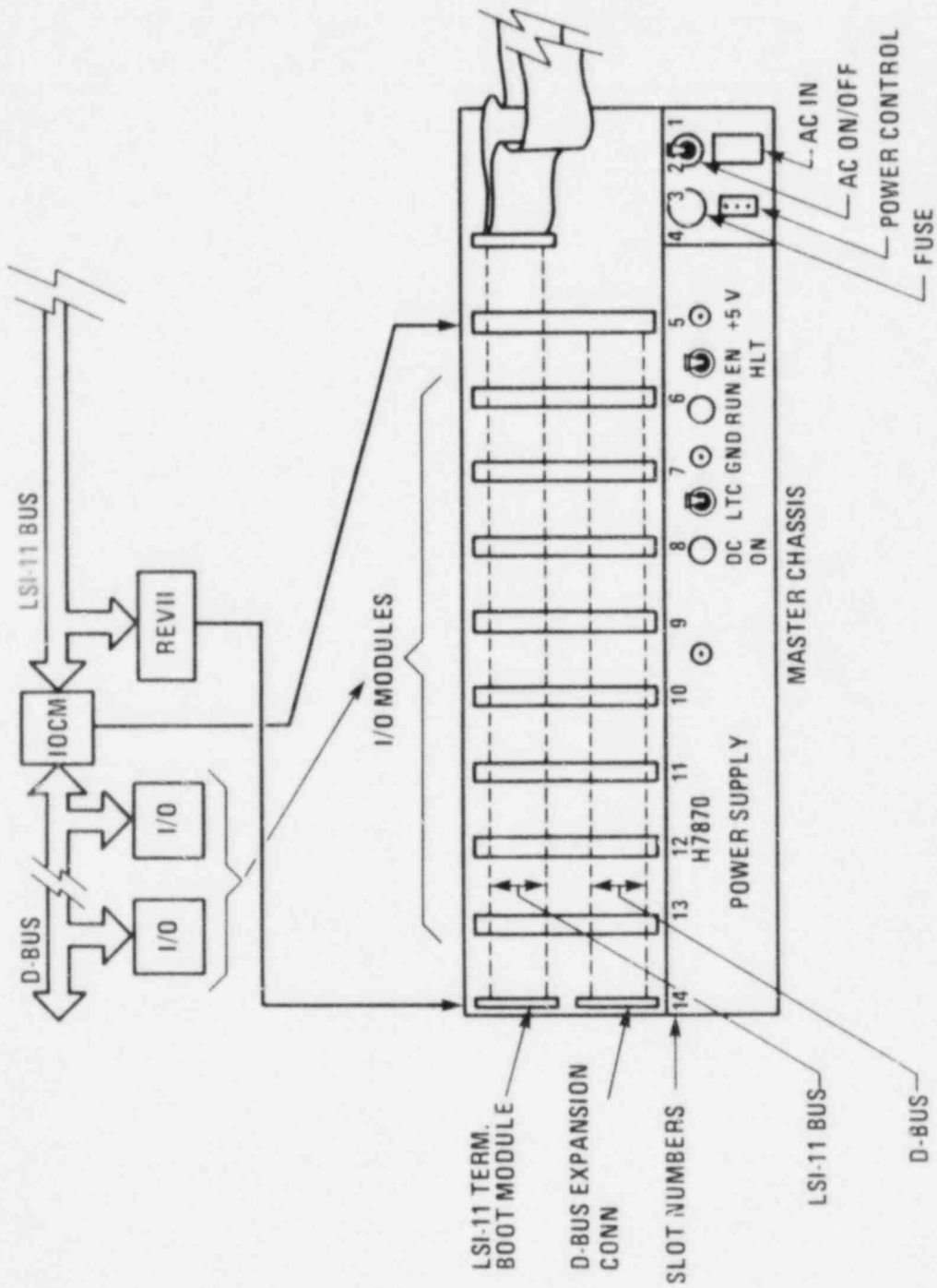


Figure 4
 MODIFIED IP300 I/O SUBSYSTEM. (H333-A CHASSIS)

SECTION 2.2.1. DATA BUS AND I/O MODULE ARRANGEMENT

The IOCM is interfaced to the individual I/O modules by a common data bus called the D-Bus. The D-Bus in each of two chassis in the subsystem will accommodate multiple I/O modules and is extended from one chassis to the other by a BC08R shielded cable. The first chassis (H333-A) has 14 slots, eight of which can be used for I/O modules. The first four slots in the H333-A normally hold the microcomputer modules (LSI-11, memory, disk controller, asynchronous line interface) but in the present configuration, three are unused and the fourth is used for the DLV11-J. The IOCM resides in slot 5 and the REV11-A terminator/bootstrap module in slot 14. Slots 6-13 hold I/O modules. One expansion chassis (H334-A) is included in the configuration and can accommodate 10 I/O modules. Mounted directly above each H333-A and H334-A chassis is a H332 screw terminal mounting chassis. The H332 assemblies connect the ORR-PSF data lines to the I/O modules. The four chassis just described are housed in a H960-CA NEMA cabinet (see Figure 5).

Five types of I/O modules are included in the PCS subsystem: the M6011 DC single-shot output, the M6012 isolated DC output, the M5013 AC input, the A014 analog/digital converter, the A157 analog multiplexer. These are described briefly below. The reader is referred to another source for further technical details concerning the modules.^[5]

The M6011 is a 16-bit non-isolated, open collector, one-shot DC voltage output module with current sink outputs for use with an external field supply. The M6011s are used in the PCS to drive SSRs for heater activation. The output pulse length is switch-selectable and ranges from 100 microseconds to 5 seconds on a per-byte basis. Each module consists of two eight-bit units. When a unit is addressed, the module waits for a timing interval to begin, then turns on the appropriate output Darlington switches for the specified period. Data are cleared from the D-Bus when a complete timing interval has occurred. Addresses of the six M6011s in the PCS are 171004-171011.

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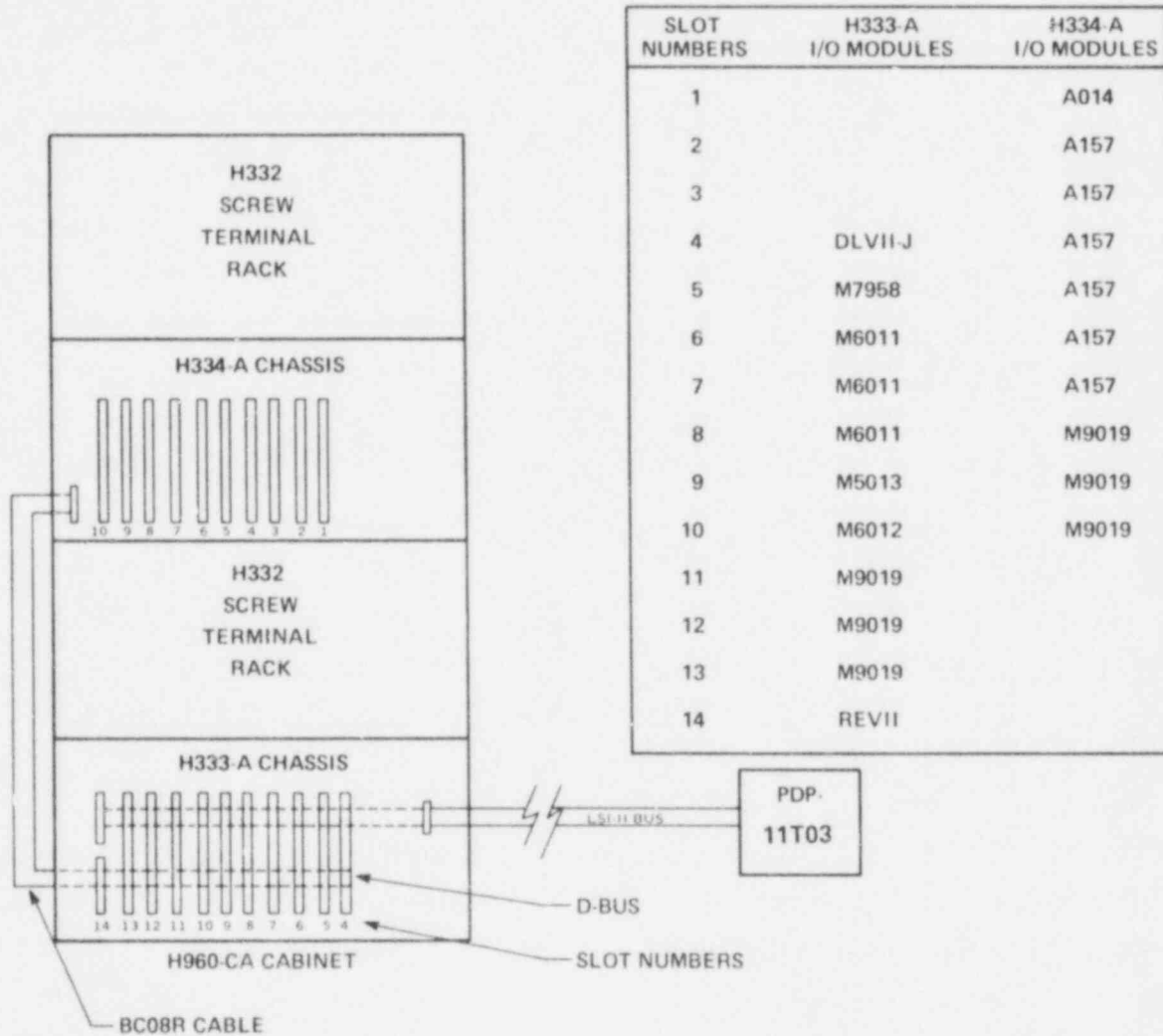


Figure 5
IP300 CABINET CONFIGURATION AND I/O MODULE SLOT ASSIGNMENTS

The M6012 is an eight-bit optically isolated DC voltage output module which provides current sink outputs for use with an external field supply. The M6012 in the PCS activates annunciators in the alarm system when needed. The module is assigned to address 171013.

The M5013 monitors up to eight contact closures and AC voltages in the frequency range of 47 to 63 Hz. An input from 0 to 30 Vrms is treated as a logical zero and an input voltage from 90 to 140 Vrms is treated as a logical one. The module is capable of initiating an interrupt upon a change-of-state of the most significant bit.

The inputs, structured as one eight-bit byte, are transformer-coupled to threshold detectors. The M5013 is assigned to address 171012 and was intended for use as a water flow indicator.

The analog input functions of the subsystem are handled by an A014 A/D converter and six A157 analog multiplexers. The A014 accepts 16 single-ended or eight differential field inputs and is designed for high-level input signals. The A157s have programmable gain and, in the PCS, accept low-level input signals. The A157s are addressed via the A014 and each accommodates 16 differential field inputs.

The A014 provides successive approximation A/D conversion of input signals from one of eight differential channels or an external multiplexed-source channel under computer control. The analog signal is converted into a 12-bit (11 bits plus sign) digital word that is read by the software. When used with the external A157 wide-range multiplexer, gain is selected by the program at the A157, thus enabling analog signals (current or voltage inputs) of different amplitudes to be read. Since the D-Bus is eight bits wide and the LSI-11 Bus is 16 bits, 12 bits of digitized analog data are transferred to the processor in two data input operations.

Data format for the A014 is given below (see Table 1). The A014 occupies four consecutive bytes of address space (171000-171003) and these four bytes are used as a control table to select channel number, multiplexer,

Table 1

A014 DATA FORMAT

Byte 0 is used to read the least significant eight bits of converted data.

Byte 1 is used to read the most significant four bits of converted data. Bits 4 to 7 will not be used.

Byte 2 is used to select a particular multiplexer and associated channel number. Bits 0 to 4 are used to select from the 16 available channels, and bits 5 to 7 permit selection from the six available multiplexer modules. Multiplexer No. 0 is reserved for the A014.

Byte 3 is used to start the conversion, monitor the status of the conversion, and select or read the multiplexer gain. Setting of bit 1, 2, or 3 will cause an interrupt in the CSR. Interpretation of bits 0, 1, 2, and 3 is as follows:

Bit		Description
0	Go/Busy	When this bit is set = 1, the A/D conversion cycle is initiated. Reading this bit = 1 means an A/D conversion cycle is in progress.
1	Done	When this bit = 1, the A/D conversion cycle has been completed and the data are available.
2	Error	When this bit = 1, one of the following errors has occurred: <ol style="list-style-type: none"> 1. A nonexistent multiplexer channel has been selected. 2. An illegal multiplexer gain has been selected. 3. A multiplexer timeout error exists.
3	Timeout	When this bit = 1, the addressed multiplexer has failed to respond to an A/D conversion cycle within the allotted time (approximately 10 msec after the GO bit was set).

Table 1 (Contd.)

A014 DATA FORMAT

Bits				Gain	GSB	MSB
7	6	5	4			
0	0	0	0	1	5 mV	5×2^{11} mV
0	0	0	1	2	2.5 mV	2.5×2^{11} mV
0	0	1	0	ILLEGAL		
0	0	1	1	ILLEGAL		
0	1	0	0	10	0.5 mV	0.5×2^{11} mV
0	1	0	1	20	0.25 mV	0.25×2^{11} mV
0	1	1	0	ILLEGAL		
0	1	1	1	ILLEGAL		
1	0	0	0	50	0.1 mV	0.1×2^{11} mV
1	0	0	1	100	0.05 mV	0.05×2^{11} mV
1	0	1	0	ILLEGAL		
1	0	1	1	ILLEGAL		
1	1	0	0	500	0.01 mV	0.01×2^{11} mV
1	1	0	1	1000	0.005 mV	0.005×2^{11} mV
1	1	1	0	ILLEGAL		
1	1	1	1	ILLEGAL		

and gain as well as to start and monitor the conversion and to store the converted data.

It should be pointed out that the A157s in the PCS IP300 Subsystem have been customized for this configuration and are no longer identical to new modules from DEC. Any switch of the current modules with factory replacements will result in input failure until the modules are altered in like manner. This modification involves the inclusion of a programmable gain selection of 500 to replace the factory-supplied gain of 200. All other gain selections remain the same. The hardware modification was necessary because a gain of 200 did not provide the needed resolution of temperature data and the next gain of 1000 could not provide the voltage range required. For programming purposes, the gain code in byte 3 for 200 was retained for a gain of 500.

The following restrictions must also be observed:

1. At the completion of a conversion, the A014 must be read with the RIF bit set in the I/O Control Module before any new data can be written into the subsystem.
2. The channel number, multiplexer number, and gain must be reselected before each conversion.
3. If a nonexistent multiplexer is addressed, internal circuitry will prevent further subsystem response and the processor traps. The condition is cleared by reading the A014 with the RIF bit set in the IOCM or by initializing the D-Bus.

SECTION 2.2.2. INPUT/OUTPUT CONTROLLER

The I/O Control Module contains the address selection logic, interrupt logic, control and status register, byte/word control logic, and bus drivers and receivers needed to interface the D-Bus and LSI-11 Bus. One major function of the IOCM is to reconcile bus width and timing differences between the buses. The D-Bus is eight bits wide and has its own unique

timing (about 16 microseconds), considerably slower than that of the LSI-11 Bus. Although timing and data path of the LSI-11 Bus and D-Bus differ, data transfer protocols are identical. This permits reasonably straightforward programming techniques once the timing differences are recognized and accommodated by appropriate software delays.

SECTION 2.2.3. SUBSYSTEM DEVICE REGISTERS AND ADDRESSING CONVENTIONS

In this configuration, 400 octal bytes are reserved in the processor's I/O address space for IP300 communications. The address range is 171000 to 171377 with bytes 171376 and 171377 being reserved for the interrupting address register (IAR) and the IOCM control and status register (CSR), respectively. The remaining 376 addresses correspond to up to 376 input/output registers (IORs) contained in the I/O modules. Module addresses are selected by dual-inline-package switches on the individual modules. Modules can have one to eight one-byte IORs, each with a unique octal address. The following addressing restrictions apply: One-byte modules can be assigned to any address in the 171000-171375 range. Two-byte modules must be assigned to consecutive addresses with the first being even. Four-byte and eight-byte modules must also have consecutive addresses with the first address ending in zero or four.

SECTION 2.2.4. INTERRUPT I/O TRANSFERS

Some of the modules in the IP300 can initiate an interrupt sequence on the D-Bus which results in a processor interrupt if the IOCM CSR enable bit is set and if the processor status allows interrupt. Interrupts are vectored through locations 234 and 236. The interrupt control line is daisy-chained along the D-Bus, creating a priority structure within the subsystem such that the module electrically closest to the IOCM has the highest priority. The relative address of the interrupting module of highest priority is passed to the IAR. Following an interrupt, the subsystem service routine reads the IAR, optionally reads module generic data, performs the input/output service, and resets the module's internal interrupt flag. CSR bit assignments and functions are listed in Table 2.

Table 2
CSR BIT DESCRIPTIONS

Bit	Description
07 (F) Read only	Flag bit = 1 indicates that the subsystem requires service
06 (E) Read/write	Enable bit = 1 enables the subsystem interrupt. If F = 1 and E = 1 and the processor status allows interrupts, the processor will be interrupted.
05 (M) Read/write	Maintenance bit = 1 forces a maintenance interrupt if E = 1. If M = 1, then F = 1. M is cleared when the CSR has been read with R = 1. Reading an IOR with M = 1 results in data equal to the address of that IOR, whether or not there is a module installed with that address.
04 (D) Read/write	Disable bit = 1 sets the I/O disable mode on all applicable I/O modules. Clearing the D-bit automatically sets the C-bit.
03 (T) Read/write	Test bit = 1 sets the I/O test mode on all applicable I/O modules.
01 (C) Write only	Clear bit = 1 causes the subsystem to reset without requiring a reset instruction; self-clearing.
00 (R) Read/write	RIF (reset interrupt flag) bit = 1 causes the I/O module being read to reset its internal interrupt flag. RIF is cleared when the I/O module or the CSR is addressed.

SECTION 2.2.5. PROGRAMMED I/O TRANSFERS

Programmed I/O transfers can be used to transfer eight-bit data or status bytes to and from the I/O modules via conventional PDP-11 byte-mode instructions. Because of unique timing constraints imposed on the PCS by (1) idiosyncrasies of the IP300 and (2) the precision with which the solid-state relays (SSRs) for heater control have to be fired, it was determined that the programmed transfer of IP300 data was preferable to interrupt-driven transfers. This approach allows more program control of the timing of transactions between the IP300 and PDP-11T03 and reduces the impact of inherent bus differences.

SECTION 2.2.6. SUBSYSTEM TIMING CONSIDERATIONS

During development of the IP300 support software, it was found that certain timing problems exist. These occur as the IOCM reconciles D-Bus and LSI-11 Bus cycle differences and can result in real-time subsystem communication delays of up to one D-Bus cycle in length. Timing inconsistencies are further aggravated between the CPU and single-shot output devices because two independent clocks are involved -- the Line Time clock for CPU event timing and a crystal-controlled clock for one-shot output pulse assertion. The timing incompatibilities here are small (maximum of 16 microseconds) and, in most applications, negligible. In the ORR-PSF application, however, heater control must be precise within the 200 millisecond period and even a short delay in asserting a single-shot pulse can cause the pulse to be skipped, resulting in an SSR misfire of 200 milliseconds in duration.

The timing inconsistencies were first discovered when erratic SSR firing patterns were noticed and investigated. The heater misfiring caused short-term capsule temperature excursions. Experimentation showed that the misfires, once started, were repeated until the two clocks became synchronized again. The misfire periods typically lasted a few seconds to two or three minutes and resulted in an average 2°C temperature drop in the affected heater zones. Once the timing conflicts were recognized, software changes were made so that less stringent demands were made on

the hardware. No total software correction of the malfunction is possible, but the severity and impact (in terms of heater misfiring) were lessened considerably by two changes. The first involved a software recognition of any missed one-shot pulse and an arbitrary rescheduling of the heater firing algorithm until synchronization is achieved. This has the effect of greatly reducing (though not eliminating) the number of misfires to the extent that temperature excursions are so small as to be undetectable in the data acquisition system. Some further improvement was made by suspending most computer system activity when CPU/subsystem communications are under way.

A certain method of eliminating the SSR misfires would be to replace the single-shot modules with latching output modules, effectively eliminating the second clock and allowing software control of the output pulse length. At this time, however, an equipment change does not seem warranted.

Other timing restrictions that were observed in the software development were:

1. At least 20 microseconds must elapse between setting the clear bit (bit 1) of the CSR and next addressing any register in the subsystem.
2. The time from setting of the interrupt flag bit in the CSR to the time the interrupt service routine reads the IAR must be at least 30 microseconds.
3. The time from the clearing of a module interrupt to the time that the software enables additional IP300 interrupts, tests the flag bit in the CSR, or reads the IAR must be at least 30 microseconds.

SECTION 3. PCS SOFTWARE

As mentioned above, DEC's RT-113B foreground/background, single-user operating system was selected for the PCS. In this report, discussion of applications software will be limited to the final process monitoring and control program and will not cover software developed for initial system tests and pre-experiment characterizations of the process. (The earlier software development is described briefly in Section 1.4.) The program used to control the ORR-PSF experiment is called Program PCS. Program PCS has background functions of reporting and storing process parameters and foreground functions of process data acquisition and control.

As explained in Section 1.4, pre-experiment tests showed that the optimum heater firing period is 200 milliseconds and the necessary time for performing all process control functions is 40 seconds. This led to the assumption that the system design could be based on a discrete-time model having 200 time frames of 200 milliseconds each. For computing purposes, each discrete period is allocated to specific tasks and task scheduling is handled by a foreground supervisory subprogram.

SECTION 3.1. PROGRAM PCS INITIALIZATION TASKS

The ORR-PSF experiment is scheduled to last two years with discontinuities in operation due to reactor conditions. When reactor power is reduced for refueling or maintenance to a level too low for the electrical heaters in the capsules to maintain the desired heat balance, the experiment is suspended until the gamma heating is sufficiently high again. Similarly, failures in the PCS or PSF instrumentation can cause temporary experiment shutdown.

Each time the experiment is resumed, Program PCS is executed anew to establish boundary conditions. While PCS is running, it has sole use of the system resources. Process control functions require nearly total system capacity and so other development work or experiment data reduction must be done off-line.

For operational ease, optional selection of default parameters is available.^[6] When parameter initialization is defaulted, variac set-points are assumed to be unchanged and automatic computer control of the process is initiated. Program PCS can operate the process in two modes: one is the Manual Mode in which the heaters are fired under computer control at fixed duty cycles so that the total power delivered to the heaters is constant and capsule temperature distributions are monitored; the second (and defaulted) mode is automatic control where new heater power demands are computed and satisfied every 40 seconds based on temperature changes. Under Automatic Mode control, the process can be regulated by one of three methods.^[3] The default method is an optimal/integral controller which translates computed heater power changes to duty cycles. Each time Program PCS executes, a disk data file having a default size of 450 records is created for storing experiment data for the estimated duration of a reactor fuel cycle.

After performing initialization tasks, Program PCS schedules the supervisory subprogram to execute every 200 milliseconds and enters the 40-second process control loop.

SECTION 3.2. BACKGROUND ACTIVITIES

Data and error logging on the user terminal at 40-second intervals and data storage on disk are carried out as foreground operations permit. Data written to the terminal reflect every temperature feedback response to heater power changes. The data format is shown in Table 3. Simulated surveillance capsule thermocouples are designated by TE1-20, SPVC thermocouples are TE 101-120, TE 201-220, and TE 301-320 for the 0T, 1/4 T, and 1/2 T specimen regions, respectively. SSC variac numbers are 1-10 and SPVC variac numbers are 11-40. The format of temperature data reflects thermocouple spatial distribution in the capsules.

Time/temperature distributions, heater duty cycles, and reactor power level are also maintained on disk for later analysis. During the first two hours of operation following resumption of the experiment, the system

Table 3

FORMAT FOR ORR-PSF 40-SECOND DATA LOG

Disk Data Filename	Record Number	Time	Date	Reactor Power Level	
Front Face (Near Reactor)		Back Face (Away from Reactor)		Variac No.	
TE 1	TE 9	TE 14	TE 8	1	21
TE101	TE109	TE114	TE108	2	22
TE201	TE209	TE214	TE208	3	23
TE301	TE309	TE314	TE308	4	24
			TE 2	TE 15	5
			TE102	TE115	6
			TE202	TE215	7
			TE302	TE315	8
				9	29
TE 3		TE 16		10	30
TE103		TE116		11	31
TE203		TE216		12	32
TE303		TE316		13	33
	TE 11		TE 4	TE 10	TE 17
	TE111		TE104	TE110	TE117
	TE211		TE204	TE210	TE217
	TE311		TE304	TE310	TE317
				15	35
				16	36
TE 5		TE 18		17	37
TE105		TE118		18	38
TE205		TE218		19	39
TE305		TE318		20	40
			TE 6	TE 19	
			TE106	TE119	
			TE206	TE219	
			TE306	TE319	
TE 7	TE 13	TE 20	TE 12		
TE107	TE113	TE120	TE112		
TE207	TE213	TE220	TE212		
TE307	TE313	TE320	TE312		

Desired Capsule Temp. SSC, SPVC1, SPVC2, SPVC3 Average Temp. TE Ref. Box Temp.
 SSC, SPVC1, SPVC2, SPVC3 Maximum Temperature Deviation
 Temperatures Rejected by Control Algorithm

Error Messages

is dynamic as gamma and electrical heat combine to achieve capsule reference temperature and data are stored at 20-minute intervals. When the temperatures reach steady state, data storage is reduced to once per hour. If any system perturbations occur after equilibrium is achieved, error flags initiate data storage at a rate of once every two minutes as long as the process remains in a dynamic state.

SECTION 3.3. FOREGROUND ACTIVITIES

SECTION 3.3.1. SCHEDULING PCS TASKS

The supervisor routine structures the process control sequence by scheduling events according to elapsed time in the 40-second control period. A time-slicing approach was used because of the necessity of refreshing the single-shot output pulses for heater control at regular 200-millisecond intervals. The scheduling capabilities of the RT-11 operating system are not such that scheduling of the one-shot output software along with other highly time-dependent software segments would always be precise. For this reason, the scheduling mechanisms of RT-11 were not used for highly time-critical events.

The supervisor initiates the heater activation sequence every 200 milliseconds by executing the heater firing algorithm described below. The output pulse length each time power is applied to a heater is 200 milliseconds but only 30 to 50 milliseconds of processor overhead is required to assert the outputs, leaving most of the interval for other operations. The duration of the output pulse, once data is strobed to the M6011, is controlled internally by the module's timer.

Other foreground functions are scheduled as follows according to an index (ISW) which is incremented by the supervisor every 200 milliseconds. The first time-slice in the control interval is used, in addition to firing heaters, to replace heater duty cycles used during the previous interval with updated ones. During the second time, half of the analog input channels are scanned and reactor power is computed. Throughout the next 83 frames, the two junction box reference temperatures are

computed, thermocouple data are corrected by the reference temperatures, and finally, the 80 thermocouple readings are converted to engineering units. Conversion of a single thermocouple input by the method described below in Section 3.3.4, plus execution of the heating firing routine consumes essentially all of one time frame. Periods 85-134 and 175-199 are used primarily for background data handling tasks and period 135 is used for process error detection. The next 36 frames following error handling are dedicated to control algorithm calculation of new heater duty cycles for the next control interval. The final frame (ISW=200) is used to read the second half of the analog inputs.

SECTION 3.3.2. HEATER FIRING ALGORITHM

Every 200 milliseconds, a decision must be made concerning individual heater status for the upcoming period. Heaters which will be fired during the period must be activated by the SSRs driven by the single-shot output devices. The decision as to whether to fire each heater is determined by the heater's duty cycle. If, for example, a heater's duty cycle to produce the needed power demand is 80%, the SSRs will be pulsed during 80 of the next 100 discrete time frames.

Electrical limitations on the heaters dictate that the heaters not be turned off for periods exceeding 0.5 second so that thermal cycling is minimized. Given this restriction, a firing algorithm was developed to avoid turning a heater off for two successive time frames. Although two periods (400 milliseconds) do not violate the restriction, it was decided that, because of the length of the experiment and attendant heater stress, a conservative heater firing sequence would be implemented. To achieve an 80% duty cycle, the SSR is pulsed in alternate time frames until the 20% of heater off-time is achieved. During the next 60 frames, the SSR would be pulsed constantly. As mentioned in Section 1.4, the computed heater duty cycles will be used twice within the control interval since new heater power demands are calculated only every 40 seconds by the control algorithm.

The smallest duty cycle allowed is 50% for the reason given in the preceding paragraph. It is desired that duty cycles equal approximately 80% to maintain capsule temperatures at the reference temperature with a reactor power level of 30 megawatts. This provides contingency for adjusting heater power to compensate for gamma heating fluctuations without changing variac setpoints. The variac setpoints were arrived at experimentally as one phase of the pre-experiment determinations.

M6011 channels and variac numbers are related as shown in Table 4.

SECTION 3.3.3. TEMPERATURE DISTRIBUTION

The capsule temperature profiles are acquired once during each 40-second interval. Half of the thermocouples are read in each of two consecutive time frames. Adequate signal settling time is provided between thermocouple sampling and each thermocouple is read four times to verify the signal stability. Also sampled at this time are the temperatures of two isothermal junction boxes through which the thermocouples are referenced to the ice-point. The thermocouple inputs are read with an amplifier gain of 500 over a voltage range of ± 20.48 millivolts. The accuracy of the temperatures at this gain is $\pm 1.5^\circ\text{C}$. The reference temperatures are input at a gain of 100 over a range of ± 102.4 millivolts with an accuracy of $\pm 0.14^\circ\text{C}$. Table 5 shows the thermocouple assignments to analog input channels.

Thermocouple voltage readings are converted to Centigrade degrees by the following method. The temperature, T_r , for each isothermal junction box is computed directly since 0-100°C is read on a 0-100 millivolt range.

To approximate temperature from measured voltage, a power series is used. Manufacturer-derived coefficients in the equations, however, are referenced to the ice-point whereas the PCS thermocouples are referenced to the isothermal box temperatures. Before correcting the thermocouple voltage reading with the isothermal box reference temperature, the voltage equivalent of the isothermal box temperature relative to the ice-point

Table 4

SINGLE-SHOT CHANNEL ASSIGNMENTS

<u>M6011 Module Number</u>	<u>M6011 Channel Number</u>	<u>Screw Terminal Number</u>	<u>Variac Number</u>	<u>Heater Plate</u>	<u>Heaters</u>
1	0	1	1	H1	1-2
1	1	2	2	H1	3-4
1	2	3	3	H1	5-6
1	3	4	4	H1	7-8
1	4	5	5	H1	9-10
1	5	6	6	H2	1-2
1	6	7	7	H2	3-4
1	7	8	8	H2	5-6
2	0	9	9	H2	7-8
2	1	10	10	H2	9-10
2	2	11	11	H3	1-2
2	3	12	12	H3	3-4
2	4	13	13	H3	5-6
2	5	14	14	H3	7-8
2	6	15	15	H3	9-10
2	7	16		----- Not Used -----	
3	0	1	16	H4	1-2
3	1	2	17	H4	3-4
3	2	3	18	H4	5-6
3	3	4	19	H4	7-8
3	4	5	20	H4	9-10
3	5	6	21	H5	1-2
3	6	7	22	H5	3-4
3	7	8	23	H5	5-6
4	0	9	24	H5	7-8
4	1	10	25	H5	9-10
4	2	11	26	H6	1-2
4	3	12	27	H6	3-4
4	4	13	28	H6	5-6
4	5	14	29	H6	7-8
4	6	15	30	H6	9-10
4	7	16		----- Not Used -----	
5	0	1	31	H7	1-2
5	1	2	32	H7	3-4
5	2	3	33	H7	5-6
5	3	4	34	H7	7-8
5	4	5	35	H7	9-10
5	5	6	36	H8	1-2
5	6	7	37	H8	3-4
5	7	8	38	H8	5-6

Table 4 (Contd.)

SINGLE-SHOT CHANNEL ASSIGNMENTS

<u>M6011 Module Number</u>	<u>M6011 Channel Number</u>	<u>Screw Terminal Number</u>	<u>Variac Number</u>	<u>Heater Plate</u>	<u>Heaters</u>
6	0	9	39	H8	7-8
6	1	10	40	H8	9-10
6	2	11	-- Computer Failure Alarm --		
6	3	12	----- Not Used -----		
6	4	13	----- Not Used -----		
6	5	14	----- Not Used -----		
6	6	15	----- Not Used -----		
6	7	16	----- Not Used -----		

Table 5

ANALOG CHANNEL ASSIGNMENTS

Channel Number	A157 #1	A157 #2	A157 #3	A157 #4	A157 #5	A157 #6
0	RTD5	TE305	TE209	TE113	TE 17	TE 1
1	RTD4	TE306	TE210	TE114	TE 18	TE 2
2	RTD2	TE307	TE211	TE115	TE 19	TE 3
3	WT	TE308	TE212	TE116	TE 20	TE 4
4	RP	TE309	TE213	TE117	TE101	TE 5
5		TE310	TE214	TE118	TE102	TE 6
6		TE311	TE215	TE119	TE103	TE 7
7		TE312	TE216	TE120	TE104	TE 8
10		TE313	TE217	TE201	TE105	TE 9
11		TE314	TE218	TE202	TE106	TE 10
12		TE315	TE219	TE203	TE107	TE 11
13		TE316	TE220	TE204	TE108	TE 12
14		TE317	TE301	TE205	TE109	TE 13
15		TE318	TE302	TE206	TE110	TE 14
16		TE319	TE303	TE207	TE111	TE 15
17		TE320	TE304	TE208	TE112	TE 16

Input Signal Definitions

RTD - Reference Temperature Device
 WT - Watt Transducer
 RP - Reactor Power
 TE - Thermocouple

must first be computed. The following equation computes the isothermal box voltage:

$$e_o = C_o + C_1 T_r + C_2 T_r^2 + C_3 T_r^3 . \quad (1)$$

The coefficients are Chromel/Alumel constants provided by the thermocouple manufacturer. The measured thermocouple voltage, e_m , is then added to e_o to get the corrected thermocouple input. Temperature is then computed from equation (3).

$$e = e_m + e_o , \quad (2)$$

$$T = A_o + A_1 e + A_2 e^2 + A_3 e^3 + A_4 e^4 + A_5 e^5 . \quad (3)$$

SECTION 3.3.4. ALARM HANDLING

After the capsule temperature profiles are determined, error checking is done to flag any out-of-limits temperatures. If 10% or more of the thermocouples record temperatures outside the range of the capsule reference temperature $\pm 10^\circ\text{C}$, a warning message is printed with the other process data, as shown in Table 3. Also, an annunciator alarm is activated in the experiment control room and in the reactor control room. Disk storage rate of process data is increased from once per hour to once every two minutes. If the temperature excursion continues and exceeds the range of reference temperature $\pm 17^\circ\text{C}$, a reactor setback occurs. The annunciator is activated again and an alarm message is printed. If the alarm was caused by a high temperature excursion, heater power is immediately reduced to zero to protect the pressure vessel specimens from annealing damage. Program PCS continues to monitor and record process data but no further automatic heater power control is generated until the experimenter determines that reactor and process conditions have normalized and restarts the program. When the alarm reflects a low temperature distribution, the PCS continues automatic heater control until terminated by the experimenter.

The temperature alarm annunciator relays are activated by an M6012 program-controlled DC output upon error detection. Operator acknowledgment of the alarm is necessary before the annunciator can be silenced.

Since the temperature alarm capability is lost during a computer failure, a watchdog timer was incorporated in the PCS to cause annunciator activation in the experiment control room and in the reactor control room if the processor halts or if, for any reason, Program PCS is suspended. The program renews a single-shot digital output pulse to the annunciator relay, maintaining a closed circuit. If the pulse is not refreshed under program control every 200 milliseconds, the output pulse times out, opening the circuit to give an alarm. When Program PCS is not executing, the annunciator circuit must be bypassed by setting the COMPUTER FAILURE ALARM switch in the experiment control room.

SECTION 3.3.5. IP300 I/O SOFTWARE

The IP300 Subsystem as marketed by Digital Equipment Corporation is a self-contained system complete with supporting software. DEC's software was not applicable to the PCS I/O subsystem, however, for two reasons. One is the custom-design aspects of the subsystem discussed above. The other is that DEC's IP300 device drivers were developed to be used in the RSX-11M/S operating systems and are not readily transferrable to an RT-11 environment.

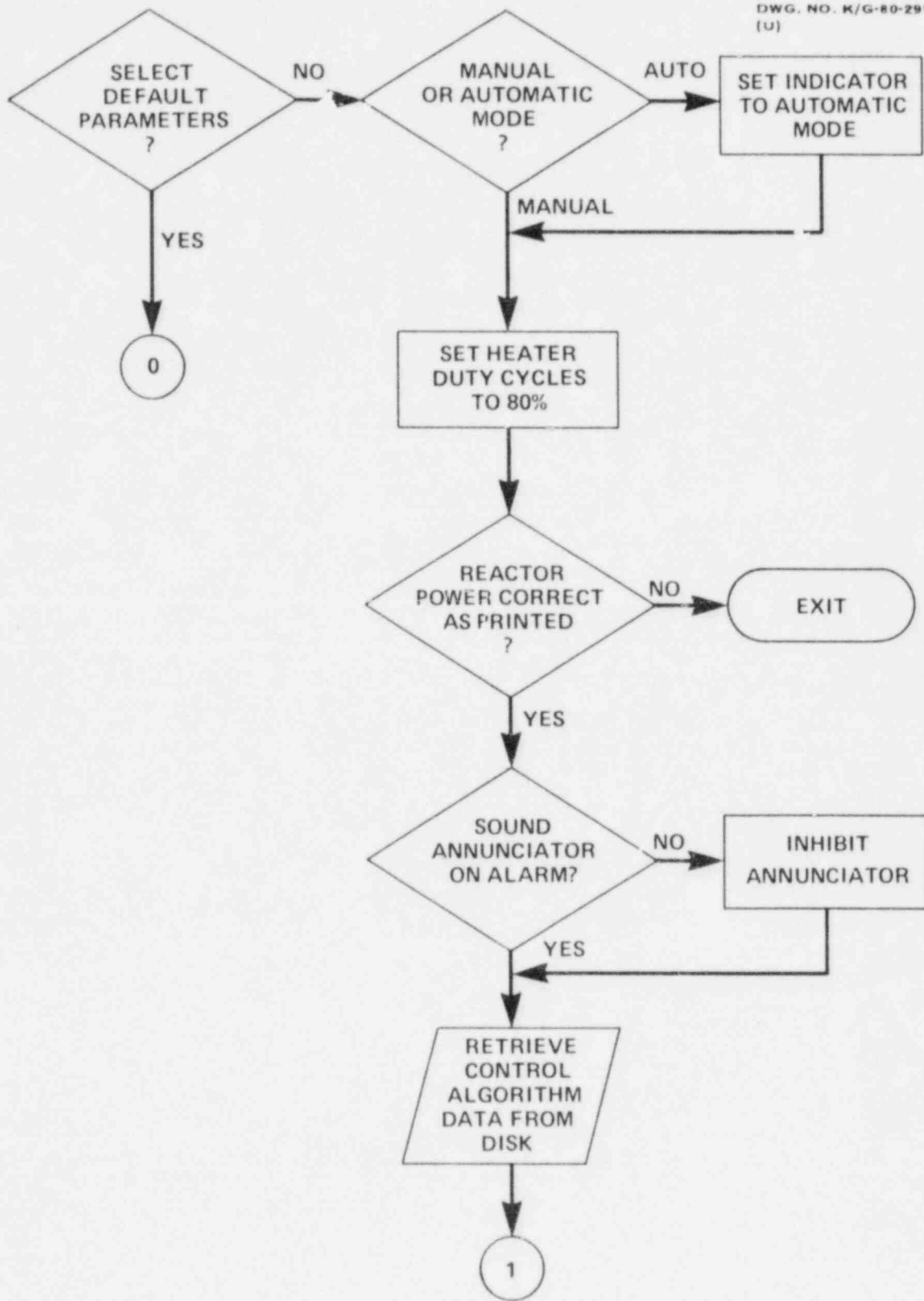
Observing the restrictions and conventions outlined in Section 2.2 for the PCS IP300, communications software was written for the IOCM and all modules on the D-Bus for use in the RT-11 system.

REFERENCES

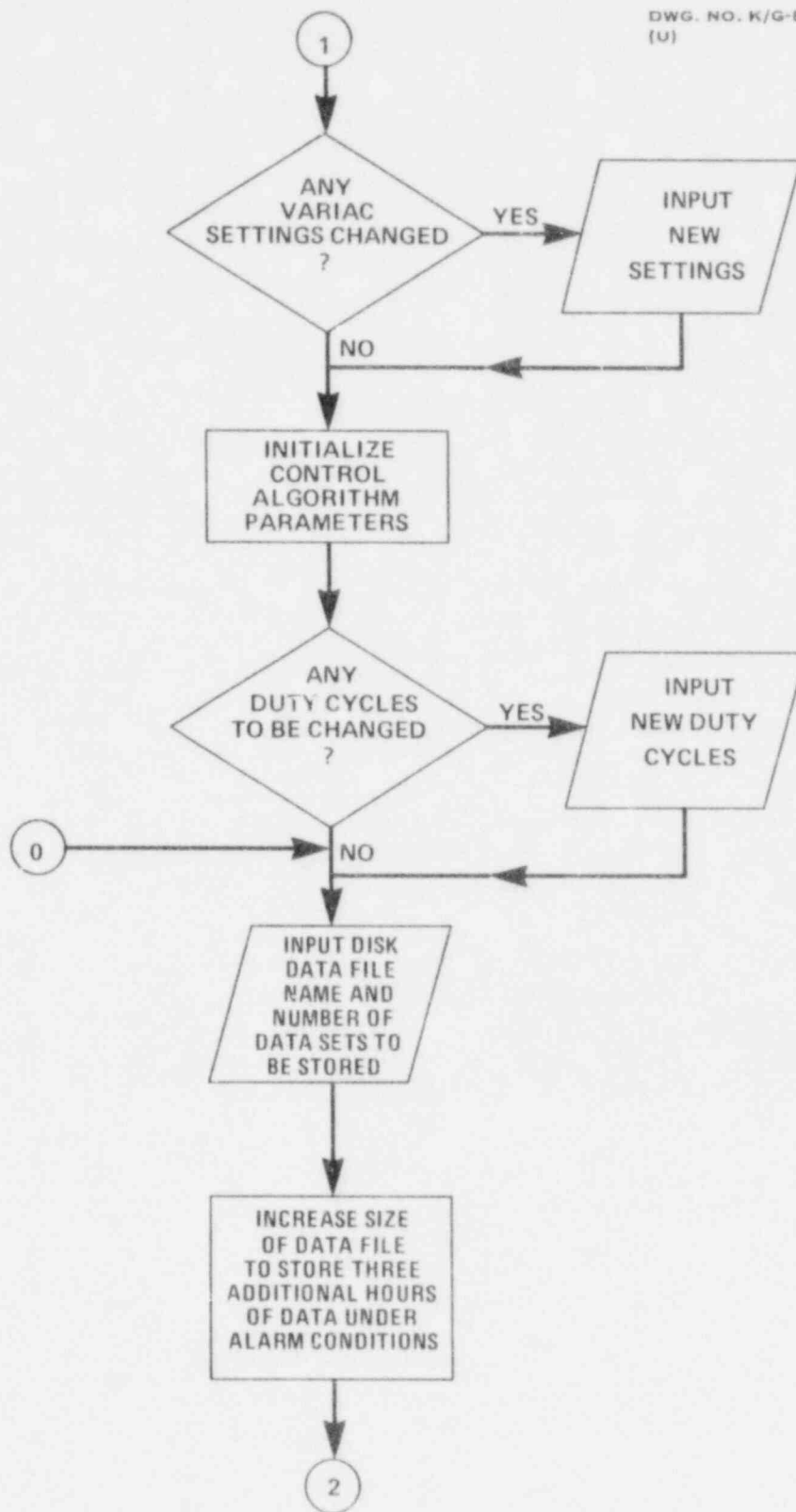
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2. Siman-Tov, I. I., *The LWR-Pressure Vessel Benchmark Facility Irradiation Capsule: Heat Transfer Analysis*, The University of Tennessee, Knoxville, To Be Published.
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4. Bryan, R. N., *Discrete-Time Regulator for a Digital Heat Control System*, The University of Tennessee, Knoxville (October 1979).
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APPENDIX A

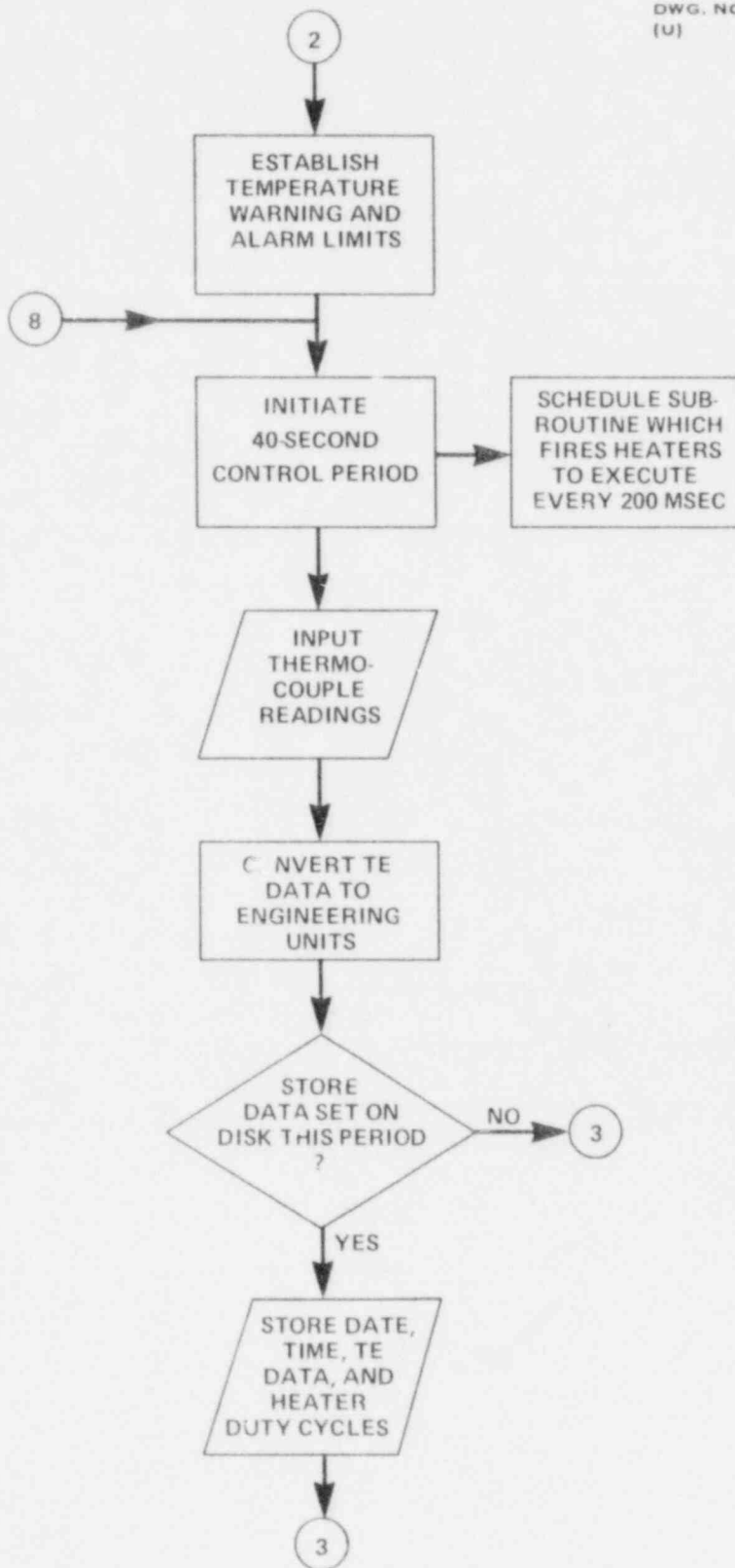
PROGRAM PCS FLOW CHART



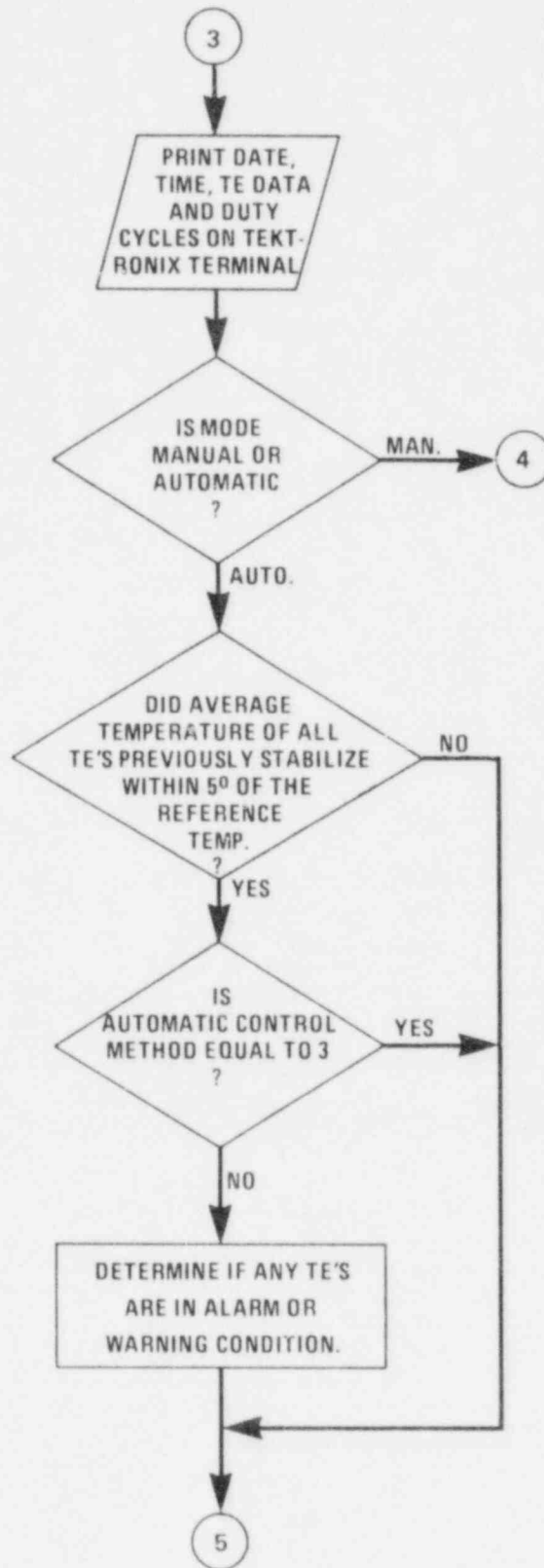
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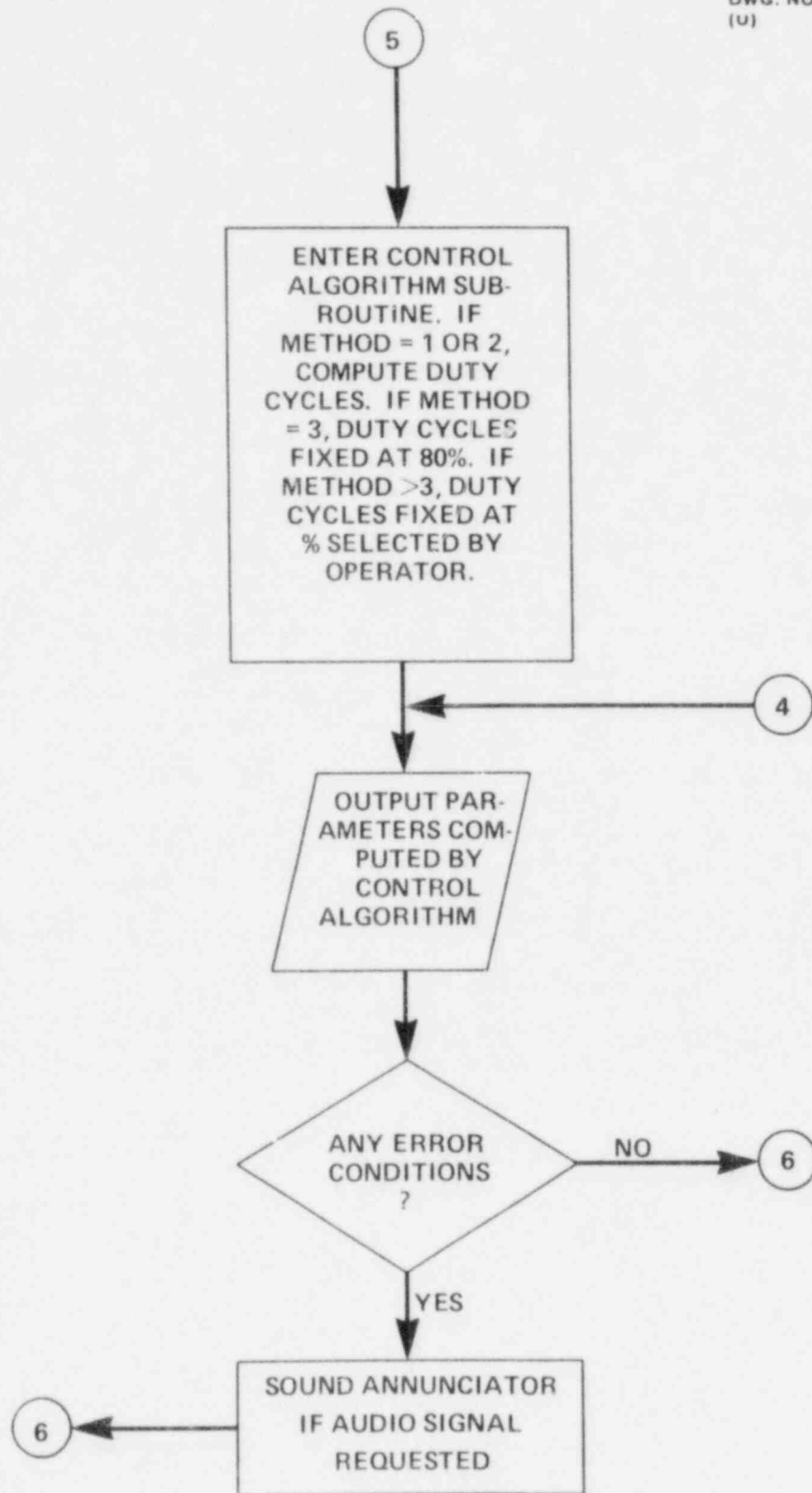
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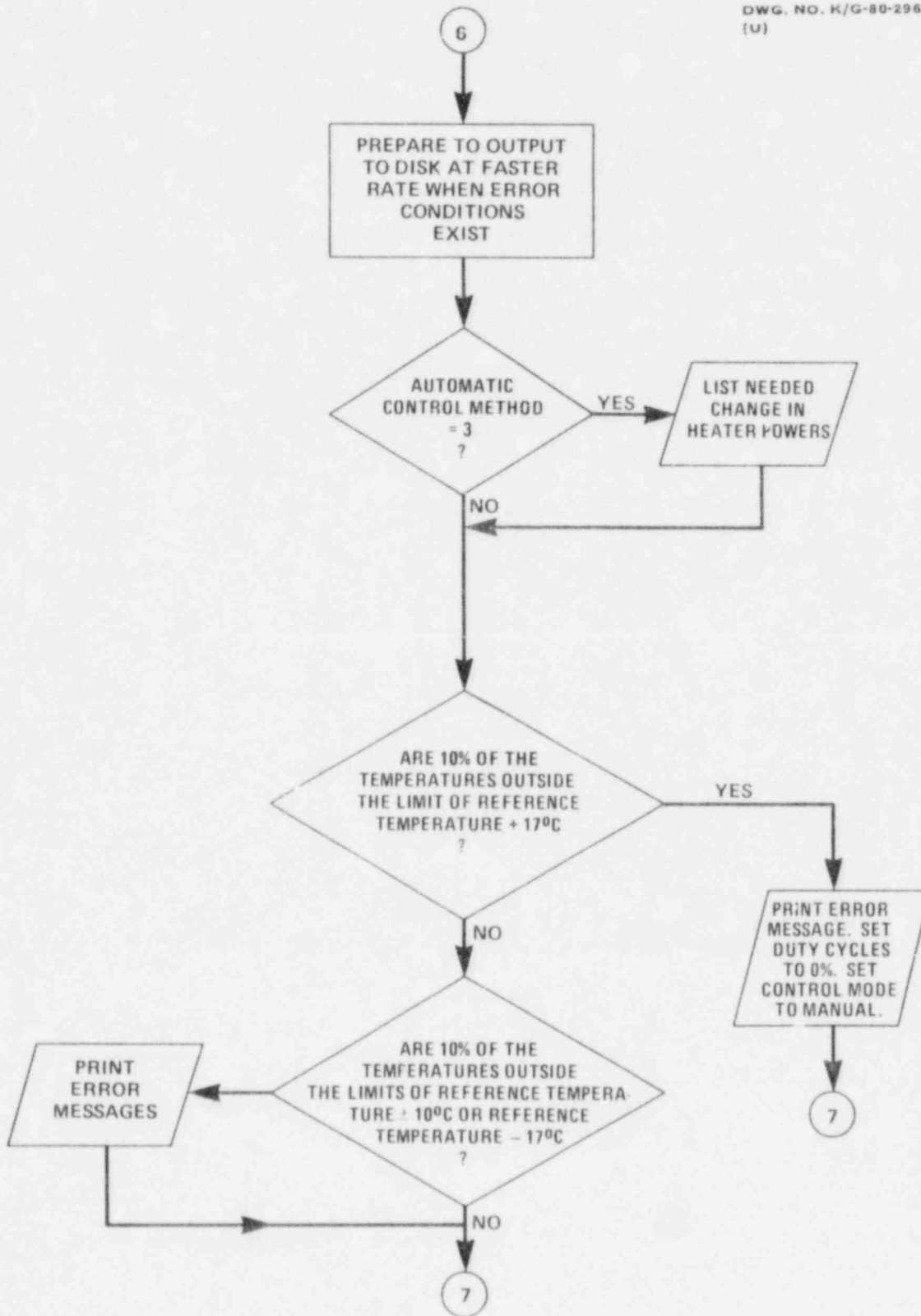
PROGRAM PCS FLOW CHART



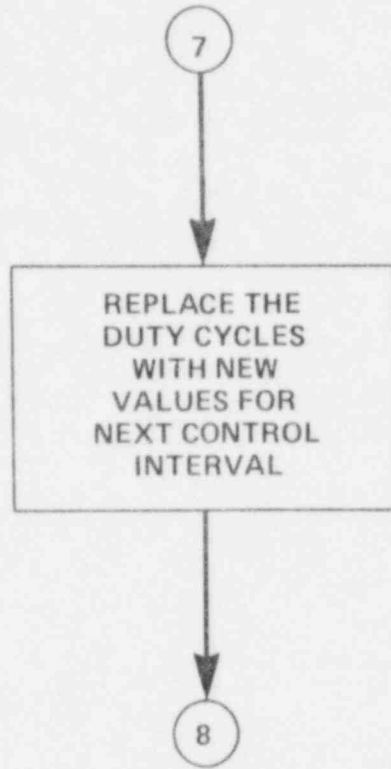
PROGRAM PCS FLOW CHART



PROGRAM PCS FLOW CHART



PROGRAM PCS FLOW CHART



PROGRAM PCS FLOW CHART

APPENDIX B

PROGRAM PCS SOURCE LISTING

```

Files copied:
DK1:PCS.FOR   to TT:PCS.FOR
C*****
C*****PROGRAM PCS.  OAK RIDGE NATIONAL LABORATORY,  JULY, 1980.
C*****
C*****PROGRAM PCS PERFORMS DATA ACQUISITION AND PROCESS CONTROL
C*****FUNCTIONS IN SUPPORT OF THE LIGHT WATER REACTOR PRESSURE VESSEL
C*****SIMULATION PROJECT AT THE OAK RIDGE RESEARCH REACTOR.
C*****
      LOGICAL#1 REPLY,NO
      INTEGER DEFAU
      COMMON/COMM/REF(2),IPF,MAUTO,ISW,M6012,WATTR,PL,IERR(10),TRD5
      COMMON/CTRDAT/IMOD,TC(20,4),TREF,NCAP,VAR(40),
      INOCTL,NTMP,TAADM,TMDV,IBDAT,U(20),IPCU(40),
      2ICMTH,IUDTR,NCPSS(4),TAVG(4),NCALL(4),NTAU,
      3CFAC(10,4),F(10,20,4),PREF(10,4),PVAR(10,4)
      4,DTMX(4),DEFAU
      COMMON/ADINP/I0,I2,I3
      COMMON/TRSG/NSG(20,4)
      COMMON/DOUT1/I6012
      COMMON/TE/IAD(85)
      COMMON/ERRC/TREFE(4)
      DIMENSION ITIME(2),FILE(3),DA(3),EMPTY(3),AMES(2,4),INDA(5)
      DATA MAUTO/0/,IPF/0/,ISW/0/,IPCU/40*80/,ISUB1/1/,NINT/0/
      1,FILE(1)/'DK2:/',FILE(3)'/'.DAT',NREC/0/,NVC/0/
      2,EMPTY/'EMPT','Y RE','CORD'/,NO/'N'/,NFULL/0/,IERR/10*0/
      3,AMES/'EXCE','ED ','EXCE','ED ','BELO','W ','BELO','W '/
      4,NINTC/0/,VAR(36,75,18.,23.25,7.,12.25,34.25,20.5,0.,28.,0.,
      511.,6.,0.,0.,7.,6.,11.,0.,0.,0.,
      60.,0.,0.,0.,0.,17.5,18.,27.,23.,8.5,
      734.,30.,24.5,11.5,18.,33.,32.,39.5,26.,16./
      DATA I6012/0/,NHRL/0/,IANN/1/,INDA/5*0/,ISTORI/30/,ISTORE/30/
      1,TCBIG/1111111./,DEFAU/1/
C*****
C*****INITIALIZE PARAMETERS.
C*****
      CALL DATE(DA)
      WRITE (5,942)DA
942  FORMAT (' ',3A4)
      WRITE (5,941)
941  FORMAT ('#INPUT DATE (1-366). ')
      READ (5,2)NODAY
      WRITE (5,940)
940  FORMAT ('#DEFAULT PARAMETERS (Y OR N)?')
      READ (5,205)REPLY
      IF (REPLY.EQ.NO)DEFAU=0
      IF (DEFAU.EQ.0)GO TO 901
C*****
C*****DEFAULT TO AUTOMATIC CONTROL (METHOD #1).  DEFAULT VARIAC
C*****SETTINGS (ARRAY VARS) WILL BE USED AND DATA FILE SIZE WILL DEFAULT
C*****TO 450 RECORDS.
C*****
      NREC=360
C*****
C*****SELECT 4-CHARACTER FILENAME.  FILENAME EXTENSION DEFAULTS TO *.DAT*.
C**
      WRITE (5,20)
      READ (5,21)FILE(2)
      MAUTO=1
      GO TO 902
C*****
C*****SELECT AUTOMATIC OR MANUAL COMPUTER MODE.  MANUAL MODE FIRES ALL
C*****HEATERS AT FIXED DUTY CYCLES AND MONITORS THE CAPSULE TEMPERATURES.
C*****AUTOMATIC MODE COMPUTES NEW DUTY CYCLES EVERY 40 SECONDS BASED ON
C*****REAL-TIME CAPSULE TEMPERATURE CHANGES,FIRES THE HEATERS ACCORDING
C*****TO THE COMPUTED DUTY CYCLES, AND PERFORMS ERROR CHECKING.
C*****
901  WRITE (5,1)
1    FORMAT ('#INPUT 0 FOR MANUAL MODE OR 1 FOR AUTOMATIC MODE. ')
      READ (5,2) MAUTO
2    FORMAT (I)
      IF(MAUTO.EQ.0)GO TO 208

```

```

C*****
C*****INPUT THE REACTOR POWER LEVEL.
C*****
902  I2=*44
      I3=*221
      CALL A014
      IAD(84)=I0-2048
C*****
C*****CONVERT TO ENGINEERING UNITS. RESOLUTION = .05 MW.
C*****
      PL=IAD(84)*.05
      IF (DEFAU.EQ.1)GO TO 905
C*****
C*****OUTPUT REACTOR POWER LEVEL. GIVE OPERATOR OPPORTUNITY TO ABORT THE
C*****PROGRAM IF REACTOR IS NOT AT NORMAL OPERATING LEVEL.
C*****
      WRITE (5,204)PL
204  FORMAT (/'$REACTOR POWER READ AS ',F5.1,' MW.',
1,' CONTINUE (Y OR N)? ')
      READ (5,205)REPLY
205  FORMAT (A1)
      IF (REPLY.EQ.NO)CALL EXIT
C*****
C*****ANNUNCIATOR ON ALARM? DEFAULT CONDITION IS YES.
C*****
      WRITE (5,566)
566  FORMAT (/'$SOUND ANNUNCIATOR ON ALARM (Y OR N)?')
      READ (5,205)REPLY
      IF (REPLY.EQ.NO)IANN=0
C*****
C*****INPUT CAPSULE CHARACTERISTIC DATA FOR USE BY CONTROL ALGORITHM.
C*****
      WRITE (5,600)
600  FORMAT (/' 15 SECOND DELAY FOR DATA RETRIEVAL.')
```

```

905  CALL ASSIGN(3,'DK1:FDBK.DAT')
      READ (3,*)(((F(I,J,K)),J=1,20),I=1,10),K=1,4)
      CALL CLOSE(3)
      IF (DEFAU.EQ.1)GO TO 61
C*****
C*****CONTROL ALGORITHM CONSTANTS ARE PRESET. IF VARIACS ARE
C*****CHANGED, A NEW VARS ARRAY (VARIAC SETTINGS IN %) MUST BE INPUT.
C*****
      WRITE (5,60)
60   FORMAT (/'$ARE ANY VARIAC SETTINGS CHANGED (Y OR N)? ')
      READ (5,205)REPLY
      IF (REPLY.EQ.NO)GO TO 61
      WRITE (5,62)
62   FORMAT (/'$INPUT NEW VARIAC SETTINGS. HOW MANY VARIACS ARE CHANGED'
1,'? ')
      READ (5,2)NVC
      WRITE (5,63)
63   FORMAT (/' INPUT VARIAC NUMBER(1-40) AND NEW VARIAC SETTING',
2'(0-100%),'/' REPEAT FOR EACH VARIAC.')
```

```

      DO 64 II=1,NVC
      WRITE (5,66)
66   FORMAT (/'$VARIAC=')
      READ (5,2)J
      WRITE (5,67)
67   FORMAT (/'$SETTING=')
64   READ (5,68)VARS(J)
61   WRITE (5,71)VARS
71   FORMAT (/' VARIAC SETTINGS'/(10F6.1))
68   FORMAT(F10.0)
C*****
C*****INITIALIZE CONTROL ALGORITHM DATA.
C*****
      IMOD=0
      CALL CNTRL
      IMOD=1
      GO TO 7
C*****
C*****IN MANUAL MODE, ALL VARIACS WILL FIRE AT 80% DUTY CYCLES UNLESS
C*****CHANGED.
```

```

C*****
208 WRITE (5,6)IPCU(1)
6   FORMAT (/ ' ALL VARIACS WILL FIRE AT DUTY CYCLES OF ',I3,
1' UNLESS CHANGED.'/' #DUTY CYCLES OF HOW MANY VARIACS, IF ANY,'
2' WILL BE CHANGED? ')
   READ (5,2)NH
   IF (NH.EQ.0)GO TO 7
   WRITE (5,8)
8   FORMAT (' INPUT VARIAC NUMBER(1-40) AND DUTY CYCLE(50-100).'/
2' REPEAT FOR EACH VARIAC.')
   DO 9 II=1,NH
   WRITE (5,10)
10  FORMAT (' #VARIAC=' )
   READ (5,2)I
52  WRITE (5,12)
12  FORMAT (' #DUTY CYCLE=' )
   READ (5,2)IPCU(I)
   IF (IPCU(I).GE.50) GO TO 9
   WRITE (5,51)
51  FORMAT (' DUTY CYCLE MUST BE 50% OR GREATER.')
   GO TO 52
9   CONTINUE
7   IF (DEFAU.EQ.1)GO TO 906
   WRITE (5,13)IPCU
13  FORMAT (/ ' VARIAC DUTY CYCLES'/(10I5))
C*****
C*****SELECT 4-CHARACTER FILENAME AND NUMBER OF RECORDS IF DEFAULT
C****:*PARAMETERS ARE NOT DESIRED.
C*****
   WRITE (5,20)
20  FORMAT (/ '#FILENAME IS (4 CHAR.) ')
   READ (5,21)FILE(2)
21  FORMAT (A4)
   WRITE (5,22)
22  FORMAT (' A DATA SET WILL BE STORED EVERY 60 MINUTES.'/
1' #HOW MANY DATA SETS DO YOU WISH TO STORE IN THIS FILE? ')
   READ (5,2)NREC
C*****
C*****ADD 90 RECORDS FOR STORING DATA EVERY 2 MINUTES FOR UP TO
C*****3 HOURS WHEN ALARM CONDITIONS EXIST.
C*****
906 IF (NREC.NE.0)NREC=NREC+90
   WRITE (5,900)
900 FORMAT (/ ' WAITING FOR DISK FILE INITIALIZATION...')
C*****
C*****CREATE A FILE ON DK2. CLOSE, THEN REOPEN THE FILE. THIS
C*****PREVENTS LOSS OF THE FILE IF PROGRAM PCS IS ABORTED BY A
C*****CONTROL C.
C*****
   CALL ASSIGN(2,FILE,12,'NEW','NC',1)
   DEFINE FILE 2(NREC,256,U,NR)
   DO 203 I=1,NREC
   II=I
203 WRITE (2,II)EMPTY
   CALL CLOSE(2)
C*****
C*****STORE DATA EVERY 20 MINUTES FOR FIRST 2 HOURS.
C*****
   ISTORE=ISTORI
   CALL ASSIGN(2,FILE,12,'OLD','NC',1)
   DEFINE FILE 2(NREC,256,U,NR)
C*****
C*****DEFINE WARNING AND ALARM LIMITS.
C*****
   TREFE(1)=TREF+10.
   TREFE(2)=TREF+17.
   TREFE(3)=TREF-10.
   TREFE(4)=TREF-17.
C*****
C*****SET FAILED TE'S TO TREF.
C*****
   TC(15,2)=TREF
   TC(11,2)=TREF
   TC(12,2)=TREF
   TC(7,4)=TREF

```



```

C*****
C*****NOTIFY OPERATOR TO ACTIVATE COMPUTER FAILURE ALARM,
C*****
      WRITE (5,904)
904  FORMAT(/' SWITCH COMPUTER FAILURE ALARM OUT OF BYPASS POSITION,')
C*****
C*****:READ ANALOG DATA (THERMOCOUPLES, REFERENCE JUNCTION TEMPERATURES,
C*****REACTOR POWER, WATT TRANSDUCER).
C*****
      IERR(9)=1
      IERR(10)=80
      CALL TCDIST

C*****
C*****WAIT FOR END OF A CLOCK TICK PREPARATORY TO SCHEDULING THE
C*****SUPERVISOR SUBPROGRAM.
C*****
4448  ITLAST=ITI
      CALL GTIM(ITIME)
      CALL CVTTIM(ITIME,IH1,IM1,IS1,IT1)
      IF (IT1.EQ.ITLAST)GO TO 4448

C*****
C*****SCHEDULE SUPERVISORY SUBPROGRAM TO EXECUTE ON A PRIORITY BASIS
C*****EVERY 12 TICKS.
C*****
      CALL SUPER(ISUB1)

C*****
C*****ENTER BACKGROUND LOOP FOR OUTPUTTING DATA TO TERMINAL AND DISK.
C*****
4      IF (ISW.EQ.86)GO TO 44
      IF (ISW.EQ.175)GO TO 444
      GO TO 4

C*****
C*****INPUT TIME
C*****
44     CALL GTIM(ITIME)
      CALL CVTTIM(ITIME,IH3,IM3,IS3,IT3)

C*****
C*****THIS LOOP IS ONLY INCORPORATED IN THE PROGRAM WHEN A DUMMY SSC
C*****IS IN PLACE. ALL TE'S ARE SET TO THE REFERENCE TEMPERATURE.
C*****
      DO 5555 I=1,20
5555  TC(I,1)=TREF

C*****
C*****INCREMENT DATE COUNTER AT MIDNIGHT.
C*****
      IF (NHRL.EQ.23.AND.IH3.EQ.0)NODAY=NODAY+1
      NHRL=IH3

C*****
C*****STORE DATA ON DISK EVERY 60 MIN, UNLESS ALARMS OR WARNINGS EXIST.
C*****THEN STORE DATA EVERY 2 MINUTES.
C*****
      NUMR=0
      NINTC=NINTC+1
      IF (NINTC.LT.ISTORE)GO TO 209
      NINTC=0
      NINT=NINT+1

C*****
C*****CHANGE STORAGE RATE TO ONCE PER HOUR AFTER FIRST 2 HOURS OF
C*****OPERATION.
C*****
      IF (NINT.EQ.6)ISTORI=90
      IF (NFULL.EQ.1)GO TO 209
      NUMR=NINT
      IF (NREC.NE.0)WRITE (2,NINT)NODAY,IH3,IM3,IS3,IT3,PL,TC,IPCU
209  WRITE (5,201)FILE,NUMR,IH3,IM3,IS3,NODAY,PL,IAD(21)
201  FORMAT (' FILE ',3A4,I5,' TIME',3I3,' DATE ',I3,
1,' REA POW=',F5.1,I5)
      WRITE (5,200)
200  FORMAT ('          FRONT FACE',21X,'BACK FACE',
111X,'VARIACS')
      WRITE (5,400)TC(1,1),TC(9,1),TC(14,1),TC(8,1),IPCU(1),IPCU(21),
1          TC(1,2),TC(9,2),TC(14,2),TC(8,2),IPCU(2),IPCU(22),
2          TC(1,3),TC(9,3),TC(14,3),TC(8,3),IPCU(3),IPCU(23),
3          TC(1,4),TC(9,4),TC(14,4),TC(8,4),IPCU(4),IPCU(24)

```

```

400  FORMAT (F6.0,6X,F6.0,6X,F6.0,12X,F6.0,12X,2I4)
      WRITE (5,401)TC(2,1),TC(15,1),IPCU(5),IPCU(25),
1      TC(2,2),TCBIG,IPCU(6),IPCU(26),
2      TC(2,3),TC(15,3),IPCU(7),IPCU(27),
3      TC(2,4),TC(15,4),IPCU(8),IPCU(28)
401  FORMAT (36X,F6.0,6X,F6.0,6X,2I4)
      WRITE (5,402)TC(3,1),TC(16,1),IPCU(9),IPCU(29),
1      TC(3,2),TC(16,2),IPCU(10),IPCU(30),
2      TC(3,3),TC(16,3),IPCU(11),IPCU(31),
3      TC(3,4),TC(16,4),IPCU(12),IPCU(32)
402  FORMAT (F6.0,18X,F6.0,30X,2I4)
      WRITE (5,403)TC(11,1),TC(4,1),TC(10,1),TC(17,1),IPCU(13),IPCU(33)
1,      TCBIG,TC(4,2),TC(10,2),TC(17,2),IPCU(14),IPCU(34)
2,      TC(11,3),TC(4,3),TC(10,3),TC(17,3),IPCU(15),IPCU(35)
3,      TC(11,4),TC(4,4),TC(10,4),TC(17,4),IPCU(16),IPCU(36)
403  FORMAT (12X,F6.0,18X,2F6.0,'*',F5.0,6X,2I4/
1(12X,F6.0,18X,3F6.0,6X,2I4))
      WRITE (5,402)TC(5,1),TC(18,1),IPCU(17),IPCU(37),
1      TC(5,2),TC(18,2),IPCU(18),IPCU(38),
2      TC(5,3),TC(18,3),IPCU(19),IPCU(39),
3      TC(5,4),TC(18,4),IPCU(20),IPCU(40)
      WRITE (5,4011)TC(6,1),TC(19,1),
1      TC(6,2),TC(19,2),
2      TC(6,3),TC(19,3),
3      TC(6,4),TC(19,4)
4011 FORMAT (36X,F6.0,6X,F6.0)
      WRITE (5,4001)TC(7,1),TC(13,1),TC(20,1),TC(12,1),
1      TC(7,2),TC(13,2),TC(20,2),TCBIG,
2      TC(7,3),TC(13,3),TC(20,3),TC(12,3),
3      TCBIG,TC(13,4),TC(20,4),TC(12,4)
4001 FORMAT (F6.0,'*',5X,F6.0,6X,F6.0,12X,F6.0/
1(F6.0,6X,F6.0,6X,F6.0,12X,F6.0))
      WRITE (5,780)
780  FORMAT (' *UNRELIABLE')
      IF (NFULL.EQ.1)WRITE (5,560)
560  FORMAT (' DISK FILE IS FULL.')
C*****
C*****SET UNRELIABLE TE'S TO TREF.
C*****
      TC(10,1)=TREF
      TC(7,1)=TREF
      GO TO 444
444  WRITE (5,501)TREF,TAUG,TRD5,DTMX
501  FORMAT (' TREF=',F4.0,' TAUG=',4F6.1,' TRD5=',F5.1/' DTMX=',4F6.1)
C*****
C*****LIST TEMPERATURES STATISTICALLY REJECTED BY THE CONTROL
C*****ALGORITHM.
C*****
      NLST=0
      DO 750 J=1,4
      DO 750 I=1,20
      IF (NSG(I,J).EQ.0)GO TO 750
      IF (NLST.EQ.0)WRITE (5,751)
751  FORMAT (' REJECTED BY CNTRL:')
      NI ST=1
      IJ=I+(J-1)*100
      WRITE (5,752)IJ
752  FORMAT (' TE ',I3)
750  CONTINUE
C*****
C*****SOUND ANNUNCIATOR WHEN WARNING OR ALARM CONDITION EXISTS.
C*****
      ISTORE=ISTORI
      DO 601 I=1,5
      IF (IERR(I).LE.8)GO TO 6012
      ISTORE=3
      INDA(I)=INDA(I)+1
      I6012=1
      IF (INDA(I).EQ.1.AND.IANN.EQ.1)CALL M6012R
      GO TO 601
6012 IF (INDA(I).GE.1)INDA(I)=0
601  CONTINUE

```

```

C*****
C*****IF METHOD 3 OF CONTROL ALGORITHM WAS SELECTED, OUTPUT
C*****COMPUTED VARIAC CHANGES.
C*****
      IF (ICMTH.EQ.3)WRITE(5,56)PVAR
56   FORMAT (' NEEDED CHANGES IN HEATER POWER'/(10F6.1))
C*****
C*****LIST ERROR CONDITIONS.
C*****IF 10% OF TC'S EXCEED TREF+17, RESET
C*****THE DUTY CYCLES OF ALL HEATERS TO 0. SET MODE TO MANUAL.
C*****
      IF (IERR(2).LE.8)GO TO 207
      MAUTO=0
      WRITE (5,210)
210  FORMAT (' ***ALL HEATERS OFF***')
      DO 211 I=1,40
211  IPCU(I)=0
C*****
C*****IF MORE THAN 10% OF TC'S EXCEED LIMITS, PRINT MESSAGE.
C*****
207  DO 206 I=1,4
      IF (IERR(I).GT.8)WRITE (5,267)(AMESS(J,I),J=1,2),TREFE(I)
      1,IH3,IM3,IS3,NODAY
267  FORMAT (' **ERROR** TEMPS ',2A4,F4.0,2X,3I3,I5)
206  CONTINUE
      IF (IERR(5).EQ.10)WRITE (5,9999)
9999 FORMAT (' **ERROR** REF TEMP INCORRECT. CALL EXPERIMENTER.')
```

```

      IERR(5)=0
C*****
C*****DEACTIVATE ALARM ANNUNCIATOR RELAY IF SET.
C*****
      IF (I6012.EQ.0)GO TO 4
      I6012=0
      CALL MA012R
      GO TO 4
```

```

C*****
C*****CLOSE DATA FILE IF IT IS FULL.
C*****
4444 IF (NINT.NE.NREC)GO TO 4
      IF (NFULL.EQ.1)GO TO 4
      NFULL=1
      CALL CLOSE(2)
      GO TO 4
      END
```

```

Files copied:
DK1: SUPER.FOR to TT: SUPER.FOR
C*****
C*****SUBPROGRAM SUPER SUPERVISES THE CONTROL SEQUENCE, COMPUTES CONTROL
C*****PARAMETERS, ADJUSTS HEATER POWERS, AND ACQUIRES TEMPERATURE DATA.
C*****SUPER RESCHEDULES ITSELF TO EXECUTE EVERY 12 TICKS (200 MSEC).
C*****200 EXECUTIONS OF SUPER (40 SECONDS) ARE REQUIRED TO COMPLETE ALL
C*****NECESSARY CONTROL AND DATA ACQUISITION FUNCTIONS BEFORE THE
C*****PROCESS IS REPEATED. SUPER SCHEDULES THESE FUNCTIONS BY TESTING
C*****AN INDEX, ISW, WHICH EQUALS 1-200, AND INITIATING THE PROPER
C*****ACTION. THESE FUNCTIONS ARE:
C*****FOR ISW=1      , REPLACE HEATER DUTY CYCLES WITH LAST COMPUTED
C*****                VALUES;
C*****  ISW=2      , READ HALF OF ANALOG INPUTS AND COMPUTE REACTOR
C*****                POWER;
C*****  ISW=3-85   , COMPUTE THE 3 JUNCTION BOX REFERENCE TEMPERATURES
C*****                AND 80 THERMOCOUPLE READINGS IN ENGINEERING UNITS;
C*****  ISW=86-134 , OUTPUT TO CRT TERMINAL AND DISK;
C*****  ISW=135   , ERROR CHECK;
C*****  ISW=136-171, COMPUTE CONTROL PARAMETERS;
C*****  ISW=172-174, FIRE HEATERS ONLY;
C*****  ISW=175-199, OUTPUT TO CRT;
C*****  ISW=200   , READ HALF OF ANALOG INPUTS AND RESET ISW.
C*****  (FOR ALL VALUES OF ISW, FIRE HEATERS.)
C*****
SUBROUTINE SUPER(ISUB1)
EXTERNAL SUPER
DIMENSION I1SUB(4)
COMMON/FLAG/IFLG
COMMON/IPCOMM/IPKEEP(10,4)
COMMON/TE/IAD(85)
COMMON/COMM/REF(2),IPF,MAUTO,ISW,M6012,WATTR,PL,IERR(10),TRD5
COMMON/CTRDAT/IMOD,TC(20,4),TREF,NCAP,VAR5(10,4),
1NOCNTL,NTHP,TAVDM,TMDV,IBDAT,U(20),IPCUR(10,4),
2ICMTH,IUDTH,NCPSS(4),TAVG(4),NCALL(4),NTAU,
3CFAC(10,4),F(10,20,4),PREF(10,4),PVAR(10,4)
DATA ICALL/12/
C*****
C*****SET TIMER TO RECALL SUPER AFTER TWELVE TICKS.
C*****
      CALL ITIMER(0,0,0,ICALL,I1SUB,1,SUPER)
C*****
C*****FIRE HEATERS.
C*****
      CALL FIRE
C*****
C*****IF SUBROUTINE M6011 DETECTED A SINGLE-SHOT MISFIRE (BECAUSE OF
C*****HARDWARE TIMING ERROR), PREPARE TO RESCHEDULE SUPER.
C*****
      ICALL=12
      IF (IFLG.NE.0)ICALL=15
C*****
C*****DETERMINE WHETHER MODE IS MANUAL OR AUTOMATIC.
C*****
      IF (MAUTO.GT.0) GO TO 8
C*****
C*****MAUTO=0. MANUAL. CALL ERROR CHECKING ROUTINE.
C*****
      IF (ISW.EQ.135)CALL ERRCHK
      GO TO 4
C*****
C*****MAUTO=1. AUTO.
C*****
      8  IF (ISW.NE.135)GO TO 88
C*****
C*****INITIALIZE CONTROL ROUTINE PARAMETERS. CALL ERROR CHECKING ROUTINE.
C*****
      NCAP=1
      NCAPC=0
      IF (IPF.EQ.1)GO TO 40
      IF (IUDTH.EQ.0)GO TO 4
      IPF=1
      40 IF (ICMTH.NE.3)CALL ERRCHK
      GO TO 4

```

```

C*****
C*****WHEN ISW=136-171, CALL CNTRL. CALL CNTRL 9 TIMES
C*****FOR EACH OF THE 4 COMPARTMENTS IN THE CAPSULES.
C*****
88      IF (ISW.LT.136.OR.ISW.GT.171)GO TO 4
        CALL CNTRL
        NCAPC=NCAPC+1
        IF (NCAPC.LT.9)GO TO 4
        NCAF=NCAF+1
        NCAPC=0
C*****
C*****EXECUTE FUNCTIONS.
C*****
4       ISW=ISW+1
        IF (ISW.GT.85.AND.ISW.LT.200)RETURN
C*****
C*****CONVERT ANALOG DATA TO ENGINEERING UNITS.
C*****
        IF (ISW.GE.3.AND.ISW.LE.85)GO TO 20
C*****
C*****REPLACE HEATER DUTY CYCLES.
C*****
        IF (ISW.EQ.1)GO TO 21
C*****
C*****READ FIRST 84 ANALOG CHANNELS.
C*****
        IF (ISW.NE.2)GO TO 9
C*****
C*****READ TE'S 41-80. COMPUTE REACTOR POWER.
C*****ISW=2.
C*****
        IERR(9)=41
        IERR(10)=80
        CALL TCDIST
        PL=IAD(84)*.05
        RETURN
C*****
C*****READ TE'S 1-40. RESET COUNTER WHEN ISW=200.
C*****
9       IERR(9)=1
        IERR(10)=40
        CALL TCDIST
        ISW=0
        RETURN
20      CALL TEMP
        RETURN
21      DO 22 I=1,4
        DO 22 J=1,10
22      IPKEEP(J,I)=IPCUR(J,I)
        RETURN
        END

```

Files copied:

DK1:FIRE.FOR to TT:FIRE.FOR

C*****

C*****SUBPROGRAM FIRE. DETERMINE WHICH HEATERS WILL BE FIRED DURING

C*****THIS DUTY CYCLE AND PULSE THE RELATED SSR'S FOR 200 MSEC.

C*****

SUBROUTINE FIRE

COMMON/COMM/REF(2),IPF,MAUTO,ISW,M6012,WATTR,PL,IERR(10),TRD5

COMMON/IPCOMM/IPKEEP(10,4)

COMMON/CTRDAT/IMOD,TC(20,4),TREF,NCAP,VARS(10,4),

1NOCTL,NTMP,TAVDH,TMDV,IBDAT,U(20),IPCUR(10,4),

2ICMTH,IUDTR,NCPSS(4),TAVG(4),NCALL(4),NTAU,

3CFAC(10,4),F(10,20,4),PREF(10,4),PVAR(10,4)

COMMON/DOUT/ID(6)

DIMENSION IMASK(10,4)

DATA IMASK/'1','2','4','10','20','40','100','200','1','2','4','10','20','40',

'1','100','1','2','4','10','20','40','100','200','1','2','4','10','20','40','100

'2','1','2','4','10','20','40','100','200','1','2'

C*****

C*****CLEAR ALL D/O CHANNELS EXCEPT THE COMPUTER FAILURE ALARM.

C*****

DO 1 I=1,5

1 ID(I)=0

ID(6)=4

ISWT=ISW+1

IF (ISW.GT.99) ISWT=ISWT-100

DO 2 I=1,4

DO 2 J=1,10

C*****

C*****NOFF=NUMBER OF TIMES HEATER IS OFF DURING EACH 100 DUTY

C*****CYCLES. (ASSUMED TO BE LESS THAN OR EQUAL TO 50.)

C*****

NOFF=100-IPKEEP(J,I)

IF (NOFF.EQ.0)GO TO 8

IF (NOFF.GT.50)GO TO 2

C*****

C*****PULSE THE HEATER EVERY OTHER DUTY CYCLE(12 TICK PERIOD)

C*****UNTIL NOFF HAS BEEN REACHED. THEN PULSE HEATER EVERY CYCLE

C*****UNTIL THE 100 DUTY CYCLES(1200 TICKS OR 20 SEC.) ARE

C*****COMPLETE. IF ISWT IS ODD, THE HEATER IS OFF.

C*****

IF (ISWT.GE.(2*NOFF))GO TO 8

IEO=MOD(ISWT,2)

IF (IEO.EQ.1)GO TO 2

C*****

C*****DETERMINE M6011 BYTES.

C*****

8 GO TO (3,4,5,6),I

C*****

C*****I=1.

C*****

3 ISUB=1

IF (J.GT.8)ISUB=2

GO TO 7

C*****

C*****I=2.

C*****

4 ISUB=2

IF (J.GT.5)ISUB=3

GO TO 7

C*****

C*****I=3.

C*****

5 ISUB=3

IF (J.GT.3)ISUB=4

GO TO 7

```

C*****
C*****I=4.
C*****
6      ISUB=5
      IF (J.GT.8)ISUB=6
7      ID(ISUB)=ID(ISUB).OR.IMASK(J,I)
2      CONTINUE
      CALL M6011
      RETURN
      END

```

Files copied:

DK1:TCDIST.FOR to TT:TCDIST.FOR

C*****

C*****SUBPROGRAM TCDIST READS ALL THERMOCOUPLES AND REACTOR POWER.

C*****

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SUBROUTINE TCDIST
  DIMENSION IAC(85),IAD(85)
  COMMON/COMM/REF(2),IPF,MAUTO,ISW,M6012,WATTR,PL,IERR(10),TRD5
  COMMON/CTRDAT/IMOD,TC(20,4),TREF,NCAP,VAR5(10,4),
  INOCTL,NTMP,TAVDM,TMDV,IBDAT,U(20),IFCUR(10,4),
  2ICMTH,IUDTR,NCFSS(4),TAVG(4),NCALL(4),NTAU,
  3CFAC(10,4),F(10,20,4),PREF(10,4),PVAR(10,4)
  COMMON/TE/IAD
  COMMON/ADINP/I0,I2,I3
  DATA IAC/'300','301','302','303','304','305','306','307','310','311
  1','312','313','314','315','316','317','240','241','242','243','244
  2','245','246','247','250','251','252','253','254','255','256','257','200','201
  3','202','203','204','205','206','207','210','211','212','213','214','215','216
  4','217','140','141','142','143','144','145','146','147','150','151','152','153
  5','154','155','156','157','100','101','102','103','104','105','106','107','110
  6','111','112','113','114','115','116','117','41','41','40','44,0/'

```

C*****

C*****SET GAIN TO 500. READ THERMOCOUPLES.

C*****

```

      I3='301
      DO 1 I=IERR(9),IERR(10)
      I2=IAC(I)
      CALL A014
1      IAD(I)=I0-2048

```

C*****

C*****SET GAIN TO 100. READ REFERENCE TEMPERATURES AND REACTOR POWER.

C*****

```

      I3='221
      DO 2 I=81,84
      I2=IAC(I)
      CALL A014
2      IAD(I)=I0-2048
      RETURN
      END

```

```

Files copied:
DK1:TEMP.FOR to TT:TEMP.FOR
C*****
C*****SUBPROGRAM TEMP CONVERTS RAW THERMOCOUPLE DATA TO ENGINEERING
C*****UNITS.
C*****
SUBROUTINE TEMP
DIMENSION ISUB(80),AD(83)
COMMON/TE/IAD(85)
COMMON/COMM/REF(2),IPF,MAUTO,ISW,M6012,WATTR,FL,IERR(10),TRD5
COMMON/CTRDAT/IMOD,TC(80),TREF,NCAP,VAR(10,4),
1NOCTL,NTMP,TAVDH,TMDV,IBDAT,U(20),IPCUR(10,4),
2ICMTH,IUDTR,NCPS(4),TAVC(4),NCALL(4),NTAU,
3CFAC(10,4),F(10,20,4),PREF(10,4),PVAR(10,4)
DATA TRD5/100./,ISUB/20*83,17*82,3*81,8*81,12*82,8*82,12*81/
C*****
C*****IAD(1)-IAD(20) =A/D DATA FOR TE'S 1-20.
C*****IAD(21)-IAD(80) =A/D DATA FOR TE'S 101-120, 201-220, 301-320.
C*****IAD(81)-IAD(83) =A/D DATA FOR ISOTHERMAL REFERENCE BOXES
C*****#4, #4, AND #5, RESPECTIVELY.
C*****AD(1)-AD(80) =TEMPERATURES IN MILLIVOLTS (CORRECTED WITH
C*****REFERENCE TEMPERATURES).
C*****AD(81)-AD(83) =ISOTHERMAL REFERENCE BOX TEMPERATURES IN
C*****MILLIVOLTS RELATIVE TO THE ICE POINT FOR EACH BOX.
C*****EO = ISOTHERMAL REFERENCE TEMPERATURE.(DEGREES C.)
C*****TR = ISOTHERMAL REFERENCE TEMPERATURE.(DEGREES F.)
C*****TC(1)-TC(80) =THERMOCOUPLE READINGS(DEGREES F.) FOR TE'S 1-20,
C*****101-120, 201-220, AND 301-320.
C*****COMPUTE THE THREE ISOTHERMAL BOX TEMPERATURES IN DEGREES C.
C*****CONVERT TO DEGREES F.
C*****EO(1)=B0+B1*IAD(81)+B2*IAD(81)**2, ETC.
C*****B0=61.9964
C*****B1=493.893*359.74/15000.=11.84487
C*****B2=13.0599*359.74**2/15000.**2=.00751164
C*****WHEN ISW=3,5 THEN J=1,3.
C*****WHEN ISW=6,85 THEN ITCN=1,80
C*****
IF (ISW.GE.6)GO TO 2
J=78+ISW
C*****
C*****CONVERT REF TEMP DATA TO MV SCALE. LSB AT GAIN OF 100 =.05 MV.
C*****
EO=IAD(J)*.05
C*****
C*****TEST REF TEMP AGAINST LAST READING. SHOULD BE STABLE.
C*****IF NOT, THE A157 HAS FAILED. SET REF TEMP EQUAL TO LAST
C*****READ VALUE.
C*****
IF (TRD5.EQ.100.)GO TO 3
DEL=ABS(E0-TRD5)
IF (DEL.LT.3)GO TO 3
IERR(5)=10
PL=30.
EO=TRD5
IAD(J)=TRD5/.05
3
TR=1.8*EO+32.
C*****
C*****COMPUTE EQUIVALENT MV READING RELATIVE TO ICE POINT FOR EACH
C*****REFERENCE TEMPERATURE.
C*****
AD(J)=-.6818602+.02111578*TR+1.023373E-05*TR**2
1-1.653833E-08*TR**3
IF (ISW.EQ.5)TRD5=EO
RETURN
C*****
C*****CONVERT TC DATA TO MV SCALE. LSB AT GAIN OF 500=.01
C*****

```



```

2      ITCN=ISW-5
      IF (ITCN.EQ.67.OR.ITCN.EQ.32.OR.ITCN.EQ.35.OR.ITCN.EQ.31)RETURN
      AD(ITCN)=IAD(ITCN)*.01+AD(ISUB(ITCN))
      TC(ITCN)=33.3132+42.5125*AD(ITCN)+.418592*AD(ITCN)**2-.0359595*
      1AD(ITCN)**3+1.19627E-03*AD(ITCN)**4-1.75727E-05*AD(ITCN)**5
C*****
C*****CONVERT TC READING TO CENTIGRADE.
C*****
      TC(ITCN)=(TC(ITCN)-32.)/1.8
C*****
C***** IF (ITCN.GE.1.AND.ITCN.LE.20)TC(ITCN)=TREF
C*****
      RETURN
      END

```

Files copied:
DK1:ERRCHK.FOR to TT:ERRCHK.FOR
SUBROUTINE ERRCHK

```

C*****
C*****DETERMINE WARNING AND ALARM CONDITIONS.
C*****
      COMMON/COMM/REF(2),IPF,MAUTO,ISW,M6012,WATTR,PL,IERR(10),TRDS
      COMMON/CTRDAT/IMOD,TC(20,4),TREF,NCAP,VAR(10,4),
      1NOCTL,NTMP,TAVDM,TMDV,IBDAT,U(20),IFCUR(10,4),
      2ICMTH,IUDTR,NCPSS(4),TAUG(4),NCALL(4),NTAU,
      3CFAC(10,4),F(10,20,4),PREF(10,4),PVAR(10,4)
      COMMON/ERRC/TREFE(4)
C*****
C*****IERR(1)-HIGH TC WARNING
C*****IERR(2)-HIGH TC ALARM
C*****IERR(3)-LOW TC WARNING
C*****IERR(4)-LOW TC ALARM
C*****
      DO 2 I=1,4
2      IERR(I)=0
C*****
C*****COUNT NUMBER OF TEMPERATURES OUT OF LIMITS.
C*****
      DO 1 I=1,20
      DO 1 J=1,4
      IF (TC(I,J).GT.TREFE(1))IERR(1)=IERR(1)+1
      IF (TC(I,J).GT.TREFE(2))IERR(2)=IERR(2)+1
      IF (TC(I,J).LT.TREFE(3))IERR(3)=IERR(3)+1
      IF (TC(I,J).LT.TREFE(4))IERR(4)=IERR(4)+1
1      CONTINUE
C*****
C*****IF ALARM CONDITION EXISTS, SUPPRESS WARNING FLAG.
C*****
      IF (IERR(2).GT.8)IERR(1)=0
      IF (IERR(4).GT.8)IERR(3)=0
      RETURN
      END

```

```

Files copied:
DK1:A014R.MAC to TT:A014R.MAC
.TITLE A014
; SUBROUTINE A014R READS 1 ANALOG INPUT CHANNEL FROM THE A014 OR
; FROM AN A157.
.PSECT ADINP,GBL,RW,D,REL,OVR
; I0=2 BYTES CONVERTED DATA,
; I2=1 BYTE A014 OR A157 ADDRESS DATA,
; I3=1 BYTE STATUS REGISTER,
I0: .BLKW 1
I2: .BLKW 1
I3: .BLKW 1
.PSECT
CSR=171377
; PREPARE TO READ THE CHANNEL FOUR TIMES.
A014:: CLR B 15
      CLR I0
; ESTABLISH ADDRESS AND GAIN, INITIATE CONVERSION.
AGAIN: MOV B 12, @A2
      MOV B 13, @A3
      INC B 15
; ALLOW TIME FOR SYNCHRONIZATION OF Q AND D BUS CYCLES.
NOP
NOP
NOP
NOP
NOP
NOP
; DETERMINE WHETHER CONVERSION IS DONE.
LOOP: MOV B @A3, I4
      BIT B #2, I4
      BNE DONE
      JMP LOOP
; CONVERSION FINISHED. SET RIF BIT.
DONE: INC B CSR
; GET HIGH BYTE OF DATA, RIF.
      MOV B @A1, I6
; MASK IRRELEVANT BITS.
      BIC #177760, I6
      SWAB I6
; GET LOW BYTE.
      BIS B @A0, I6
      ADD I6, I0
; DETERMINE IF FOUR READINGS OF THE CHANNEL HAVE BEEN TAKEN.
; IF SO, AVERAGE AND RETURN.
      BIT B #4, I5
      BNE AVG
      JMP AGAIN
AVG: ASR I0
     ASR I0
     RTS PC
A0: 171000
A1: 171001
A2: 171002
A3: 171003
I4: 0
I5: 0
I6: 0
.END

```

Files copied:

DK1:M6011R.MAC to TT:M6011R.MAC

.TITLE M6011

```
# SUBROUTINE M6011R INITIATES SINGLE-SHOT DIGITAL OUTPUT PULSES OF
# 200 MSEC FROM THE 6 M6011 MODULES. THE FIRST 40 OUTPUT CHANNELS DRIVE
# THE SOLID STATE RELAYS FOR HEATER CONTROL. CHANNEL 41 MAINTAINS A
# WATCHDOG TIMER FOR SENSING COMPUTER FAILURE.
```

```
.PSECT DOUT,GBL,RW,D,REL,OVR
I1: .BLKW 1
I2: .BLKW 1
I3: .BLKW 1
I4: .BLKW 1
I5: .BLKW 1
I6: .BLKW 1
```

```
.PSECT FLAG,GBL,RW,D,REL,OVR
FLG: .BLKW 1
.PSECT
```

```
# TEST CHANNEL 41. IRRECONCILABLE TIMING INCONSISTENCIES BETWEEN THE
# M6011 HARDWARE AND THE PDP-1/03 (LTC AND CRYSTAL-CONTROLLED M6011
# CLOCK AND Q AND D BUSES) SOMETIMES CAUSE OUTPUT PULSES TO BE SKIPPED.
# CHANNEL 41 (WATCHDOG TIMER) SHOULD ALWAYS BE ACTIVE AND IS THEREFORE
# A GOOD TEST POINT. IF IT IS NOT ACTIVE, AN ERROR FLAG IS SET AND THE
# SUPERVISORY ROUTINE (SUPER) RESCHEDULES EXECUTION OF M6011R AT A DIFF-
# ERENT INTERVAL. THIS CORRECTIVE ACTION HAS THE EFFECT OF LIMITING THE
# NUMBER OF MISSED PULSES TO 1 OR 2 RATHER THAN ALLOWING THE MISSES TO
# CONTINUE UNTIL THE TIMING OF THE MODULE AND COMPUTER HAS DRIFTED BACK
# TO AN ACCEPTABLE LIMIT.
```

```
M6011:: CLR FLG
        MOVB @A6,IX1
        BITB #4,IX1
        BNE NXT
        INC FLG
NXT:    MOVB I1,@A1
        MOVB I2,@A2
        MOVB I3,@A3
        MOVB I4,@A4
        MOVB I5,@A5
        MOVB I6,@A6
# DELAY FOR D-BUS CYCLE.
        NOP
        NOP
        NOP
```

```
# TEST CHANNEL 41 AGAIN.
        MOVB @A6,IX1
        BITB #4,IX1
        RNF RTN
        INC FLG
RTN:    RTS PC
```

```
IX1:   0
A1:    171004
A2:    171005
A3:    171006
A4:    171007
A5:    171010
A6:    171011
        .END
```

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