COMPUTER PROGRAMS FOR OPERATION OF THE HIGH TEMPERATURE LATTICE TEST REACTOR (HTLTR)

VOLUME I

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COMPUTER PROGRAMS FOR OPERATION OF THE HIGH TEMPERATURE LATTICE TEST REACTOR (HTLTR)

VOLUME I

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OPERATIONAL PROGRAMS FOR THE HIGH TEMPERATURE LATTICE TEST REACTOR (HTLTR)

ABSTRACT

A digital computer has been interfaced with a reactor measurement and control system. Descriptions are given for all the computer programs which are an integral part of that system and which allow the operation of the reactor and associated equipment. Program functions, detailed coding descriptions and listings are included. In addition, program integration and techniques for updating the system are described.

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I. INTRODUCTION

This document describes the computer programmed system for the High Temperature Lattice Test Reactor (HTLTR). A small digital computer has been interfaced with the reactor instrumentation and control system. The programmed measurement and control system (PMACS) is an on-line, real time application, with direct digital computer control being applied to the heating and cooling loops associated with the reactor. There is no closed loop control for the nuclear system; however, the system is much more than a data acquisition or logging process. The main system programs are quite sophisticated in the areas of aiding reactor operations and fulfilling safety requirements. In addition, other parts of the programmed system allow diverse on-line data output.

The reactor facility, located at Pacific Northwest Laboratory, Richland, Washington, will be used to take nuclear data at high temperatures (1000°C). This data will provide support for the design of high temperature power reactors.

The reactor consists of a ten foot cube of graphite with a removable central section--all enclosed within an insulated, gas-tight container.

The driver fuel consists mainly of UO_2 of about 5 - 10 weight per cent enrichment.

The reactor is heated with numerous graphite heater bars powered with 384 kw. Temperature measurements are taken from 32 thermocouple inputs and two movable high precision RTD's (0 - 400°).

The reactor blanket is a recirculating nitrogen atmosphere at low pressure. Controlling and monitoring devices associated with the gas system are: (1) one gas blower, (2) seven digital stepping valves, (3) two binary (open-closed) valves, (4) four feedback flow transducer elements, (5) gas chromatographs and moisture monitors, (6) ten low precision RTD's (0 - 400°C).

The flux level is measured by digitized signals from boron-lined ion chambers. The flux level is controlled with 8 horizontal control rods and four vertical safety rods.

The complete computer programmed system is composed of a highly integrated set of executive control and utility routines and another set of programs which operationally, depend upon both the digital computer and the interfaced measurement and control system (Astrodata 4022-100 and

4022-101). A general description of the reactor system programs is indeed a description of the reactor instrumentation requirements for the HTLTR. Briefly, the requirements are (1) the capability of monitoring nuclear flux and automatic calculation of reactor period and power. (2) Control loops for heating the reactor and maintaining a desired temperature. (3) Control loops for cooling the reactor and operating vital equipment within safe limits. (4) Detection of the off-on or closed-open status of mechanical devices such as valves and reactor doors, hereafter, called watch channel or direct digital inputs. (5) The ability to accurately measure the position of all horizontal control rods every .1 second and to complete the operator-computer control with respect to operational safety requirements. In addition, the capability must exist to monitor the vertical rod status at all times. (6) The capability of logging, displaying, and storing all measured data and watch channel inputs (as described above) in meaningful, easy-to-read form for reactor operations and the physics staff. (7) The capability of scramming the reactor must exist--independent of operator intervention. This is merely an extension of (1), (4), and (5) above in conjunction with the safety requirements. (8) The capability for operator communication with the computer must exist. The operator must, for example, be able to ask for heat control, turn heat control off, demand various outputs (demand displays or logging on typewriters), and ask to move the control rods. These are but a few of the many computer or demand program actions. In section VII, the detailed description of the keyboard executive and operator-machine communication is described.

A rather detailed description of the general systems requires a knowledge of the digital transfer registers within the Astrodata hardware and the computer-Astrodata commands for bi-directional transfer of data. In addition, one must become somewhat familiar with the mechanical devices and their characteristics. For example, it is not sufficient to assume a valve is closed and thereby initiate computer commands to activate the stepping motors--for the valve may have reached its fail safe position (possibly closed) and yet the threaded drive may indicate a partially open condition. A general description of the Astrodata-computer interface is described in section II of this document. Further hardware-program details are included with each specific program.

Because of the close interdependency between the computer, the interface system and the hardware of the reactor system itself, any Fortran language was impossible. Even if such special command structure did not exist, a Fortran system would have been impractical. These reasons are discussed in Section III. Again, because of this inter-dependency, the programming and computer memory requirements sometimes were responsible for actual hardware and interface modifications--and of course, the converse was true with regard to programming. The peculiarities of the hardware complicated much of the functional programming. The general program philosophy and the programmed system is also discussed in Section III.

Section IV includes a detailed description of the main executive program and a group of service and utility programs. These programs are permanent core residents and are necessary for even the most limited operation. The executive control (MAIN) is the idling loop and has program control whenever an interrupt is not being serviced or when any other program is not executing. MAIN coordinates the system and allows the execution of all non-interrupt programs. Two of the service routines described in this section are interrupt driven programs--the analog to digital (AD) conversion routine and the micro-tape interrupt routine (MICRO) which is initialized by the program, MAIN. The remaining are strictly utility routines, used by the I/O and systems programs.

Section V is concerned with the interrupt driven timing control program (TIME), which is entered ten times per second. All the system program timing demands are derived from TIME and depending on the reactor systems in operation, various other check routines are called periodically.

The next section describes the programs responsible for input-output of data. The Teletype input (all of the operator requests) and some limited output are described in the keyboard executive routine, KEP. The IN and OUT routines handle all the data generated by the systems, the logging and the alarm limit programs. This section also describes the output to the alpha-numeric colored display--the permanent display and the scratch pad portion, used for demand displays and alarms. In addition, this section includes descriptions of the demand logging and display programs.

Section VII describes the LIMIT program whose main function is to examine PMACS inputs for off-normal conditions and to cause output alarms when necessary.

Section VIII describes the reactor system programs and their interactions. For convenience of description and partly because of program structure, the arbitrary classification used here is: (1) GAS-HEAT (2) NUCLEAR (3) GAS PURITY (4) REACTOR RODS (5) SCRAM SYSTEM.

Section IX describes four maintenance type programs which are an integral part of the PMACS system and not "off-line" programs. One program is used for running the flux digitizer units in a non-nuclear mode, or when the reactor is not being operated. A rod maintenance and a valve calibrate program are requested by the operator. Rod maintenance program has been used extensively to locate hardware problems associated with both horizontal and vertical rods.

Section X and XI describe the initialization routines and programming procedures.

Since the total programmed system demands the precise allocation of computer core and because of the characteristics of the system which allows the preparation (assembly and loading) of programs, the preparation of an operating system becomes a quite detailed procedure. It can easily be seen that program changes and updating will occasionally be needed. For example, if the operations staff can save themselves time and effort by a simple program change, then the programmed system should be updated--especially during long reactor down periods. Any time a program change is made, a special updating procedure must be followed. All programs must be written in special areas on the storage (magnetic) tape. Section XI describes these procedures in detail.

II. BRIEF DESCRIPTION OF THE COMPUTER AND THE ASTRODATA INTERFACE

The basic computer system used is a PDP-7, manufactured by Digital Equipment Corporation . The central processing unit has the extended arithmetic option (MQ register with multiply, divide and shift commands) and is supplied with an 8,192 word core of 18 bits per word. Standard equipment, supplied with the PDP-7, consists of a high speed, optical paper tape reader capable of reading 8-channel, 1-inch tape of the fanfold variety, a high speed paper tape punch, two magnetic tape units (DECTAPE TYPE 555 dual transports), two Teletype Model 35 KSR and the necessary circuitry to allow 18 digital inputs (one watch channel) to be read into the information collector and to decode computer words for generating control pulses.

The system has two standard Tektronix 564 oscilloscope units which can be run in the normal mode or can be used as storage scopes. Thus, two different point plots can be presented--under program control. One of the units is used as a backup for the Astrodata Alpha-numeric display. The interface was done locally and can be switched readily.

The PDP-7 was also supplied with a 16 channel automatic priority interrupt (API). Multilevel interrupts are allowed, thus a higher priority interrupt supersedes a lower interrupt already in progress. There are two API modes. (1) A single instruction mode which, upon interrupt, merely increments a core counter and returns control to the interrupted program. At present, this feature is used for stepping valves a prescribed number of inches. For example if valve X is to be driven 500 pulses (corresponding to y inches), a core address is initialized with a count of - 500 and the interrupt facility is enabled. Astrodata circuitry has been modified so that when the counter is equal to zero (after 500 pulse interrupts in the example above) the valve stepping motor is automatically deselected. (2) The second mode is the regular multi-instruction which allows subroutines to be entered and executed. These interrupt service routines allow interrupt from lower channels only when they have completed their function, restored proper registers and given the command (Debreak--DBR) to return API to the receptive state. The following assignment has been made--given with channel 0 as highest priority with lower priority in a decreasing order.

CHANNEL NO.	FUNCTION
0	SCRAM
1	Mictotape data & error flags
2	.1 sec timer
3	Not used
4	Not used
5	A-D conversion complete
6	Not used
7	Not used
8	Keyboard flag (Teletype #1)
9	Not used
10	Not used
11	Not used
12	Not used
13	Valve stepping motor
14	Not used
15	60 cycle clock

FIGURE 1. API PRIORITY

Two hardware modifications have been made. Core space and programming capabilities were increased by allowing the use of core locations 0 - 7, in addition to 10_8 - 17_8, as auto indexing registers.[3] Input or Teletype command reliability was insured by allowing the optional change over between duplex and simplex operations. Thus when the programming system is in control, the keyboard program prints the actual character received. If the program is not entered, depression of a Teletype key <u>does not</u> cause printing. This is called the duplex mode. Simplex mode is the normal typer mode with or without computer control.

A small interfacing modification was also made--allowing the interchange of the two Teletypes. If the input Teletype fails, the output Teletype can be plugged in for immediate use. For further details, see reference 2.

A schematic block diagram in Figure 2 shows the PDP-7 computer interfaced with the Astrodata system. The following are the Astrodata components which are under program control.

(a) Analog calibration unit, multiplexer, analog-to digital converter and two amplifiers selectable by computer command. Output of the ADC is a 0 - 12 bit word followed by an end of conversion signal which flags the PDP-7 priority interrupt (API). There are 128 input channels which are scanned once every second.

(b) Two flux digitizer units consisting of a current-to-voltage amplifier which produces an output proportional to the ion chamber current. The amplifier has 12 gain ranges providing a full scale range of 10^{-11} to 10^{-4} amperes. Ranges settings are under program control and each range has a calibration input that corresponds to approximately 10% full scale. It, too, is under program control, as well as calibration of a zero reading. In one second a maximum of 10^5 counts can be collected in the Astrodata AC register. An Astrodata flux storage register can accept the AC contents at any time (under program control), and thus can be used as a buffer if counting is to be continued in the AC register.

(c) Alpha-Numeric Display unit accepts BCD data from a fixed computer core location by using the "data break"--cycle stealing process. the three color (blue-green-red) unit allows character generation of 26 alphabetic, 10 numeric and 2 special characters--the minus sign and period. The unit will display 420 characters including spaces and/or color change indicators. The 420 characters are made up of a 20 x 21 matrix. Only 140 core locations are used.

(d) Digital outputs provide 32 contact outputs used to open and close relays for 4 saturable reactors, gas system valves, various warning horns, moisture monitors, gas blower and process water pumps.

(e) Stepping motor outputs which allow driving (under a programmable pulse rate) of the horizontal rods, 7 valves (no rate) and the vertical rods (no rate).

(f) Eight Analog output channels with a DAC. These are used for the heater power and to drive the CRT units.

(g) System clock--using a two-megacycle crystal-controlled oscillator. From this circuitry, there is derived the .1 second interrupt (wired into the API system) or the basic program timing loop which results in periodic program execution and the pulsing of activity sensors or deadmen every .1 second to keep the safety circuit made up--if in a nuclear mode.

(h) Rod position counters which allow the program to zero out the horizontal rod counters. At present, the transfer of this computer control word to the Astrodata unit sets the rod counters to 1000_8. This offset was necessary to eliminate a "negative" count when decreasing the count or driving the rod out--thus eliminating the programming chore of detecting a sequence such as 24000 (full scale in) to 0 (almost out) and then to 65000^+ (past zero).

(i) Safety circuit make up flip-flops and activity sensors or deadmen pulsing outputs which must be done when in the nuclear mode of operation or when rod maintenance programs are being used. Functional commands are provided to turn on or set the logic level for both PMACS safety circuit channels. To perform any of the functions listed under a, b, d, e, f, h, or i, the proper command word must be sent to the Astrodata CDR function register. Special computer commands have been provided to test if the CDR register is ready to accept a new function code and to transfer the code from the computer to the CDR register. For a complete listing of transfer commands, see Table 12.

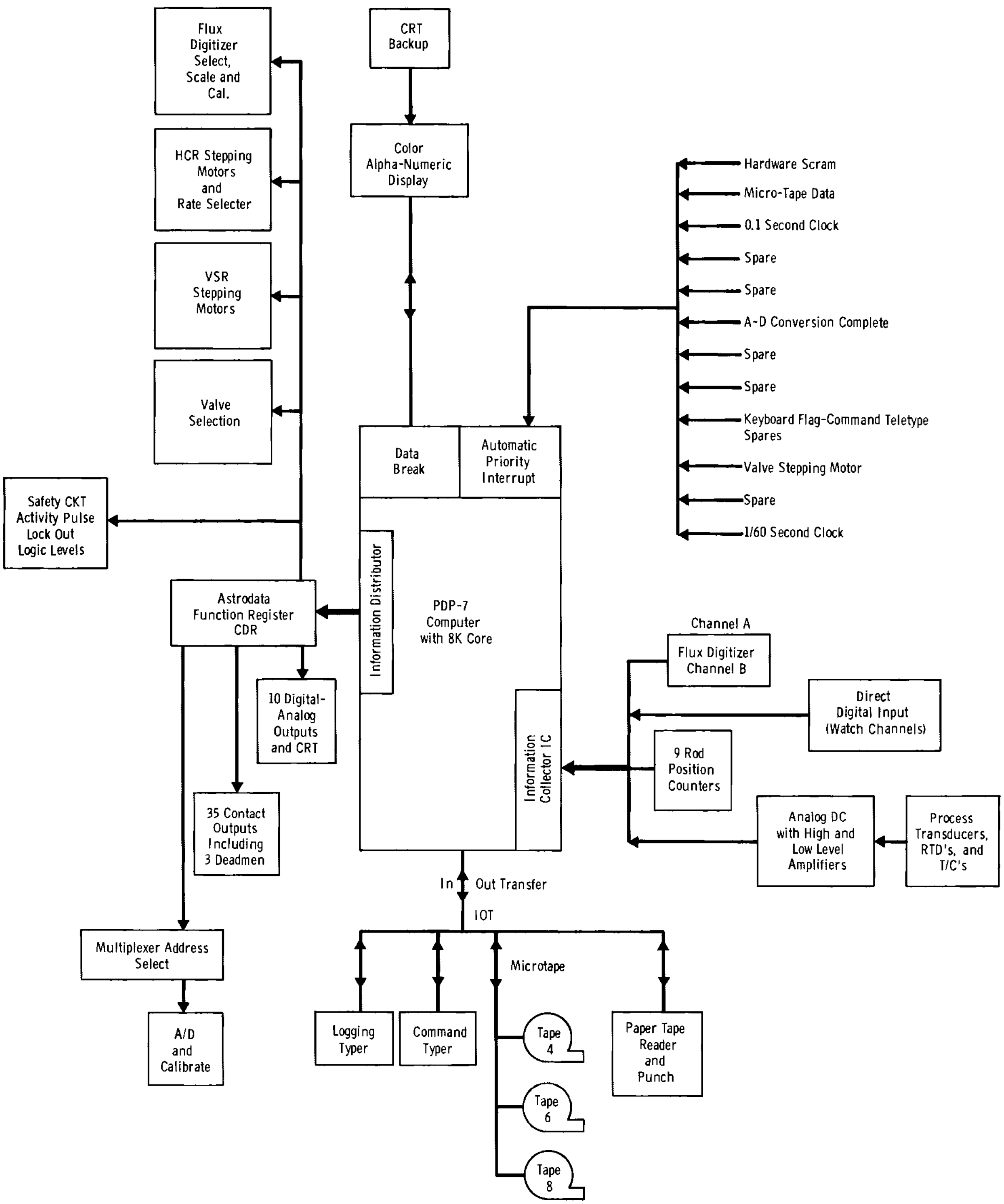


FIGURE 2

Astrodata - Computer Interface

III. GENERAL PROGRAM DESCRIPTION AND PHILOSOPHY

Besides the overall requirements mentioned earlier, the programs are largely influenced by basic operations needs, rigid safety requirements, the availability of computer core and the magnetic tape storage, and the requirements imposed by hardware and electro-mechanical reactor equipment.

Since operations must be able to interrogate the PMACS system for reactor information at any time and initiate reactor control or actions leading to control, over 150 separate Teletype commands were made available. For those type of operator requests (via the Teletype) which demand some sort of action such as moving rods or opening gas system valves, the programs themselves permit the action if and only if certain necessary conditions are met. This involves the examination of many program parameters. In the case of the 14 different types of log outs (temperatures, pressures, raw flux, etc.) the logging programs must be able to reference many core locations. Other types of programs had to have access to other program inputs and outputs and parameters. To avoid duplication of program constants and common reference parameters and tables, a large equivalence system and constant pool was devised--for use by all programs, whether permanent core residents or transient (scratch area) programs.

The logic and flow of the functional programs reflect the many years of experience of operating personnel. If a certain condition demands a particular programmed action and this condition is almost sure never to happen, the programmed instruction set must still exist. If there were no safety requirements, a program to move the control rods would be about three (3) instructions long. Safety requirements make that program about 250-300 instructions long. There are numerous examples of this sort. In addition, the programs have been written to guard against operator errors--even if safety is not the main issue.

A single example will illustrate the program requirements demanded by electro-mechanical devices and the existing hardware-computer interface. In order for the computer and the operator to determine if a control rod is all the way out, a limit switch must be set--the rod drive mechanism must actually make a solid contact with the switch. The preliminary rod monitor program (entered every .1 sec), upon receiving the switch status (watch channel indicator bit), deselected the rod driving motor when the limit "made up". Further monitoring showed the rod not all the way out. It was then determined that a certain amount of flutter existed--the switch going on and off several times before a solid setting. Accordingly, the program had to detect the first limit change and then keep driving the motor until the contact or limit was "made up" four consecutive times; i.e., 4 consecutive .1 second positive samples--and then deselect the motor.

If the reactor is in the nuclear mode at a set temperature, there are twenty (20) major programs which completely use all 8 k of core. Figure 3 shows the program-core allocation.

CORE AREA		PROGRAMS
NO.	OCTAL LOCATION	
6	17500 - 17777	ALPHA-NUMERIC DISPLAY AND STORAGE TABLES
5	16100 - 17477	SCRATCH AREA
4	14402 - 16077	MICRO, OUT, IN, GAP
3	11060 - 14401	CONSTANT POOL, BIN, BTB, AD
2	6100 - 11057	GASCYC, NUCLEAR, ROD MAINT., MAN
1	0 - 6077	MAIN, HODPOD, DATA, KEP, SCRAM, ENGR, LIMIT, TIME, RCS, ROD

FIGURE 3. PROGRAM-CORE ALLOCATION

In addition to the core residents, twenty-six (26) additional programs were written--programs having a combined instruction set which is approximately 10,000 long. Counting tables, constants and programs, there are about 18×10^3

programmed words. Only four of the above mentioned 26 additional programs are completely independent programs; namely, the high and low microtape writers which store programs onto storage tape, the pre-initialization program (PNIT) which initiates the total programmed system and the equivalence maker which is used for program preparation in generating the EQ table. The rest of these programs form an integral part of the programmed system. The core capacity has essentially been doubled by chain linking various operational programs and by the use of a core scratch or overlay area which is used by seventeen (17) programs. These working programs are retrieved one at a time by operator request from micro magnetic tape, stored in the scratch area and executed. The scratch area is then free for another demand program.

Because computer core limitations were such a problem and because tape transfer was comparatively slow with regard to system timing demands (thus making program "swapping" prohibitive) all conversion and I/O routines were compactly written with no frills or frosting. All messages are extremely brief.

Using any kind of Fortran compiler and Fortran operating system was completely out of the question. In the first place, the PDP-7 Fortran operating system occupies about 3000_{10} words of core. Secondly, even if the core capacity were extended, the compiler would have to be re-written and tailored to recognize all of the numerous Astrodata interface commands unique to this system. In addition, the complex interrupt system would have made a good portion of any Fortran library routines available for only special classes of programs. In other words, an interrupt routine (say, the .1 sec interrupt in which all period calculations are done) could not use the same Fortran routines as a control program unless elaborate multi-programming techniques were employed.

The program package is a multi-programmed system--only to the extent that several programs may be at different levels of execution because of I/O or other delays. A program may be waiting for a valve to re-position or for a hardware count register to indicate completion of a sampling process. Further details are presented in the discussion of the main executive.

All program calculations in this system are done using a fixed point arithmetic with the programmer keeping track of the binary point and the range of numbers for each calculation. A one word (18 bit) floating point package was considered, but more accuracy was needed for many of the calculations.

IV. MAIN CONTROL AND SERVICE PROGRAMS

This section describes the main control programs and two of the interrupt service routines--all of these programs are permanent core residents during the run mode of the programmed system.

EXECUTIVE CONTROL (MAIN OR MLOOP).

The functions of MLOOP are to: (1) Listen for keyboard (operator commands and call the keyboard executive routine. (2) Print out any error messages and control the message queue table. See tables 13 and 14. Handle microtape requests and select appropriate tape drives for subsequent transfer. (4) To interrogate the program on-off status table in order to determine if a program is in core and ready for execution -- and if so, turn control over to that program, which finishes execution or reaches a state where it must wait for I/O or some other device. If N programs are ready to execute, MLOOP will turn control over to each in turn. (5) After this function is performed, MLOOP calls on a general purpose continuous display routine called HODPOD. The five (5) major functions are then repeated. At any point in this chain of events, whether control is in MLOOP itself or in one of its called programs, if a hardware interrupt occurs, control temporarily passes to the interrupt service routine which executes and immediately returns to the proper point in the interruptable program.

Detailed Description - MLOOP. At the start of the loop, the teletype print flag is examined and if a character has not been printed yet, control passes to the program point, tagged as M.20. Otherwise, if there is another character from the buffer (TELTAB) to print, the teleprinter is selected to type the character and command is passed to tag M.20. If there are no more buffer characters (indicated by a zero entry in TELTAB--set by the UNPAC routine) the TELTAB pointer (auto 10 address) is re-initialized and the first entry is zeroed out. The message queue table, TELQ, is then examined. If it is empty, (indicated by TDEX=24_8), control passes to tag, M.20. If not, the last entry TELQ+24 is unloaded and used in the UNPAC routine which refills TELTAB. TELQ+24 contains the control word which tells UNPAC where the message table starts and how many packed (3 trimmed ASCII characters per core word) words are in the message. If there are other entries in TELQ, the queue is pushed down so the next in line is in TELQ+24. (See description of TELOUT for procedure of loading the queue table).

The section beginning at M.20 checks the mictotape status. If any tapes are being deselected (indicated by TFLAG=777777--set by MICRO tape routine) the delay counter, MWORD2 is incremented. A 35 millisecond delay must occur between deselection and re-selection of microtapes. When the delay is accomplished, the tapes are made "not busy", indicated by TFLAG=0. Control then passes to that portion of the program which interrogates the on-off status of all non-interrupt functional programs. The status table which is examined is called FLTAB. The general structure of the table is shown in Figure 4. The detailed structure is shown in Figure 5. MLOOP examines the status bits in the first FLTAB word of the three control word sequence for all nine[(1)] possible programs. If a program or data transfer request has been made and if the tapes are not busy, status number three is initiated. Information from the second and third words is extracted and made available for the microtape routine (MICRO). Thus, TFLAG is set < 0 if a write is requested or > 0 if a read is requested. In addition, BLOCK = correct block number, ONG contains the correct FLTAB index so that MICRO can set bit 1 (set status 4) on completion of transfer and finally, auto index register 11 points to the correct core load address. MLOOP actually selects the proper tape and sets a search forward mode. Five of the nine programs are permanent core residents. The control words associated with two of these programs are used for transfer of data to and from microtape which serves as a buffer for all output on tape #2. When tape transfer is complete (status 4), MLOOP passes control to either IN or OUT, depending on the data transfer direction. The third program, LIMIT, always has its FLTAB entry set to either status 3 or 4, but <u>no tape transfer is involved</u> in this case. The fourth program, GAP, is handled exactly the same way as LIMIT. The fifth program, DATA, is always "on" or in status 4. The TIME routine turns LIMIT "on" (sets bit 1) every 10 seconds and after execution, LIMIT turns itself "off" by resetting bit 1. The gas purity program, GAP, is turned "on" every sec.

In summary, if MLOOP finds status 2, it initiates status 3. When the status 4 condition exists, MLOOP transfers control to the N^{th} program. If

---

(1) This number is not indicative of the total number of programs since many programs use the same core area at different times, but still use the same FLTAB entry.

Table Entry	Control Words	Program	Core Resident
FLTAB+1 +2 +3	Word 1 Spare Spare	GAP	Yes
+4 +5 +6	Word 1 2 3	OUT	Yes
+7 +10 +11	Word 1 " 2 " 3	ANALOG DISPLAY NUCLEAR DR ROD MAINT.	No
+12 +13 +14	Word 1 " 2 " 3	GAS-CYC	No
+15 +16 +17	Word 1 Spare Spare	LIMIT	Yes
+20 +21 +22	Word 1 " 2 " 3	SCRATCH AREA VALVE CALIBRATION LOGS & DMDISP	No
+23 +24 +25	Word 1 " 2 " 3	IN	Yes
+26 +27 +30	Word 1 Spare Spare	DATA	Yes
+31 +32 FLTAB +33	Spare Spare Spare	Spare	----

FIGURE 4. FLTAB - PROGRAM STATUS

status 4 does not exist, MLOOP continues checking the rest of the programs. When finished, the subroutine, HODPOD is called (main function of HODPOD is display and data manipulation for I/O) and upon return, control passes to the start of MLOOP.

More than one program can be "on" or in status 4 condition, because it may be necessary for a functional program to delay or wait for data transfer. In order to optimally service the Teletype and update the alpha-numeric display, it is necessary to cycle through MLOOP at least every 1/10 second. Hence, if any program finds it necessary to wait before completing execution, it must use one of the two wait macros, WAIT1 or WAIT3. A call to WAIT1 results in the storing of the next program address (the pc) after the call statement into the proper FLTAB entry. Thus, at the proper time, MLOOP will transfer control to the correct entry point of the n^{th} program. WAIT3 stores the address of two locations above (pc-3) the call statement. Both WAIT1 and WAIT3, then transfer control to that portion of MLOOP which is checking the status of programs.

When the n^{th} program has finished execution, it turns itself off by resetting the FLTAB entry to status 1 condition and returns control to MLOOP at the point tagged, EXIT.

ANALOG-DIGITAL SERVICE (AD).

AD is an interrupt service routine which is entered from the interrupt vector each time a digital conversion is completed. This routine drives the analog-digital converter which digitizes voltage signals from feedback transducers, resistance temperature devices and thermocouples. A total of 128 input channels are converted once every 1.28 seconds. The converted raw counts are stored in a current value table--making them available for all function programs. The AD routine is initialized in the INIT program with a request for conversion of channel 0. From then on, the 128 channels are scanned in a cyclic manner, with the normal cycle interrupted when a request for automatic calibration is made. The routine also switches back and forth from low gain to high gain amplifier when the proper channel is encountered.

Detailed Description of AD. After the AC and MQ registers are saved, the converted count is brought in from the Astrodata register and saved in a location called INPUT. A check is made on the calibrate request word, RCAL.

If RCAL = 0, there is no request and control passes to that part of the program tagged AD.100. Otherwise, RCAL will be the non-zero astro command for a specific high or low gain calibrate and the word is immediately transferred to ASTRODATA. A switch is set for the next entry when the calibrate is done. INPUT is stored in the current value table, CTAB and control passes to a point labeled ADOUT, where registers are restored and control passes to the interrupted program. The calling program cannot request a calibrate when RCAL $\neq$ 0 which indicates a cal already in progress. When the next entry is made, the input value is placed in VCAL ready for use by the calibrate or requesting program. At this time RCAL is set to zero. Control is then passed to that part of the program tagged AD.200. At this point the cyclic counter CHAN, is incremented by one and a check is made to see if CHAN = 1 (indicating the number 2 hi-precision RTD is about to be sampled). If this is the case, the proper range (set in TIME) is shifted into bits 6-9 of the ASTRO master command word, (the program label is WORD). The scan request is made and an exit is made via ADOUT. If CHAN = 2, this signals that it is time to switch to the low gain amplifier (Gain = 75, M_v range 0 to 66, maximum voltage = 5 at full scale--2048 counts). Accordingly, the master command word is modified, the request is made and control passes to ADOUT. In a similar fashion, the master command word is modified for high gain (gain = 1) when CHAN = 12_{10} and again for low gain when CHAN = 104_{10}. When CHAN = 128, the range (found in SCALE1) is shifted into bits 6-9 of the Astro command word for channel 0 or the number 1 RTD. The routine is now ready to repeat the cycle.

AD uses its own astrodata wait routine (ADAST) to check if the astrodata registers are ready to accept data. When ready, the request or command word is transferred from the PDP-7.

The storage routine, STOD, is entered with CHAN (channel number) in the AC register. The proper storage address in CTAB is:

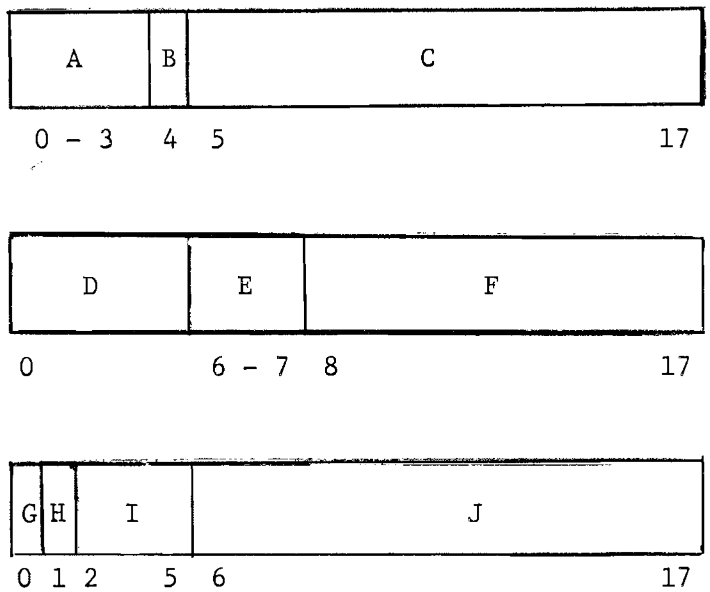
$$\text{Address} = (\text{CHAN}) \cdot 2 + 1 + \text{CTAB (address)}$$

Thus the raw values are stored in the odd entries in CTAB, the even entries contain engineering conversion indices and other information for the particular channel. The CTAB table can be examined by looking at CTABX in the program listings for INIT--Volume II.

FLTAB+M
Control Word 1

FLTAB+M+1
Control Word 2

FLTAB+M+2
Control Word 3



A: ON-OFF and Request Status Bits

(Bits) 0	1	2	3		Status
0	0	0	0	(1)	Program Off and No Request
1	0	0	1	(2)	Program Off with Request Made
1	0	1	1	(3)	Program Off but Tape Transfer in Progress
1	1	1	1	(4)	Program On and Tape Transfer Complete

B: Not Used
C: Current entry address to program X
D: Index to FLTAB+n (used by micro)
Index=n
E: No. of blocks (256 words) to transfer
E=1, 2 or 3
F: Tape storage block number
G: Bit0=1 Write Tape
Bit0=0 Read Tape
H: Not used
I: Tape unit no.
J: Core Load address - 1

FIGURE 5. FLTAB - DETAILED STRUCTURE

MICROTAPE SERVICE (MICRO)

MICRO is the magnetic tape interrupt service routine. It is entered from the interrupt vector each time a data word is ready to read, a data word has been written or when an error is detected. A brief description of the magnetic tape will help clarify the program logic. For more detail see reference 3. The 1 mil Mylar tape is 3/4 inch wide and about 260 feet long. Individual 18-bit words--assembled by the tape control unit--arrive at the computer approximately every 200 microseconds. The tapes are divided into 576_{10} blocks--each block containing 256_{10} 18-bit words, thus allowing storage of 147,456 computer words. The tapes are a relatively slow access device, since it takes approximately 53 milliseconds to transfer a block (one word at a time) and about 40 seconds for a complete traverse time.

There are four programmed modes of operation--Search, Read, Write, and Move. Move is used to rewind without requesting or supplying information. In the "Search" mode, the interrupt flag is set each time a block number is read. In the "Read" mode, a data word has been read. In the "Write" mode, the interrupt signals that a data word has been written. Further, when in the "Write" mode, the initial checksum (777777) is automatically written and when in the "Read" mode the programmer must read the initial checksum. A block end flag (interrupt) is set when the system is ready to write the ending checksum (actually the 257th storage word).

The error flag (interrupt) occurs when (1) end of tape is detected, (2) mark track or timing error occurs, (3) program fails to unload or load the data buffer in the time alloted.

As mentioned earlier, MLOOP actually selects the proper tape unit and sets the Search forward mode. Tape unit 4 is the program storage tape. See table 15 for program storage allocation. During run time, the write will be permanently locked on unit 4. Tape units 6 and 8 will have the write enabled--in order to store data. Any transfer involves complete blocks only. The maximum number of blocks read into core is <u>three</u>.

<u>Detailed Description of MICRO</u>. The first interrupt is caused by a block number read in the Search mode--accordingly transfer is made to the program point tagged by SEARCH. If the block number read matches with the requested block (BLOCK), control passes to the location named, FOUND. If no match occurs and

the BLOCK > current block, search forward is continued and the program exits at the point labeled, RETRN. If BLOCK < current block, search reverse is set and the variable switch set to REVERS. The program stays in this mode until BLOCK > current block, at which time, search forward is set. This cycle is repeated three times and if the BLOCK has not been found, an error exit (E.1) occurs.

When the correct block is found, TFLAG is examined. If TFLAG < 0, the switches, RITE and WCHECK are set, the Write mode is requested, CHECK is set equal to 777777, and exit occurs.

The next entry point (after the automatic checksum has been written) is at the point named, RITE. Entry remains here until 256 words are written. Each time the location, CHECK is updated. Let $W_i = i^{th}$ written data word and let $-\emptyset = 777777$, then after writing 256 words, we have

$$\text{CHECK} = -\emptyset + \sum_{i=1}^{256} W_i \quad .$$

The next interrupt will be the block end flag--which is requesting the storage of the programmed checksum. CHECK is complemented (-CHECK) and written in the 257th word. WCOUNT (set by MLOOP) is incremented and if not zero, Write mode is still on. If WCOUNT = 0, writing is finished, DELA entry is set for next interrupt and the program exits via RETRN.

At entry, DELA, the FLTAB entry is set to status 4 (the address of FLTAB + X is in ONG--also set by MLOOP). The deselection time delay is set (MWORD2 and TFLAG), SEARCH switch is set or initialized, tapes are stopped and deselected and the program exits.

When a read request is made (TFLAG > 0), the read switches are set and read forward mode requested. The first read entry is at the point named, BCHECK, where the beginning checksum is read. In the same fashion as described in writing,

$$\text{CHECK} = -\emptyset + \sum_{i=1}^{256} W_i \quad .$$

At the end of the block, the ending checksum (-CHECK) is read and added to CHECK. An error exit occurs if $-\text{CHECK} + \text{CHECK} \neq -\emptyset$. When reading is done, a sequence similar to that described in the Write mode, is followed.

In case of any kind of an error the FLTAB entry is never set to status 4 and the tapes are deselected. When an end of tape error occurs, MICRO automatically rewinds the tape before deselecting. The error print outs are listed in table 13.

BINARY TO BCD CONVERSION (BTB)

The calling program must deposit the location of the binary point into a format word, FORM. BTB uses FORM to separate the integer and fraction. The calling program then loads the number into the AC register and calls BTB. Suppose the octal number, 0014.40, is to be converted. FORM would equal 6 (6 binary bits) and after the conversion the buffer, ABUF would appear as:

```
ABUF + 1
     + 2
     + 3
     + 4     261    / 1
     + 5     264    / 4
     + 6     256    / period
     + 7     264    / 4
     + 8     260    / 0
     + 9     260    / 0
     + 10    260    / 0
     + 11    260    / 0
     + 12    260    / 0
```

Since any integer can be represented as

$$N = 10\ (Q) + R$$

where

$$0 \leq R < 10 \quad ,$$

the following iteration is performed.

BTB performs the following loop--divide N by 10, add 260 to R and store in ABUF. Set N = Q and repeat six times.

In the case of the fraction, since

$$N = \sum_{i=1}^{j} \alpha_i \, 10^{-i}$$

N is multiplied by 10, α_1 is separated, added to 260 and stored. Set N = fractional part remaining and repeat the sequence up to six times. Note that the BCD period or decimal point is always at ABUF + 7. Calling programs have to test for leading and trailing BDC zeros (260).

BCD TO BINARY CONVERSION (BIN)

BIN uses the number buffer (NBUF) which is filled by the keyboard routine (KEP). KEP supplies BIN with the pointer of the last NBUF entry or the least significant digit of integer or mixed number. Suppose the operator had typed in the number 123.49; NBUF would appear as follows (NBUF+1 and 2 are used for identification numbers in the setpoint format).

NBUF+3	61	/BCD 1
+4	62	/BCD 2
+5	63	/BCD 3
+6	256	/ .
+7	64	/BCD 4
+8	71	/BCD 9

The pointer, LJAX, would equal 8. The calling program, which is always a subprogram in KEP, has no calling argument--it merely jumps to subroutine BIN. After the 6 is masked off, the conversion proceeds.

Let x_k = k - th masked entry.

Let j = LJAX.

$$\text{Then, } N = \sum_{i=1}^{j} X_{j-i} \; 10^{i-1} \quad ,$$

where j = number of characters to the right or left of the period. In the case of fractions,

$$F = N/10^{i} \quad .$$

F is stored in the MQ register and N is in the AC register when the routine returns to the calling program.

MESSAGE QUEUE AND BUFFER ROUTINES

The first of these routines, TELOUT, can be used by all programs except the interrupt service routines. TELOUT stacks the message control word into the queue table, TELQ. Up to 20 (decimal) control words can be stored. The next available storage location is indexed by the pointer, TDEX--as shown below:

TELQ,	.	
TELQ+1	.	
	.	
	.	
	.	
TELQ+17		TDEX = 17 (available Loc)
TELQ+18	Message 3	
TELQ+19	Message 2	
TELQ+20	Message 1	Ready to be unloaded by MLOOP

The message word, which is placed in the accumulator at the time the calling program uses TELOUT, has the following format:

BITS 0 1 2 3 4 5---------------------------17

A	B

A = Length of message (MAX length - 23_8)

B = Core address -1 of message table

The address must be one less since an auto index is used in UNPAC to load the table contents.

The UNPAC routine is called by MLOOP with the format word in the AC. UNPAC makes sure the $0 < \text{table length} < 24_8$. If this inequality is satisfied, the message table words are unpacked, converted to 8 bit ASCII character representations and placed in the table, TELTAB, ready for use by Teletype #1. TELTAB has a maximum length of 102_8.

ENGINEERING CONVERSION (ENGR)

ENGR routine may be called by all programs, except the interrupt service routines. The calling program supplies ENGR with the conversion equation index (actually the core address of the index) and ENGR uses this information to find the correct raw analog-digital count, which has been stored by the AD routine into the current value table, CTAB. This raw count is converted to the particular prescribed units by using the proper programmed equation and the converted value is returned to the calling program. Most calling problems will be aware of the position of the binary point; however, ENGR automatically supplies this position in a common storage word labeled, FORM. The actual conversion equation and the corresponding units are tabulated below. All calculations are done using fixed point arithmetic. In all cases C = raw digital counts.

(1) Low precision RTD - Low Gain Amplifier (0-1.201 volts).

$T = a\,C + b\ (20°C \leq T \leq 392°C)$

a	b	Range
.700	- 5.944	$C \leq 108$
.760	-13.020	$C \leq 272$
.885	-48.110	$C \leq 492$

(2) Heater thermocouples - High Gain Amplifier (0-20 mV).

$T = a\,C + b\ (27° \leq T \leq 1668°C)$. Reference junction temperature = 27°C.

a	b	Range
5.094	28.05	$C \leq 12$
4.421	36.37	$C \leq 27$
3.748	55.19	$C \leq 58$
3.246	85.31	$C \leq 120$
2.848	134.68	$C \leq 240$
2.407	244.24	$C \leq 615$

(3) Graphite thermocouples - Low Gain Amplifier (0-55.11 mV).

$T = a\,C + b$, $(27° \leq T \leq 1340°C)$ Reference junction temperature = 27°C.

a	b	Range
.7988	25.18	$C \leq 250$
.7739	33.51	$C \leq 1022$
.8598	-60.78	$C \leq 1692$

(4) Hall Effect Devices

KW = .078125 C (Side and Core) KW = 2.4,mV (0-55 mV) Approximately.
KW = .039 C (Top and Bottom) KW = 1.4,mV (0-46 mV) Approximately.

(5) Flow transducers - High Gain Amplifier (0-20 Mv).

The three transducers are to measure flow (CFM) in three different lines--reference to standard temperature and pressure. The basic approximating equation used here is:

$$\text{CFM} = (359/60)\ SP_d^2 \sqrt{Y}, \tag{5.2}$$

where $S = f(O_d/P_d)$

O_d = orifice diameter of inner plate

P_d = pipe diameter

Y = (hw x pressure * 273)/(d x temp. x 14.7)

d = density of N_2 at STP (.0782 lb/ft^3)

hw = inches of H_2O

Manufacturer's data for inches of H_2O is:

$$hw = .5\ Mv \tag{5.3}$$

High Gain mV - count relation is:

$$M_v = \text{counts}/30.72 \tag{5.4}$$

The constants P_d, O_d, and S for the four flow transducers are given below.

Transducer	P_d	O_d	S
1 FT 12	7.981	6.246	.478
2 FT 12	3.068	.881	.049
3 FT 12	6.065	1.534	.038
4 FT 12	6.065	1.534	.038

Using the data above with the relations (5.2), (5.3), and (5.4), the following equations are derived. These equations are used in the engineering routine:

1 FT 12 — Range: 0 - 3000 CFM

(5.5) $CFM = 423.3 \sqrt{CP_1/T_1}$

P_1 = 14.7 + pressure (E.U.) from 1 PT 12 transducer

T_1 = 273 + temperature (E.U.) from 1 TE 12 RTD

2 FT 12 — Range: 0 40 CFM

(5.6) $CFM = 6.2 \sqrt{CP_2/T_2}$

P_2 = 14.7 + 2 PT 12 - .1 reading

T_2 = 273 + temperature from 3 TE 12 RTD

3 FT 12 & 4 FT 12 — Range: 0 - 100 CFM

(5.7 $CFM = 16.8 \sqrt{CP_1/ T_3}$

T_3 = 273 + temperature from 5 TE 12 RTD

(6) Pressure transducers - High Gain Amplifier (0 - 20 Mv)

$$P = .00813\ C\ (0 \le P \le 5.0\ \text{PSID})$$

(7) Differential Pressure transducers - High Gain (0 - 20 Mv)

There are two of these transducers - the associated data is given in the table below. Engineering units (P) will be in PSID and not inches of H_2O.

TRANSDUCER NO.	PSID at 20 M_v	BASIC EQUATION
1 PD12	.18	$P = .009\ M_v$
2 PD12	3.6	$P = .18\ M_v$

Using relation (1) we have,

for 1 PD12
$$P = .000293\ C$$
$$P = .000115_8\ C$$

for 2 PD12
$$P = .00585\ C$$
$$P = .003_8\ C$$

(8) Absolute Pressure - Low Gain Amplifier (0-5 volts)

P = .00976 C (0-20 PSI)

(9) Gas Blower - Low Gain Amplifier (0.16 Volts - 1 amp)

AMPS = .152 C

(10) Valve Position - Low Gain Amplifier ($-2.5 \leq$ volts ≤ 2.5)

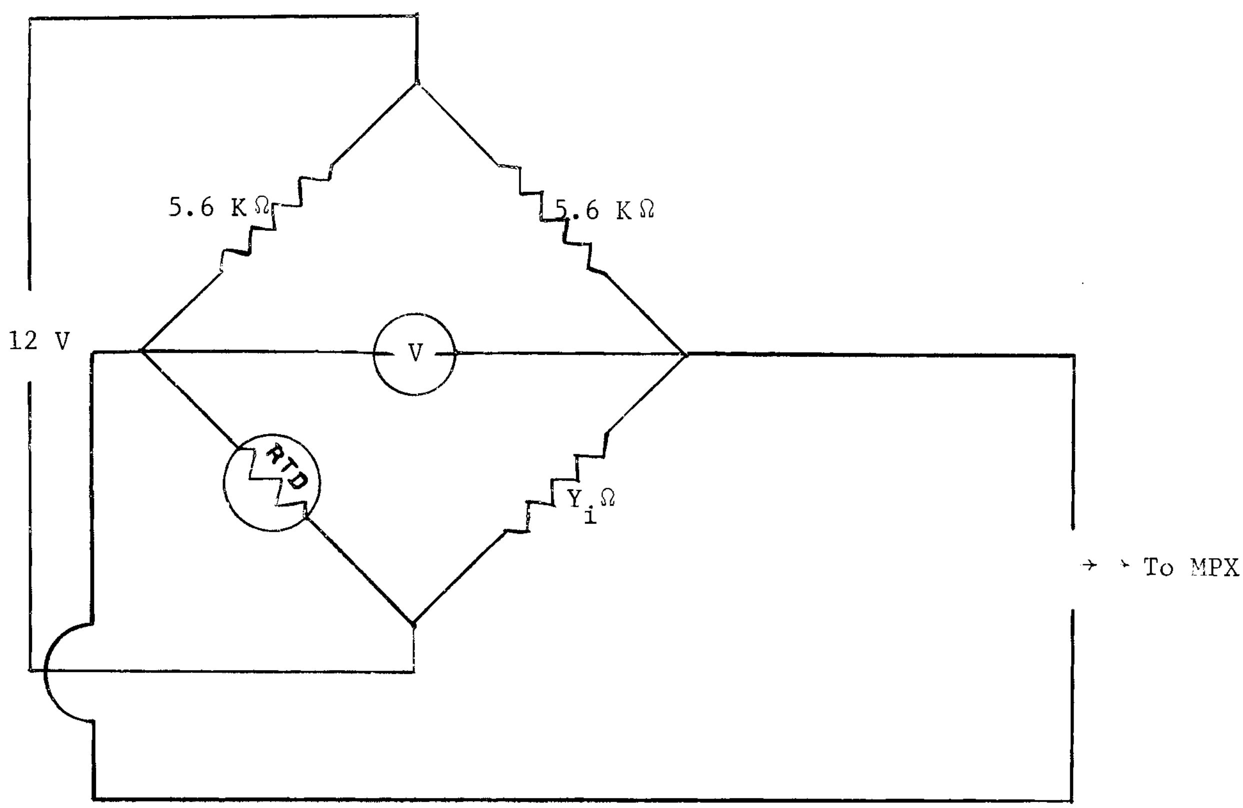
Percent open = .048 C + 50 (P = 20 volts + 50)

(11) Rod Position - Low Gain Amplifier ($-5 \leq$ volts ≤ 5)

Inches = .001416 C

(12) High Precision RTD - High Gain Amplifier (0-75 Mv)

In the wheatstone bridge with 12 volt input, two of the resistances are known and fixed at 5.6 K Ω. A third resistance is known for each of the 10 ranges associated with the high precision RTD's; hence, a reference voltage can be calculated for each range. The circuit is shown below:



Let Y_i = Ω and X_i = reference voltage, then

$$X_i = 12 \left[Y_i/(Y_i + 5600) \right]$$

The 10 values of Y are listed below:

Y_1 = 432.4	Y_6 = 735.7
Y_2 = 493.0	Y_7 = 796.4
Y_3 = 553.7	Y_8 = 857.0
Y_4 = 614.4	Y_9 + 917.7
Y_5 = 675.0	Y_{10} = 978.4

Using the manufacturer's table of R_T versus Temperature, a voltage can be calculated for each degree C. Denote the Voltage to the multiplexer as V_{ik} where the i subscript refers to the range, i = 1, 10 and k refers to the temperatures in each range.

Range	1	k = 0,45
"	2	k = 40,85
	.	.
	.	.
	.	.
	.	.
	.	.
	10	k = 360, 405

There will be some overlap, although this definition is somewhat arbitrary. The basic equation (used in an off line FORTRAN program) is

$$V_{ik} = X_i - 12 \left[R_T/(R_T + 5600) \right]$$

For each i, fit a straight line using k points; thus,

$$T = a_i \; V_{ik} + b_i$$

Where T is temperature, degrees C. Using the relation V_{ik} = C/30720,

$$T = a_i \; c/30720 + b_i \quad .$$

RANGE	a_i	b_i	$a_i/30720 = k_i$
1	346.7	- 00.67	.01128
2	358.1	37.65	.01165
3	369.7	76.46	.01203
4	381.6	115.67	.01242
5	393.8	155.27	.01281
6	406.3	195.53	.01322
7	419.0	236.19	.01363
8	432.1	277.31	.01406
9	445.4	319.13	.01449
10	458.3	361.47	.01491

In all the engineering equations, the following relations were used to determine the count-volt equivalence:

Let C = digitizer counts

G = 1 (gain)

V = voltage input

Mv = millivolt input

Low Gain Amplifier

0 - 5 volts corresponds to 0 - 2048 counts

$\therefore \quad V = C/409.6$

High Gain Amplifier

G = 75 fixed by RTD calibration.

$\therefore Mv = C \times 10^3/(75 \times 409.6)$

$Mv = C/30.72$

Special care must be given to the counts in the A-D converter. The sign bit (bit 6) is set when and only when a positive voltage is input. Real zero (0000) corresponds to -5 volts. Thus, the correspondence is as follows:

0000 ⟷ -5 volts

⋮ ⋮

3776 ⟷ -X volts
4000 ⟷ 0 volts

⋮ ⋮

7777 ⟷ +5 volts

The only devices which generate negative input voltages are:

(1) Rod transducers.

(2) Valve transducers.

(3) Precision RTD's.

Detailed Program Description - ENGR. ENGR is entered from the calling routine with the address of the raw channel format word from the CTAB table. The format word associated with each of the analog inputs (raw counts) has three sections corresponding to three indices:

0 — 5	6 — 11	12 — 17
PNUM	CDEX	LDEX

These indices, shown above in an 18 bit word, have certain uses in the LIMIT routine (see description of LIMIT) and are used in ENGR in the following specific way:

(a) LDEX is not used.

(b) CDEX is the conversion equation index and must be > 0 and < 23 (octal).

(c) PNUM is used to pick up or index the various constants for any one given conversion equation.

Using the CDEX index, the proper conversion engineering conversion is performed. Whenever conversion is being done for positive voltage input devices, the subroutine, NCHK is used first. NCHK checks for any negative offset and if this is found, the raw counts (CADD) are set to zero.

The low and high precision RTD's, and the thermocouples have range and constant tables corresponding to more than one curve fit over the complete temperature range. The subroutine, TRANGE, is used to find the proper slope and intercept for a given raw count. It returns with the slope or intercept table index set for immediate pickup. In order to compute the flow of N_2 gas (using the three equations described above) it is necessary to first have the appropriate temperature and pressure readings. The HODPOD routine calls the engineering routine periodically so that the temperatures and pressures can be computed. ENGR stores these values in the table called C115--for later use in the flow calculations.

The remaining calculations or sections in ENGR are straightforward multiplications which follow the pattern outlined in the equations described above. All sections have numerous comments on the program listing.

TEMPERATURE AVERAGING (AV.SUB)

Average temperatures are computed by the AV.SUB routine which is a subprogram in HODPOD. The average temperature obtained from the sixteen core thermocouples is stored in the symbolic address, CRAV. The average temperature of the four top thermocouples is stored in TPAV; the average of eight side thermocouples is stored in SDAV and the average of four bottom thermocouples is stored in BTAV. In addition, the grand stack average of all 32 thermocouples is stored in STAV.

These average values can be used by display, logging, and system programs. The average values are updated more than ten times a second. Of course, this is not necessary--it is merely a programming convenience which bypasses the need for setting auxiliary time counters. The four group averages are always shown as a part of the permanent display section.

When AV.SUB obtains the raw counts (corresponding to a particular thermocouple) a check is made for an error flag. The LIMIT routine sets the error flag when a thermocouple is malfunctioning or disabled. If 50% or more of the thermocouples (in any group) are bad, AV.SUB causes the heat (in case heat is turned on) to be turned off by setting the flag, HEOO = 0. This is followed by the error message, "HOB".

V. TIMING CONTROL (TIME)

The program, TIME, is automatically entered and executed ten (10) times per second. This is an interrupt driven program which performs the following functions:

(1) Calls the nuclear check programs whenever the reactor is being operated or in the "nuclear mode."

(2) Monitors the two analog channels which correspond to the high precision RTD inputs. The monitoring is necessary because the two RTD's have 10 different ranges. (See description in the engineering routine). Time sets the proper scale for each channel, thus allowing the scanner program (AD) to actually make the request for range change via the Astrodata function register.

(3) Every 10 seconds, turn on the LIMIT routine for alarm checking.

(4) Turn on the gas purity check program (GAP) once every second.

(5) When time, update the time of the day (hours and minutes) and the day of the year--these three current time values are needed for file storage, log headings and the command typer's print-out response.

(6) Increment, every 1/10 second, all ten auxiliary time counters used by the gas-heat programs. These timers are in a table labeled, G.TV.

(7) Read, convert and store the horizontal rod counters ten times a second. The digital feedback counts are stored in a table called RODCUR, and thus are available for logging or inspection by other programs. Convert the digital count to an inch reading (4 counts = 1 mil) for all nine HCR's and store in a table called T. The display program (part of the routine, HODPOD) displays the current HCR positions by using the T table.

(8) Check to see if any HCR's or VSR's are selected and if so, enter the correct monitor routine--RODM for HCR's and VMON routine for VSR's. The monitor routines, which deselect rod motors at the proper time, are described in section VIII.

(9) Reset any horn relays after a 4 - 5 second delay if they have been set or blown. For example, when the nuclear program makes up the safety circuit, the safety circuit horn must be blown. If a VSR slips off its upper limit while in the core load mode (defined to be that mode in which the reactor door is open, all HCR's are closed and two VSR's are up and two are all the way in) then the core load horn is blown.

(10) Call in the analog-digital calibrate program six times a day. This program uses the scratch area; hence, TIME must make sure the area is free. The calibrate program, ADCC, tests the A/D circuitry and the RTD bridges. For details, see section IX.

Detailed Description - TIME. After the AC and Q registers are saved, control passes to a section labeled, TIMER. At this point, the functions (3) and (4) listed above, are performed. The cell locations, DAY, HRS and MIN are used for time storage. The first part of the word HRS has a BCD, T, left adjusted; the first portion of MIN has a BCD colon. Whenever time is printed or stored, it appears as (for example) 273T 08:30.

Upon completion of this section, function (6) is carried out and nuclear programs are checked. If the FLTAB + 7 entry is 50, NUC1 is on and the scram checking routine is bypassed because the safety circuit is not made at this time. If the word, SAFE = 505050, this indicates that NUC2 is in core and the safety circuit is made. Control passes to the check routine, RCS and than to the nuclear program, NUC2 and finally back to TIME at the location tagged by a T.100.

The section following T.100 checks the RTD ranges. If the analog-digital raw counts fall in the proper range, no updating of ranges takes place. The range is updated if the inequality, $200_8 < \text{counts} < 7600_8$ is not satisfied. The current range for RTD one and two is found in SCALE1 and SCALE2, respectively.

The rod monitor programs are entered when the flag, RSEL ≠ 0. A further check occurs when the flag, PASS, is examined. Thus if RSEL ≠ 0 and PASS = 0, VMON (vertical rod monitor) is called. If RSEL ≠ 0 and PASS ≠ 0, RODM, (HCR monitor) is called.

The timer flag, ADTIM is incremented every 1/10 second and upon reaching zero (approximately 4 hours), the scratch area status is checked. If FLTAB + 20 = 0, the area is free and the ADCC program is called in. If status 4 (see figure 5) is set and if the demand display is in the area (indicated by FLTAB + 21 = 206036), the area is overlayed with the ADCC program. If any other status or condition exists, the timer, ADTIM is decremented by one and a wait is initiated.

At tag, T.155, the AC and Q registers are restored and all interrupt channels are enabled and control passes back to the interrupted program.

VI. INPUT-OUTPUT PROGRAMS

This section describes the regular I/O routines. The only input is via the command typer on Teletype #1. The all-important linkage between operator and computer is discussed. Examination of the detailed tables 13-27, inclusive, will help clarify the written description. Some output occurs on the command typer--the very limited three letter mnemonics are listed in Table 18. The remainder of the section describes the output (Teletype # 2 and core to microtape) system and the alpha-numeric display output--both the permanent or constantly updated display and the demand and system displays.

KEYBOARD EXECUTIVE (KEP)

KEP is entered from the interrupt vector every time the operator depresses a teletype key. KEP must accumulate the number and letter character strings and upon receipt of a carriage return, determine if a valid command has been given. A list of the valid commands and their functions are given in Tables 20 - 27, inclusive. A valid command is acknowledged by causing a typeout of the time of day on the input or command Teletype. An invalid command causes a question mark to be printed. There are some exceptions--certain commands are legal and pass through KEP's logic--causing the setting of program flags. Various system programs may be in such a state that certain of these flags are ignored. As an example, the command to turn off the gas system may be ignored if the valves are not in the correct position as determined by the gas system programs.

If the first character of an input string is a slash (/), all following characters up to and including a rubout are interpreted as a comment only. Spaces are ignored and depressing the rubout key deletes the current line. All valid commands must begin with an asterisk. Since an asterisk requires the depression of the shift key and the asterisk key, it becomes almost impossible to initiate any program action by leaning against the keyboard. The keyboard is under the duplex mode, whereby only those characters received, in the print buffer, are printed back under program control.

The following is a list of the major functions which KEP performs.

(1) Cause functional programs to be transferred from storage tape to core for execution.

(2) Allow operators to "turn off" certain programs.

(3) Allow on-line communication between operators and programs which are executing.

(4) Cause the time of day to be stored in core for updating every minute.

(5) Permit the changing of various control setpoints.

(6) Assimilate operator data and call the control rod selection routines.

KEP is the essential link between the operator and the total programmed system. It allows the observation of reactor measurements, the pre-operational checks on computer inputs and outputs and permits the initiation of the various reactor systems such as heat, cool, and nuclear.

Detailed Description of KEP. The keyboard or input character is read and printed to acknowledge the input. After receiving the asterisk, each input character is stored in either a number buffer (NBUF - maximum numbers allowed is nine [9]) or a letter buffer (LBUF - maximum letters allowed is six [6]). Besides numbers or letters, the only other legal character (after the asterisk) is a period which is automatically stored in NBUF as a decimal point. After storing an individual character, KEP returns control to the interrupted program.

When a carriage return occurs, the KEP routine begins to analyze the total character string. There are eight permissable beginning letters (after the asterisk), that is, LBUF + 1 must be the trimmed ASCII code which represents one of the letters, N, D, G, E, M, L, R, S or T. The first six letters (N, D, G, E, M, L) indicate a possible request for programs which are stored on microtape. When proper conditions (to be described below) are satisfied, three steps take place.

(1) KEP calls a subroutine, ABUSY, which checks to see if the requested core area is busy. The area is free if and only if, the FLTAB entry is in status 1 condition. In this case, step two is accomplished, otherwise, an error exit occurs and the message "ARB" is printed out.

(2) The proper tape request words are loaded into the FLTAB table and status 2 is enabled.

(3) Control passes to the program point labeled, KEP5 - at this point, various KEP switches and counters are reinitialized for the next entry, time of the day (for printing) is requested, and control is passed to the interrupted program.

The above 3 steps will be called a normal exit in the discussion below. There are two error exits. Error exit 1 is executed when such things as wrong letters or numbers are entered from the keyboard. This exit prints out a question mark and goes to KEP5. Error exit 2 prints "ARB" (area busy) and goes to KEP5.

Detailed descriptions of the major commands are given below:

N -- followed by U and C (NUC) is a request for the nuclear program--hence, the initiation of the nuclear mode. The request is honored only if the nuclear programs are not in core and when the area (FLTAB + 7) is free. The request, "NUC OFF", may be received and in this case, the safety circuit must be made up (SAFE = 505050). When the off command occurs, location 44_8 is set to zero and thus NUC2 (the nuclear program) is made aware of the request. NUC2 will turn itself off upon receipt of the signal. After all checking is done, a normal KEP exit occurs.

D -- Means a request for a specific demand display. Control passes to program point K.D, where the second letter of the input string is examined. If LBUF + 2 = W, this indicates a watch channel and the first number, NBUF + 1 is checked. If NUBF + 1 $\leq$ 8, DWAT is set to zero and DISFLG = NBUF + 1. These flags are used by the display program. If NBUF + 1 > 8, an error exit 1 is executed, otherwise, the normal exit procedure is followed. If the second letter is not a W, the checking of the correct number and the setting of DWAT is bypassed. The display program checks on the validity of the NBUF entries after it is loaded into the core scratch area.

E -- Means erase the demand display area. Control passes to point K.E, where DISFLG is set equal to one and the display program is requested as above.

M -- Signifies a possible request for one of the maintenance type programs. "MRD" is a request for rod maintenance. Since this program uses the same core area as nuclear, a special test is made. The flag, SAFE, must be zero--indicating nuclear programs not in core and FLTAB + 8 must show a non-busy status. "MRD OFF" causes a signal flag (RODTAB + 1 = 0) setting. Upon receipt of this signal, RODTIM (rod maintenance) will turn itself off and free the area.

"MAN" request will be honored when SAFE = 0. MAN (the digitizer test and maintenance program) will use the same core area as the nuclear program.

"MVL" is a request for the valve calibration program which uses the scratch area and must be used when the gas system programs are in core. There is no off command for this program, because it turns itself off after calibrating one valve.

L -- Signifies a request for a demand log. For a list of all logs, see Table 21. Control passes to the program point labeled, K.L, where LBUF + 2 is examined. If it is an S, the scratch area is made available. The scratch area is made available. The request, for any log, is honored if the area is not busy and if the proper log number has been typed in. Logs 1 - 14 are the only ones allowed. If more logs are added to the system, this program check (in the K.L. section) must be modified. Since all logs use the scratch area and therefore begin at 16100_8, the setting of tape control words is the same for all--except for the tape storage block for the particular log. To save space, the correct block number is calculated using the log number. All logs were stored sequentially on storage tape 4 beginning with log 1 in block 42_8, log 2 in block 46_8 and etc. The correct block number is,

$$B = 36_8 + (4)\cdot(N) \quad N = 1,2,\ldots 13_{10}.$$

After B is calculated the normal exit procedure is executed.

R -- Means that a rod move has been requested. Control passes to that portion tagged with a K.R., where a jump to subroutine, ROD is executed. ROD analyzes the remaining letter and number strings in LBUF and NBUF respectively. The instruction immediately below the JMS ROD, is used as an argument (it is executed at the proper time) in the ROD subroutine. ROD executes either a normal exit (back to KEP5) or error exit 1 (back to KERR).

S -- This command signals KEP that a core insertion is to be made. It is used to set flags for various programs, to change or initialize setpoints, move valves, set operating modes and to signal executing programs to perform certain functions. The command string is composed of two parts. The first part has a fixed format--thus following the S, there must be 2 letters and 2 numbers. For example, SGA02 is a valid command. The second half is a variable format--thus, a decimal number (up to 6 digits) may follow and if the letter O is typed in, the following number is used as an octal value. In this case, the number must be 6 digits long or else error exit 1 occurs. The octal number of the converted decimal number is stored in the temporary address called T1. No fractions are allowed.

The fixed format (2 letters and 2 numbers) is stored in T2 as a trimmed ASCII word. If the 2 numbers are zero, this indicates that a T1 value is to be stored in single entry table. Otherwise the 2 digit number is used as an index to a multi-entry table and T1 value gets stored in the table + index address.

The two letters--left adjusted in the first 12 bits of a word (called T4 in the program) are matched with all legal two letter codes--found in the first word of the pair in a table called SETTAB. The table SETTAB has the following arrangement:

(Example)

1st pair	24	14	00	/TL Ø Ø
	XX	XX	XX	/ address of TL
		⋮		
nth pair	14	20	14	/LP 14 (table is 14_8 long)
	XX	XX	XX	/ address of first table entry
		⋮		

If the T4 matches with the SETTAB entry, T1 gets stored. If no match is found, error exit 1 occurs.

T -- The T command is used only at start up or initialization time or before the core area beginning at 7000_8 is overlayed with the GASCYC program. Transfer is made to octal location 7001 (INIT program). A total of seven numbers must have been typed in--three digits for the day of the year, followed by a 2 digit number indicating hour, and last, another 2 digit number for minutes. For example, the Teletype command might appear as *T 021 24 03. If 7 numbers are not received, error exit 1 occurs. Otherwise, the day, hour, and minute are stored and two instructions in KEP are modified so a T command is no longer a legal command. The two instructions are replaced with two others which allow KEP to recognize a request for the gas cycle program (GASCYC).

ORIGINAL INSTRUCTIONS	FINAL INSTRUCTIONS
K.2, SAD TT	K.2, SAD GG
JMP 7001	JMP K.G

G -- Followed by AS (GAS) is a request for the gas system programs (GASCYC). The request is honored if the proper core area (FLTAB + 12) is not busy. No other programs use this core area, but GASCYC may already be on and if this is the case, a request will result in error exit 2 where "ARB" is printed out. "GAS OFF" command will only set GA00 = 8, thus informing the system program of the request.

All exits from KEP end up at the section tagged with KEP5. At this point, GNERR is set < 0 to signal a time of the day print out for a valid command. The number buffer counter (KEPB) is reset for nine (9) numbers, and the number buffer (NBUF) and letter buffer (LBUF) areas are set to zero. The saved registers are restored and after enabling the interrupt, the final exit is made.

PERMANENT DISPLAY (HODPOD)

The HODPOD routine is called every time control passes through the main executive loop. The major function performed is the constant updating of the alpha-numeric display. The small, but important duties, other than the display update, are listed for easy reference:

(1) Pulse the gas-heat system deadman. The approximate cycle time for HODPOD is 1/50 second. If, for some reason, program control is not periodically transferred through the main loop (which calls HODPOD) the deadman will not be pulsed (Astrodata command via function register). If the deadman is not pulsed, three things occur; (a) heater breakers are opened, (b) all valves go to their fail safe position and (c) the gas blower is turned off. This deadman is always pulsed when the PMACS system is running--even though the gas-heat system may not be running.

(2) Call the engineering conversion routine to store temperature and pressure values for flow calculations (see description in ENGR).

(3) Output any three letter error message which may have been generated by interrupt driven routines. There are six error flags--if an error has occurred, the BCD message is placed in the location following the flag and the one word message is queued by using TELOUT. Figure 6 shows the error table structure.

FXERR,	0	/ NUC2 errors
	0	
TAPERR,	0	/ Micro Tape error
	0	
ADERR,	0	/ AD Scan error
	0	
TMERR,	0	/ Time
	0	
RDERR	0	/ ROD error
	0	
GNERR,	0	/ Spare
	0	

FIGURE 6. INTERRUPT ERROR TABLE

(4) Call the temperature averaging subroutine (AV.SUB). This routine was described in section IV.

(5) Make sure the A/D scanner is functioning. The current requested channel address should change every time through HODPOD since an interrupt occurs (in AD) 128 times/sec. The message, "SCAN DEAD" is printed if the channel address does not continually change.

Display Functions (HODPOD). All values must be converted to BCD code and packed three to a word before depositing in the prescribed core locations. See Figure 7 for a schematic of the display screen. The reactor power and period are displayed (in green) across the first row. This is the maximum power of the two calculations for each flux digitizer. The displayed period may be a 8 sec. average of both channels, or a 1 sec. average if a significant flux change occurs. (See description of nuclear program for details). The period is displayed as "INF" (infinite) and power as 0.00 when not in the nuclear mode. The absolute pressure is also displayed on the same top row with a "P" prefix.

Positions of the nine HCR's are displayed to the nearest .001 inches, and the vertical rods are represented by "V" codes, where V is displayed in green if the rod is out, blue if all the way in and red if between upper and lower limits.

The average temperatures (computed in AV.SUB) are displayed in the proper sequence, "T" (top), "S" (side, "B" (bottom) and "C" (core).

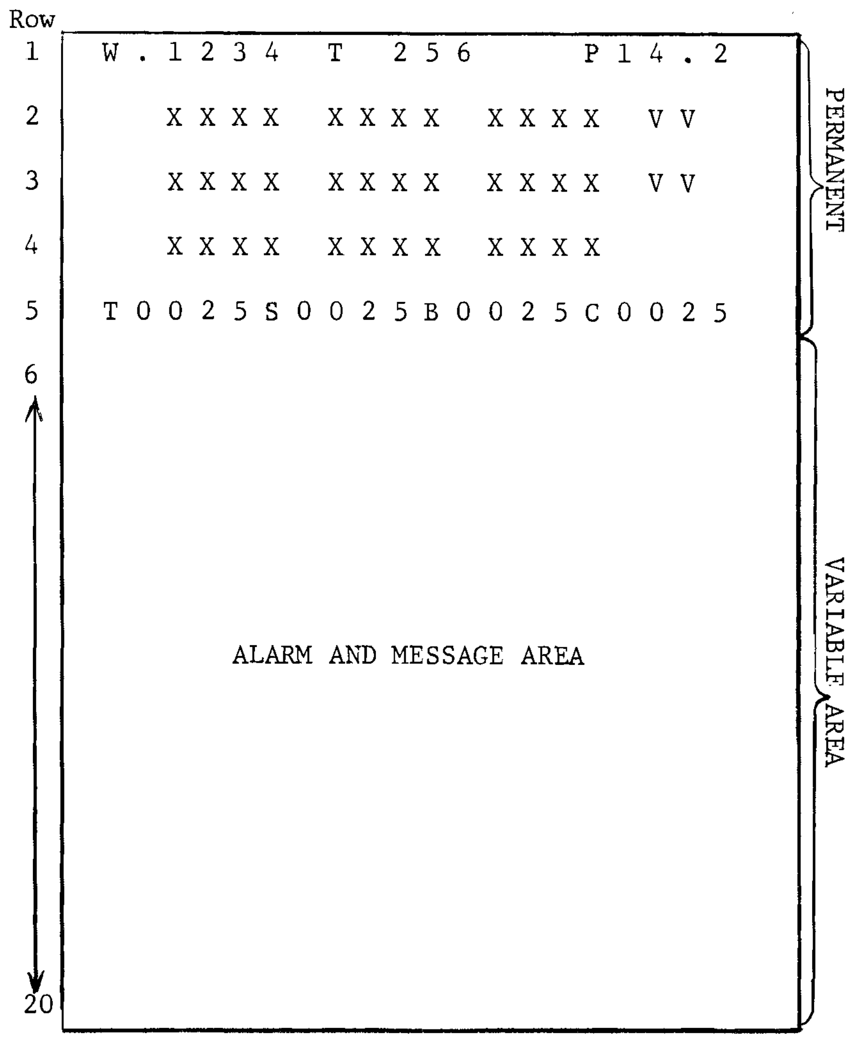


FIGURE 7. SCHEMATIC OF ALPHA-NUMERIC DISPLAY

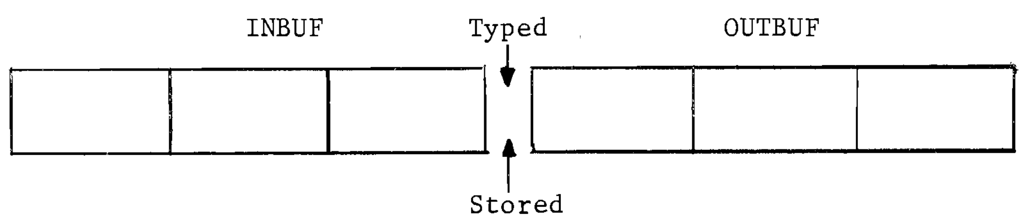
TAPE-CORE BUFFERED OUTPUT (IN-OUT)

The IN-OUT programs are designed so that OUT can store data on magnetic tape with a minimum of delay. All or part of the data written on tape may also be written out by the Teletype. The data must be buffered because of the relatively slow speed of the Teletype. To allow for the time differences in the output devices, two buffers (NBUF and OUTBUF) are used. Each buffer is 256 words in length, thus facilitating the two-way transfer of magnetic tape blocks which are also composed of 256 data words.

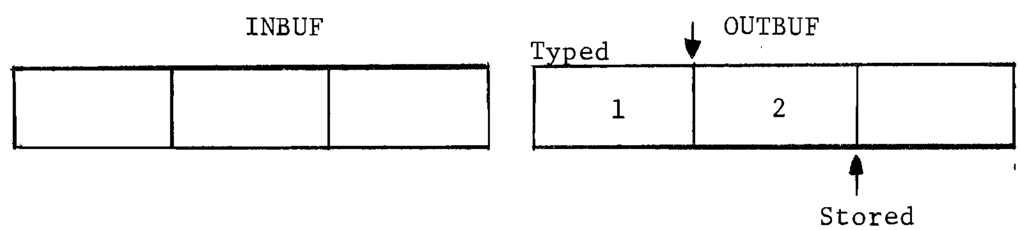
Two indices are used by the IN and OUT routines. The storage index is used to indicate what portion of the OUTBUF has been filled by incoming data. The typing index indicates the position of the next word to be typed.

For illustrational purposes, suppose that each buffer is divided into three parts.

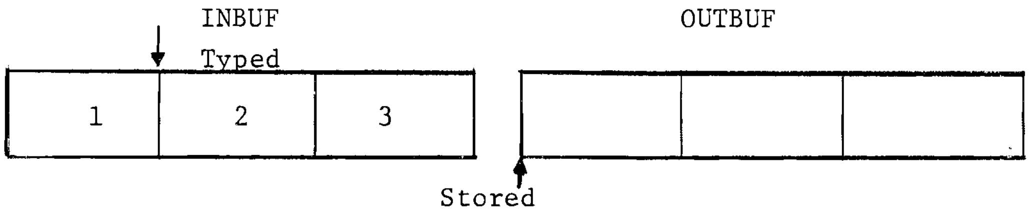
Example 1. Before any initial storing of data, OUTBUF is not full and INBUF is empty. The storage index shows that no data has been entered and the typing index shows nothing to type.



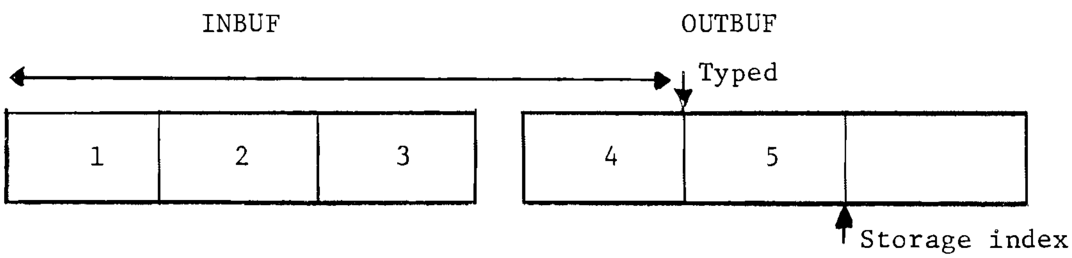
Example 2. INBUF is still empty, but OUTBUF is partially filled. There is a delay in the filling of OUTBUF, and the Teletype has started typing out of OUTBUF. One third has been typed.



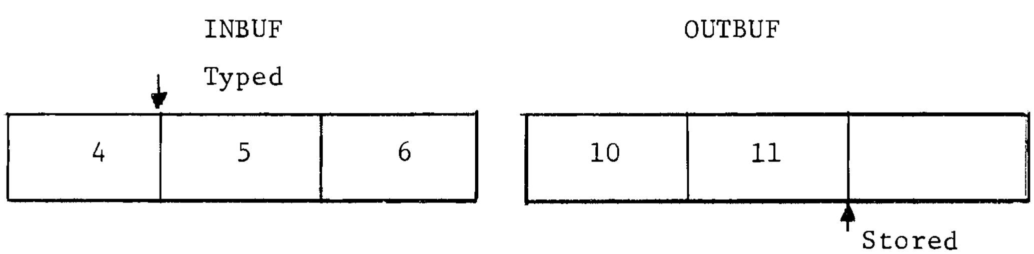
Example 3. OUTBUF is full and has been written on tape. All of the data has been transferred to INBUF from tape. The typing index is set for INBUF, the OUTBUF storage index is reset and new data will be stored in OUTBUF.



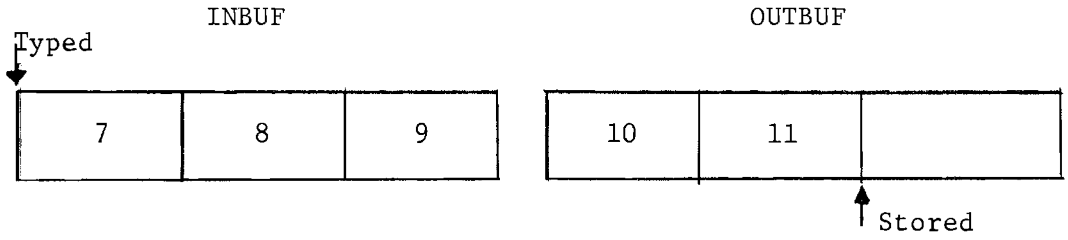
Example 4. OUTBUF has been partially filled again, say 2/3 full, and INBUF has been completely typed. Since the Teletype has caught up with the data, typing continues into OUTBUF, for example, to the 1/3 mark.



Example 5. When a large quantity of data is accumulated, OUTBUF may fill up and be written onto tape several times before one block can be typed. Suppose that sections 4 - 11 of OUTBUF have filled up, and sections 4 through 9 have been written to tape.



Example 6. There is now a delay in the filling of OUTBUF; sections 5 and 6 have been typed from INBUF. The typing index cannot, at this time, continue to index OUTBUF as before because sections 7, 8, and 9 are on tape but have not been typed. Accordingly, sections 7, 8, and 9 are transferred from tape to INBUF and typing continues.



The OUT subroutine is used for storing data in a buffer and transferring that buffer to magnetic tape. The data may be retrieved later from tape by other programs. A single character or a table of characters may be transferred to the buffer, by calling OUT.

When a program has data to be stored or typed, it must call on the subroutine, OUTOK. If OUT is currently being used, the MAIN loop is re-entered using the WAIT routine. If OUT is free, the classification code is now stored with the code at the beginning of the data string by means of the OUTIME routine. The actual instructions for accomplishing the preceding are listed below:

```
/ Calling Program
            JMS   OUTOK        / IS OUT BUSY
            LAC   CODE         / SET UP DATA CODE
            DAC   OUTPUT
            JMS   OUTIME       / OUTPUT THE TIME OF OUTPUT
```

The OUT program is now ready to store the actual data. The calling program may send its data to OUT in any of three ways.

1. Example of ASCII coded "A" to be written on tape by OUT.

```
            LAC (301           / "3" to be removed
            JMS OUT
      / RETURN
```

2. Example of trimmed ASCII coded "A".

```
            LAC (1
            JMS   OUT
      / RETURN
```

3. Example of a table to be written in trimmed ASCII form by OUT.

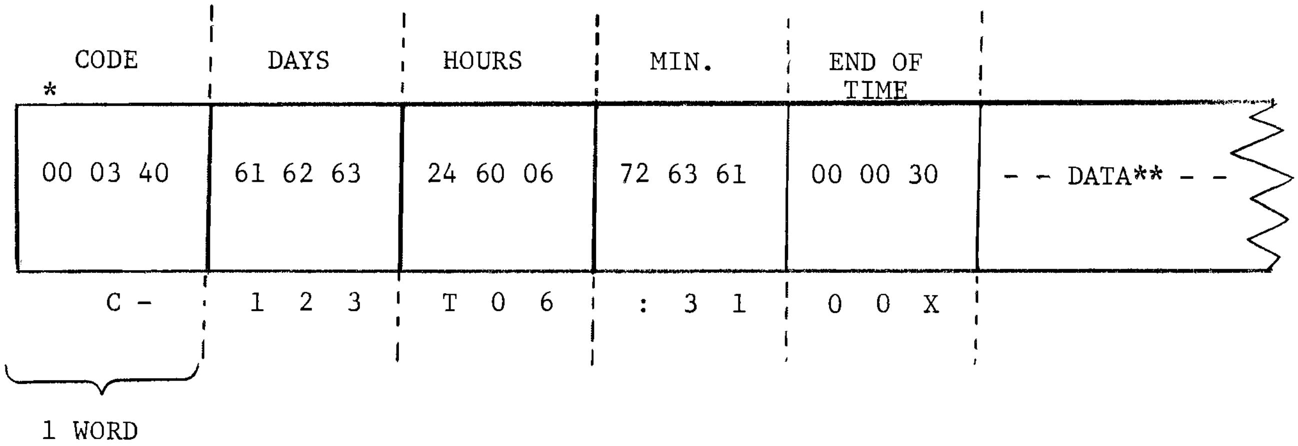
```
        LAM   / ALL 7's indicate a table
        JMS   OUT
        LAC   Table
TABLE,        01  02  03   / A, B, C
              04  05  06   / D, E, F
              00  00  00   / 0's Last entry signify end of table
```

OUT first checks to see if the data word contains all sevens. This indicates a table of trimmed ASCII is to be written out to tape. The first entry is unpacked and then repacked. At this time the data is checked for special characters. These special characters--the blank, line feed, and carriage return, do not readily convert to the trimmed ASCII form without being confused with other characters. Thus, a 34 is assigned to a blank, a 36 to a line feed and a 37 to a carriage return.

When three characters have been packed in a word, the word is stored in OUTBUF. The OUTBUF storage index is incremented and is ready for the next storage word. When the entire OUT buffer is full, it is sent to tape. A busy indicator, OUTOFF, is set so that other programs will not store data while tape transfers are occurring. When the tape transfer is complete, FLTAB + 4 is set to zero and this signals the OUT routine to reset the storage index and OUTOFF (busy flag) in order to allow more data to be stored. At this time a check is made on tape storage. If 1050_8 blocks have been written, the tape storage index is reset to block 7. The tape unit is set to either 6 or 8, depending on whether 8 or 6 had just been filled.

The program, IN, performs as a Teletype driver routine and a data buffer scheduler. Thus, when there is any data to be typed, IN, unpacks the data words, selects typer #2 and requests a character print. As can be seen from the description of the IN-OUT buffer system given above, IN may be picking up data words from the INBUF or OUTBUF area. When the end of INBUF has been reached, the INBUF microtape block number and the tape block number just written out to tape, are compared. If the block numbers are the same, the typing or pick-up index points to the OUTBUF area. If the block numbers are different, the Teletype is lagging behind the output data and one or more blocks are queued up on microtape. The next sequential block must be transferred into INBUF and the pick-up index reset to the beginning of the buffer area.

Typing ends when the pick-up index equals the storage index. When the index indicates more data, the first word of a data string is examined for code and type or no-type status. Figure 8 shows a typical code word structure.



* Signifies beginning of data strings - need not start at beginning of a word.

** Data continued, may be several strings of data per $256_{(10)}$ word table.

FIGURE 8. TYPICAL IN-OUT DATA STRING

The code is compared with a TYPTAB table to determine the type status. For example, if symbolic location TL00 = 204, this means not to type any logs. Note that the data is stored on microtape regardless of the type status. See Table 21 for list of log commands to start and stop typing. Table 20 lists nuclear data (print) commands.

As mentioned, IN, must request the next microtape data block transfer. If block 1050_8 is reached, this is considered to be the last block and accordingly, the proper unit and starting block 7 must be initialized for the next request. If unit 8 was being used, unit 6 must be used for further transfer and if unit 6 was currently used, the converse must occur.

INTERNAL DATA ROUTINE (DATA)

This routine, entered from MAIN--every loop cycle, causes transfer to tape of any data which may have been generated by the heat and nuclear programs. The heat program periodically stores the average temperatures (core, side, top and bottom thermocouple averages) in a table called, AVTEM. The nuclear program will store, on demand only, the average one-minute flux level (period and power) in the SSTAB table. In addition, an operator demand will cause the nuclear program to store high accuracy flux measurements in the STAB table. When this is the case, every eight seconds, two pair, with three values each, are stored in STAB. The two pair correspond to the two flux digitizers and are composed of high accuracy periods (using average flux ratio values over an eight second period--with a second order approximation for the exponential), calculated power and the power scale which was mentioned in the description of the NU2 program.

The DATA routine is also responsible for sending out an identifying code and time of the day for the items listed above. The code for temperatures is GG and a log type out might appear as follows:

GG 271 T 10:38

The same format is used for the 1 minute flux values, with a letter code, FA. The code for the 8 second measurements is NH.

The data indicator (used to determine if any new data has been generated) is the first data word of the examined table--TABLE + 1. If this location is 777777, no data is indicated; otherwise the values are to be logged and stored.

In the case of the temperature data, after fixing the identifying code and time, the table value is converted to BCD code and taken to OUT by use of the subroutine AOUT. After this, the table data is moved up (in a "pop-up" fashion) and the new storage index is fixed--all this being done in the subroutine, MOVEUP.

The flux data is handled in an identical way with the exception of calling a subroutine (DA121), to check on the period; that is, if the period is infinite or negative or if the entry is "XXX", which indicates the digitizer was busy at the time of data storage, the call to AOUT is bypassed and the appropriate BCD code (INF, NEG, or XXX) is stored. The last subroutine call is for MOVEUP, which deserves a brief description.

MOVEUP accomplishes the table push up and storage index bookkeeping. The arguments used are (1) the number of data items or the length of the data set in the table and (2) the command, load table beginning address (LAC TABLE). An example table will illustrate. Assume the data set is of length two and only 2 sets are allowed.

Before Data

Core Address	Table name	Entry
500	XTAB	501
501		777777
502		0
503		777777
504		0
505		777777

The first entry (501) is the storage pointer used by the data generating program.

After Data (1 Set)

500	XTAB	503
501		Data (1)
502		Data (2)
503		777777
504		0
505		777777

MOVEUP would output Data (1) and Data (2), reset XTAB to 501 and set 777777 → Data (1). The call sequence would be:

```
LAC TWO
JMS MOVEUP
LAC XTAB
```

Data generating programs must check on table overflow by examining the storage index. In the above example, if XTAB > 504, a table overflow has occurred and an error message would be printed.

LOGGING ROUTINES (1 - 14)

All logging routines can be requested, at any time, by the operator. The log programs use the scratch area of core. With the exception of Log 12 and Log 13, all logs cause their information to be tape-buffered and free the scratch area before any actual typing occurs. Table 21 contains a list of all logs and their subject. It can be seen that the majority of these programs cause printing of analog input data. The general heading for this type consists of the subject, the analog channel number and/or identification, raw digital counts for that channel and the engineering units corresponding to the raw counts. The raw counts are extracted from the CTAB table which is updated every second by the AD routine. Table 28 shows the logging outputs on Teletype #2. The programs, LOG 1, LOG 12, and LOG 13, have not been included in table form. LOG 1 will type out the complete set of 128 analog input channels. LOG 12 will type out any individual analog input channel--further description is given below. LOG 13, which is described below, is used as a dynamic core location dump--allowing examination of program flags, parameters and setpoints during the real time operation of PMACS. LOG 14 types out the current watch channel status word and its complement.

The description below will cover a detailed description of a typical log program--followed by a brief description of the special logs and those requiring inputs other than analog signals.

Description of a Typical Log. When a log is called, the demand display area is erased and the data code (log number), along with the time of day, is sent to the I/O routine, OUT. The code for any log number greater than 9 is lettered in order to save a digit space. Thus the code for log 10 is A, log 11 has a B, log 12 has a C and so forth. These codes are used more for internal identification than external type outs. Retrieval programs will search for certain codes corresponding to certain data.

A "33" code signals the log program that the heading has been typed (moved to the OUT buffer). The raw counts for the particular analog channel are converted to engineering units by calling the routine ENGR, and the BCD conversion is handled in BTB.

The logs have a paging routine which can be altered by setting AC sense switch 11. Thus, several logs are relatively short and can be typed out on one page. AC switch 11 will signal the log to insert only a few blank lines between successive logs.

When a particular log is finished, the demand display (DMDISP) is called back into the core scratch area. If a display program had been executing (continually monitoring and displaying data) at the time of a log request, that same display program will automatically be restored at log completion time. This means that all logs must set up the request to read in the display program from microtape #4.

LOG 7. This log must type out the engineering units (parts/million) for the particular gas sample analyzed by the gas chromatograph. In addition, H_2O concentrations (PPM--as analyzed by the moisture monitors) are typed out. The LIMIT routine reads in the raw counts from the analog raw count table, CTAB, converts to engineering units and stores in the core table, GPTAB. If the value is greater than 3777_8, the value is divided by 64_{10} for storage purposes, since bits 0 - 6 of the storage word are used for alarm flags and identification indices. When this is done, bit 6 is set to signal LOG 7, which then must extract the value from GPTAB and multiply by 64 before typing the value out.

LOG 8. In addition to the digitized analog transducer reading (raw counts and engineering units - % open) for the seven stepping valves, the contents of a table, VPOS, are typed out under the heading "p.p." The table, VPOS, contains the current requested pulse count for each of the seven valves. This is the count that corresponds to the stepping motor pulses which move the valve.

The current status for the three binary or two way valves (3, 4, and 6FC12) is also typed out as either "OPEN" or "CLOSED."

LOG 9. In addition to the analog input, HCR positions (inches) can be computed from the current rod counters. LOG 9 types out the digital count for all nine HCR's. The count is placed in the RODCUR table by TIME. Also, the counts are converted to equivalent inches of rod travel by TIME and placed in a table, T, which is used by LOG 9. These values are typed out under the heading "P.I."

LOG 12. This program is used for maintenance purposes and types out on the command Teletype. The operator may request a single analog channel (Identification, raw counts and engineering units). The program stays in core until the operator gives a LS (Stop) command. The channel number, which is entered by the keyboard and stored in ANOO, is examined. The program will exit if ANOO is equal to zero and wait until ANOO is changed. At this time, it checks to make certain that the channel number is not larger than 128. An error message, a question mark, is typed if this has been done. If no error occurs, the channel number is used as an index to pick up corresponding raw counts from CTAB and the raw counts are changed to engineering units and then typed out, using the TELOUT routine. A typical print out would appear as the following:

* SANOO 4077 563.2

The set of letters is typed by the operator and LOG 12 answers with the octal raw counts and engineering units.

LOG 13. This log remains in the core scratch area until the operator depresses the asterisk key on the Teletype. LOG 13 bypasses the keyboard executive routine, KEP, and sets up its own interrupt service routine and buffer system. When an asterisk is received, control is returned to KEP and LOG 13 is turned off.

LOG 13 allows the operator to type the contents of any location in core during the real time operation of the system. Table 21 shows a list of operator commands; however, a description will better illustrate the available options which LOG 13 allows.

As previously mentioned, a common area was set up for use by all programs. Some of the more important symbolic names and addresses in that common area are included in a table, L13TAB, found in the LOG 13 program. These symbolic names can be obtained by looking at the symbolic listing of LOG 13. If the operator wishes to request the value or contents of one of these symbolic addresses, he may type the symbolic name with a carriage return; for example, suppose FLTAB contained 13161 (octal). The type out would appear as:

FLTAB 13161

where, 13161 is the LOG 13 response. Other examples follow--with the operator or input underlined and the computer response not underlined.

Example 2: Suppose the contents of FLTAB + 22 and FLTAB + 23_{10} were 37_8 and 43_8, respectively, then:

<u>FLTAB + D22,2</u>	37
	43

The D stands for decimal and the comma is used as the delimiter.

Example 3: Same as above--using octal numbers.

<u>FLTAB + 26,2</u>	37
	43

Example 4: Suppose FLTAB is at location 1000_8 and contains 13_8.

<u>1000</u>	13

One very nice option can be used by merely using the line-feed key after an initial request. Suppose location x contains a 7, x + 1, a 33, and x + 2, a 104. Let LF denote line feed.

Example 5:

<u>X</u>	7
<u>LF</u>	33
<u>LF</u>	104

Suppose x is at absolute address 1100_8 and the operator types a · = combination. The response will give the current address.

Example 6:

<u>· =</u>	1102

<u>DEMAND DISPLAY</u>.

The demand display program, DMDISP, resides in the scratch area and constantly monitors for any new operator request. DMDISP remains in the scratch area until there is a demand for one of the 14 logs or one of the maintenance routines. Whenever one of the replacing scratch programs terminates, it always calls DMDISP back into core.

When a request is acknowledged, DMDISP will continually update the particular requested display; that is, the displayed values will be updated everytime through the main loop. Any display headings will not be updated. If a display is requested while a current one is being updated, the current heading and values are moved up. The old locations are erased and the new request is shown as below:

PERMANENT AREA (NEVER ERASED)
PREVIOUS DISPLAY
CURRENT DISPLAY

Although the previous display may still be on the screen, only the new or current one will be updated.

There are four system displays: (1) Gas purity--requested by D1, (2) Valve position, Pressures and Gas flow--requested by D2, (3) Heater Power and maximum heater and graphite stack temperatures--D3 and (4) analog positions of HCR rods--D4. The watch channel displays (DW1 - DW8) are listed in Table 22.

Whenever any display is being updated, the appropriate code (corresponds with the operator command--D1, D2, ...DW8) is displayed intermittently. This has the effect of an exaggerated flicker and assures the operator that the program is, indeed, being constantly updated.

Display Details. The flag, DDOO, contains the display number which has been set by KEP after the operator request. On the first time through, DMDISP loads the display headings and sets DDOO < 0 so that subsequent entries will update the data only.

Lines of the display are unpacked--three words at a time and stored in the table, DPTAB. Two control words are associated with the sets of data to be continually updated. The words (DISW1 and DISW2) are described in Figure 9 . A typical display line section is shown in Figure 10.

VII. LIMIT CHECK AND ALARM (LIMIT)

The LIMIT routine is a permanent core resident which is routinely executed once every ten seconds. Its primary function is to examine PMACS inputs for off-normal conditions and to indicate these conditions to the operator. An off-normal condition, for some inputs, is defined by the state of the related system program. The inputs checked include watch channels, analog inputs, and gas purity values calculated by program (GAP). LIMIT also sets GASCYC flags on certain alarm conditions for automatic reactor shut down or emergency

CONTROL WORD 1
DISW1

A	B	C
Bits 0 – 2	3	4 – 17

CONTROL WORD 2
DISW2

D	E	F
Bits 0 – 2	3 – 5	6 – 17

FIELD	BITS	CONTENTS
A*	0-2	Placement of decimal point for various data.
B	3	Bit 3 = 1, send data to ENGR.
C	4-17	Address where data found.
D	0-2	Position in word (0, 1, or 2) of desired character.
E	3-5	Number of characters to be updated including color code.
F	6-17	Address in display (Nth Word in display).

* Bit 0	CXXX. (Color code plus 3 integers)
Bits 1+2	CXX.
Bit 1	CX.
Bit 2	C.

FIGURE 9. DMDISP CONTROL WORDS

```
c 1 P c 1 . 2 3 4 c 2 P c 4 . 1 2 c P 3 - - -

    I.D.     Data     I.D.     Data     etc.

c = color code, green is normal and red is alarm
    condition.

DPTAB        .        To change the data of 1P,
             c        the program unpacks and stores
                      9 consecutive characters in
             1        Table DPTAB.
             .
             2
             3
             4
             c
             2
             P
```

FIGURE 10. TYPICAL DISPLAY LINE AND TABLE

cooling. LIMIT is executed immediately whenever the reactor safety circuit is tripped by external hardware. This is to identify the source of the safety circuit trip to the operator.

All alarms appear on the alpha-numeric display in red. Watch channel alarms are identified by an abbreviated message. The analog signals appear identified with a mnemonic and the value displayed in engineering units. The gas purity values appear in a similar manner. When an off-normal condition occurs, the proper message will be displayed on the alpha-numeric screen in red, an audible alarm chime will sound (no more than once per cycle), the logging Teletype will print the date, time, (no more than once per cycle) and the alarm message preceded by a number symbol (3), and the message will be stored on microtape. The operator can prevent the type out by his option. As long as the off-normal condition persists, the alarm message will be displayed and, in the case of the analog values, updated each ten seconds.

When the alarm returns to normal or is bypassed, the display will change color to blue, the audible chime will sound, the Teletype will print the date, time, and the alarm message preceded by an exclamation point (!) and the message will be stored on microtape.

The alarms are displayed below the alpha-numeric continuous display and have priority over demand displays. Each alarm uses one line on the display and allows up to fifteen alarms during any cycle. If more than fifteen alarm conditions exist, the display full message (DPF) will be typed out and one additional alarm (new or old) will be logged out once per minute.

In addition to the off-normal conditions, LIMIT checks all watch channel words for malfunction of switch or circuit. If each watch channel is not complemented, a mnemonic is typed. See Table 14. This indicates an open, shorted, or grounded circuit. The operator must determine the faulty circuit by the watch channel demand display.

Whenever the HEAT program is on, all graphite and heater thermocouples are checked for failure in addition to the high limit check. If the value drops downscale or deviates from the average graphite temperature by a preset amount, the thermocouple is assumed to be bad. If the HEAT program is not on, the operator may bypass (or reset) the thermocouple check. LIMIT will turn off HEAT (cause GASCYC to turn off the reactor heaters) if any heater or graphite thermocouple reaches its limit, a heater thermocouple is assumed bad, or if any heater group exceeds its electrical power limit. LIMIT will set the emergency cooling flag for GASCYC if any moisture monitor reaches a value in excess of its high limit.

VIII. SYSTEM PROGRAMS

There are only three major reactor systems: (1) Cooling, (2) Heating, and (3) Nuclear. From the program standpoint, these systems can be better understood and described if five divisions are considered; namely, (1) Gas-Heat, (2) Nuclear (flux measurement), (3) Gas purity, (4) Reactor rods (VSR's and HCR's), and (5) The programmed scram system. The systems will be discussed in the above mentioned order.

GAS-HEAT SYSTEM (GASCYC)

The programs related to the gas and heat systems consist of 11 distinct segments on 4 magnetic tape links. The gas and heat systems program is approximately 2400 (octal) words long. Since the storage area assigned to this program is only 1350 (octal) words, the program was broken into sections. Short routines in each section call other sections as they are needed. Each program section on magnetic tape is called a link. A group of subroutines, which remain in core, occupy 700 (octal) locations and are used by all the tape links.

Each of the program segments has a name that roughly describes the state of the reactor gas and heat systems when that particular segment is entered from the main program loop. The six main criteria for determining a reactor state are:

(1) The initial valve positions.

(2) The alarm conditions which are monitored by the LIMIT routine.

(3) The alarm conditions which the gas-heat program monitors.

(4) The allowable states that can be entered from an existing state.

(5) The blower operating status.

(6) The average stack temperature.

The operator may position any of the 7 digital valves and 3 binary valves by keyboard command. The position ranges are 0% to 100% open in units of 0.1%. If the operator requests an open position greater than 100%, 100% is used and the message "VPE" is typed.

Figure 11 depicts the sequence in which the operator may request the different gas-heat system states. The heating system segment may only be executed when the gas system is in the "gas heat" state. The heat segment automatically forces the average reactor stack temperatures to the setpoint selected by the operator. At the operator's request, the core heater bank is shut off, and the setpoint temperature is maintained using the top, side, and bottom heater banks. The operator may also set any heater bank to some fraction of its maximum output. Setting the heater outputs manually shuts off the automatic heat controller.

All the digital valves are calibrated when the gas-heat programs are initially called. The mechanical valve positioner has slack in its linkage so that the valves become uncalibrated after several hours under automatic control. When the disagreement between the digital drive motor position and the valve stem position become excessive, the operator may calibrate a valve

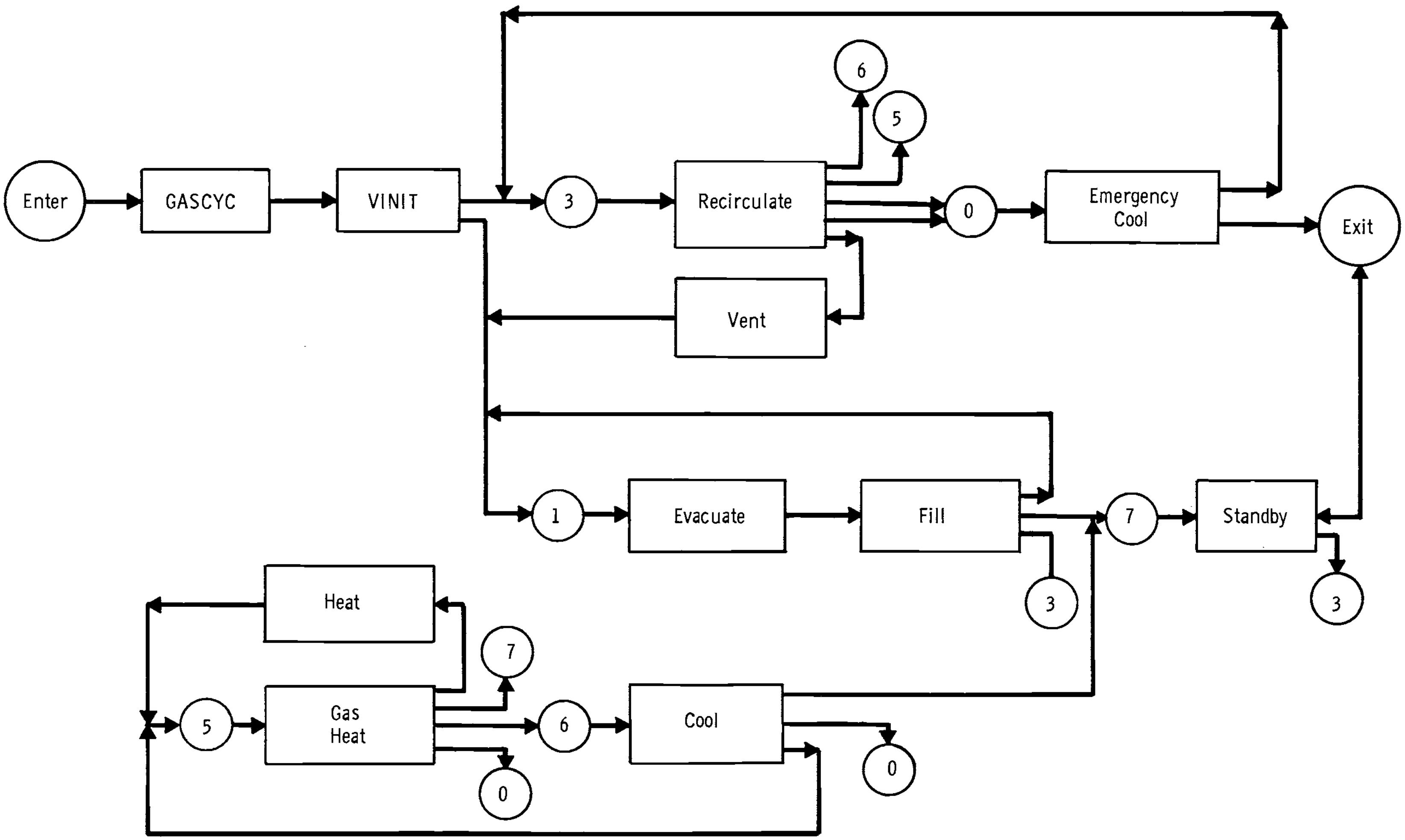


FIGURE 11
Communication Between Gas and Heat System States

approximately by using limit switches, or he may call the valve calibrate routine.

Detailed Description. The areas that will be covered in detail are: features common to all program states and descriptions of the function of each state. The three common features for the magnetic tape links used in the gas and heat system program are the linking procedure, the method of predetermining the communication among the various states, and the major subroutines common to all states.

Linking Procedures. The links are read into core from magnetic tape by the MAIN executive routine after an operator or internal program request. As stated previously, the core area reserved for the gas-heat systems programs is 1350 (octal) words of which 1300 are contiguous. Links 2, 3, and 4 are loaded into locations 6100 through 6477 (one block) and link 1 is loaded into locations 6400 through 7377 (two blocks). This must be done because the MICRO routine reads exactly 1 block at a time. The subroutine package and the "emergency cool" state program reside in locations 6500 through 7377 (1 3/4 blocks). Although it is just a few words long, the program in link 1, which calls the second link, has to start at 6400 in order that 2 blocks can be read into core. The program on link 2 starts at 6100 and extends through 6477, thus overlaying the program in link 1 that calls link 2. When link 3 is called, it overlays link 2, and link 4 overlays link 3. Link 2 calls link 3 and link 3 calls link 4; line 3 may also be called by link 4. The call sequence for link 3 is a residence routine of a few words and remains available as long as the gas-heat system programs are active. This is necessary, since links 3 and 4 may call one another.

Communication Among Program States. To call the gas-heat programs initially, the operator types the following characters,

*GAS ↓

where ↓ is a carriage return. Under the operator's commands, MAIN calls the first magnetic tape link which contains the routine, GASCYC, and the subroutine package. The sole purpose of GASCYC is to call the second tape link containing the program VINIT. The program, VINIT, initializes variables and constants for links 3 and 4 and calls link 3 which contains most of the program states. Before calling link 3, VINIT sets the program entrance point in link 3 to either "evacuate" (low temperature) or "recirculate" (high temperature). The temperature break point is a variable whose value may be easily changed. The operator may request a transfer to another state by typing the characters,

*SGA ØØ N

where N is one of the digits 0 through 9. The digits correspond to the program states as listed in Table 1.

TABLE 1

Gas Program States

Decimal Number	Octal Number	Program Mnemonic	Program State	Magnetic Tape Link
0	0	ECO	Emergency Cool	Resident
1	1	EVA	Evacuate	#3
2	2	FIL	Fill	#3
3	3	REC	Recirculate	#3
4	4	VEN	Vent	#3
5	5	GHE	Gas Heat	#4
6	6	COO	Cool	#3
7	7	STA	Standby	#3
8	10	SHU	Shutoff	Resident

The HTLTR operating group determined the order in which the operator may request program states. Each program state is assigned an identification number as listed in Table 1. Notice that the two program states GASCYC and VINIT in Figure 11 are not in the table. When the gas-heat programs are called, these two program segments are entered automatically. Also, "shutdown" is listed as a state, but is not in Figure 11. The program for this state consists of a few commands to type the message "GOF" and to stop execution of the gas and heat systems programs. No matter what state is requested by the operator, communication is confined to the paths shown in Figure 11. For example, if the program state was "evacuate" (number 1), only the fill request would be honored.

Subroutines. There are five subroutines that remain in core as long as the gas and heat systems programs are active. Subroutine VMOVER handles the manual and automatic valve control; INIT (not to be confused with PMACS start up "INIT") initializes all digital and binary valves to their proper values when mode when the average temperature was more than 10°C away from the setpoint temperature. The other sub-mode, the regulate mode, provides proportional-plus-integral control of the top, side and bottom heater banks. The breaker for the core heaters is opened, so there are no hot areas around the heaters and there is a smaller temperature gradient in the core. The controller calculations are similar to those performed in VMOVER for control of the gas-system valves.

The heat-transfer and electrical characteristics change with changes in the temperature. The electrical characteristics effect control, because the heater rods are graphite. In order to compensate for the non-linear response of the heating system, two sets of controller constants are used. Before each control calculation is performed, graphite temperature is tested to determine if the low temperature (below 400°C) or high temperature (above 400°C) set of constants whould be used. This feature gives faster and more stable control than control with only one set of constants.

For large increases in setpoint (this is approximately 100°C for the present set of controller constants) the controller requests maximum power from all heater banks. The heater banks are not perfectly balanced, so the rates at which the four reactor sections (top, side, bottom and core) change temperatures are not equal. With keyboard commands the operator may limit the maximum output from the heater banks in order to balance and limit the rate at which the temperature increases.

The power load, when the heater controls are adjusted for maximum output, is approximately 400 kilowatts. In order to not drop this load immediately when HEAT is shut off and possibly introduce noise into the computer, the breakers are not opened until 20 seconds after the control signals are set to zero.

NUCLEAR SYSTEM (NU1, NU2, RCS)

The NUCLEAR program performs all of its functions for both flux digitizer units. (See page 6 this document, for a brief review of the digitizer units). Thus, in the description given below, this duality is always in-allowing the nuclear program initialization and the "making up" of the safety circuit for the nuclear mode of operation.

(2) To find the proper range or to make sure the digitizer is "on scale" and to keep the digitizer on scale whenever the reactor is in the nuclear or core load mode. "On scale" is equivalent to satisfying the inequality: $15 \times 10^3 < \text{counts} < 85 \times 10^3$. When on range zero, counts need only be greater than 8×10^3. This criteria is based on a one second accumulation in the flux registers with full scale at 10^5 counts.

(3) Calculate a low accuracy period, τ, ten times each second to compare with a period limit, τ_s, set by the operator.

$$\tau = .1 \left[\phi_i / \Delta\phi_{i+1}\right] \quad \text{where}$$

$$\Delta\phi_{i+1} = \phi_{i+1} - \phi_i, \quad \text{and}$$

$$\phi_i = \text{the counts accumulated over the } i^{th} \text{ interval.}$$

This amounts to taking second differences of the contents of the flux register at any time, t_j, since the flux register represents the integrated flux,

$$\int_{t_o}^{t_j} \phi \, dt,$$

and the 1/10 second calculation demands the contribution of counts for each 1/10 second interval. If $\Delta\phi_{i+1} \leq 0$, the calculation is not done.

The sampled data must exhibit a definite trend and the random noise is filtered; therefore, the following device is used for the .1 sec check. Denote the operating period setpoint as τ_s. A comparison is made using the .1 sec τ and τ_s; thus if, $\tau \leq \tau_s$, a potential trip or scram is involved. If this trip condition is observed n_r consecutive times, a programmed scram actually occurs. The number, n_r, is a function of the digitizer range and has been determined empirically. Counting statistics can be employed and n_r can be adjusted.

(4) At the end of each second, $\omega = 1/\tau$, is calculated for two purposes.

There are four different commands used for effecting data transfer. TSF1 = 703602, transfers raw counts from AC register #1 to storage register #1. The contents of the AC register are not changed. An identical command TSF2 = 703604, is used for channel 2. FD17 = 705012 and FD27 = 705014, transfer the contents of the storage registers 1 and 2, respectively, to the PDP-7 AC. A two machine cycle wait must be used between the two commands TSF1 and FD17 or TSF2 and FD27. This delay allows the complete transfer from the AC to the storage register involved.

All relay switching times, involving the digitizer equipment, approach 100 milliseconds. This is no problem since the nuclear programs are entered from the .1 sec. interrupt routine. The major problem in the programming is to keep track of a series of switching times. In addition, the time response of the digitizer is range dependent--thus on the more sensitive ranges, noise filtering devices have introduced large time constants. For example, it may only take about 1 second to accomplish a range change (range 11 to range 10) and obtain a full second zero offset count. Performing this same function while changing from range 1 to range 0, may require many seconds. One of the program features is the incorporation of delay tables which can be easily changed if more filtering is required.

There are two nuclear programs--labeled NU1 and NU2. The first program, NU1, is an initialization program whose main functions are outlined in (1) and (2) above. NU1 will be described first.

<u>NU1</u>. Entry is first made from the main loop and <u>not</u> the .1 second interrupt, TIME. Control passes to that portion of the program tagged, I.500. The flag, SAFE, is set to 50, thus signaling TIME to begin calling NU1.

The second entry transfers control to I.502. If any of the safety checks (see flow diagram for NU1) are not satisfied, digitizer relays are opened and the nuclear program is turned "off"--indicated by SAFE = 0. When all checks indicate a go condition, control passes to the section tagged I.1.

In this section, three major functions must be fulfilled. First the zero offset reading must be obtained for all twelve digitizer ranges. This is the reading taken with the data relays open. The offsets must satisfy the inequality ($20 < Z < 3000$) and then they are placed in two tables which are range changes and sets the proper time delays corresponding to the current range. Time delays can be found in the table, DLA. The subroutine, CHEKZ, performs the inequality check mentioned above.

Secondly, both digitizer units are calibrated. This is done in the subroutine, CALBR. A switch to range 7 is made for both units in order to speed up the response time. However, the calibrate circuitry is not dependent upon range setting. After a 4 second delay, the flux AC's are zeroed out and a 1 second reading is taken. The calibrate should add about 10% of the full scale reading of 100,000 counts. Hence a one second reading on range 7, with the zero offset subtracted, should satisfy the inequality, 9000 < counts < 11,000.

Finally, the digitizers must be put "on scale." This is done starting with digitizer 1 on range 6 (set SCALE = 6). A fail count is set to three and the test loop begins. The range change is initiated by FIDDLE, the data relay is closed, the flux AC is zeroed and a one second count is taken. The routine, HILO, checks the inequality, 15,000 < counts < 85,000 and signals when satisfied--at which point the sequence is repeated for digitizer 2. Note that the lower limit is 8,000 when on range zero. If the inequality is not satisfied, the range is decreased by one and the sequence repeated. Successive checks on ranges 6 through 0 are repeated three times before a failure message is printed and the nuclear programs are turned "off." The on range "scale setting" for unit #1 is placed in NS1 (equivalenced to SFUX1) and the setting for unit #2 goes into NS2 (equivalenced to SFUX2) thereby making both available for the NU2 program.

When both digitizer units are on scale, control passes to tag point I.100 where the following initialization is done: The zero offset which corresponds to the current range is placed in ZFUX1 and ZFUX2 for digitizers 1 and 2 respectively. The quantity, .1 (ZFUX) is placed in TZ1 and TZ2 for TCALC's use in NU2. The proper range change delay and consecutive trip count (described in NU2) corresponding to the current range, are placed into AUXA and AUXB for both units. Eight second, 1 second, and 60 second timers are set for use in NU2. Power factors are set for NU2.

Finally, "NUC 1 OK" is typed out and the microtape control words are loaded into FLTAB so that the NU2 program can be loaded into core--overlaying NU1.

NU2. The NU2 program must accomplish the items listed in (2), (3), (4) and (5) above. There is a small initialization section in NU2. Control passes to that portion tagged, INITF, until initialization is complete. If NU1 has executed (indicated by SAFE - 5050), the safety circuit is made up by transferring the proper astrodata commands. A jump to subroutine SCRAM is placed in channel 0 (highest priority) of the program interrupt vector--thus setting the proper program switch for any scram resulting from hardware sources such as power failure, scram buttons or EG & G channels. The flag, SAFE, is set to 505050--indicating that the circuit is complete and that NU2 should be entered from TIME.

When first entered from TIME, the flux AC's are set to zero to establish a timing cycle. The addresses of RFUX table entries for unit #1 are set. (See RFUX for description of all variable program tags). The address of ZFUX1 is placed into ZFUX so that the correct zero offset for unit #1 can be used in the subroutines. Later, when calculations for unit #2 are being used, the address of ZFUX2 will be placed into ZFUX. In fact, two subroutines have been especially written to perform this address change function for 16 different variable addresses. These subroutines are called IMOD1 and IMOD2. Since all RFUX table entries are in pairs--always for unit #1 and unit #2, IMOD2 can increment all addresses by one for unit #2 and IMOD1 can decrement by one in order to reset addresses for unit #1.

After addresses are set for unit #1, a one second accumulation of counts are taken for both units, and the flux value $\phi(I)$ is established for each unit. This $\phi(I)$ is used in the 1 second period calculation routine. In a similar manner, a .1 second old flux value is eatablished for the .1 second calculation.

Finally, the entry switch is set so the INITF section is bypassed. Also, the scram interrupt (API channel 0) is enabled and thus placed in a receptive state.

As long as the nuclear mode or core load mode (fuel loading with flux monitoring) exists, the program, NU2, will, every .1 second, call the subroutine, TRANS, to obtain the flux readings, and then proceed to the flux level checks.

If neither digitizer or unit is busy (in the range change process) the .1 second calculation routine, TCALC, is entered--first for unit #1 and then #2. If one second has not elapsed, control always passes to F905--where the nuclear safe deadmen are pulsed, the OFF request is checked and program exit is made for the current .1 second cycle. The pulsing of the deadmen (through Astrodata commands) serve two purposes: (a) signal that all nuclear checks are satisfactory, (b) signal that the .1 second interrupt is working, and that control does not remain in a malfunctioning program loop.

When one second has elapsed, the routine, CALC, is entered for unit #1 and then #2. (CALC and TCALC are described below). After this, the maximum power is displayed (placed into POWER for HODPOD to display) and if unit scales differ by more than four, transfer is made to C1.7, scram code 7 is loaded and a program scram occurs. Otherwise, subroutine RCHK is called to see if a new range change is needed for either unit. Whether or not a change is required, control then passes to tagged portion, F55.

The average omega, $\bar{\omega} = (\omega^1 + \omega^2)/2$ is calculated. The program symbol is WD, where $WD = (\omega^1 + \omega^2)$. The following inequality must be satisfied if any display updating is to occur.

$$|\bar{\omega} \quad \omega_D| > \sigma \quad ,$$

where, ω_D, (program symbol, OMEGA) is the comparison omega or last significant omega and σ (currently σ = .002) is the standard deviation obtained from observed omegas. If updating is necessary, subroutine, OMD calculates $\tau = 1/\omega$ and this value is placed in PERIOD for HODPOD's use. Also, one should note that two consecutive significant changes are necessary for a display update. This technique eliminates some of the noise spikes--especially on sensitive ranges with only a small neutron source. If an update takes place, OMEGA = $\bar{\omega}$ and if on the 6th or 7th second of an 8 second cycle, AUX2 is set to signal the HIACC subroutine to bypass any period display updating.

If 8 seconds has elapsed, the HIACC routine is called, and a high accuracy period is calculated--using the last eight flux ratios obtained from the CALC routine. HIACC is called twice--once for each unit. When neither unit is busy and if AUX2 has not been set, an average omega is calculated. OMEGA is updated with this value, and OMOD is used to calculate τ and update the display without any further test. If the 1 second override has been set (AUX2 $\neq$ 0), all of the above updating is bypassed. In either case, if one minute has elapsed, and if the store flag (ND01) is set, the current display or average period and power is stored into a table labeled, SSTAB. (The routine, DATA, moves this nuclear data to microtape). Three entries are made in the SSTAB--period, normalized power and power scale or information which is used to separate integer and fractional portions of the power. Finally, control passes to the section F905 described above.

Care is taken to be sure that none of the omega averaging takes place when one of the units is busy making a range change. When this is the case, CALC is only entered once and the flag, AUX1 = 1 unless the period was infinite (AUX1 = 0). The AUX1 flag signals the main program when to divide by 1 or 2 or when to merely output a BCD code for infinity.

The three major subroutines, used by NU2, will now be described.

TCALC. This is the .1 second safety check routine which calculates a

$$\tau = .1 \left[\phi_i / \Delta\phi_{i+1} \right] .$$

Using program symbols as capitalized names for easy cross reference,

$$\tau = .1 \left[\frac{\phi_i - \phi_{i-1} - TZ}{\left(\phi_{i+1} - \phi_i\right) - OFUX} \right]$$

where TZ = .1 (Zero offset)

$$OFUX = \phi_i - \phi_{i-1}$$

Assume zero offset is linear. If $\tau < \tau_s$ for N_r consecutive times, a programmed scram occurs. (τ_s is the period setpoint whose program symbol is ND03. N_r is a range dependent number which is found in the SFACT table).

CALC. This is the one second safety check routine which causes a scram if (a) τ = 8 seconds, (b) $\tau < \tau_s$ (c) $\phi_{i+1} > 100,000$ (d) power > P_s (3) power > 2000 watts (f) unit not on scale. (counts > 5000).

τ_s has been defined as the period setpoint--set by the operator. P_s is defined, now, to be the operator power set point. ϕ_{i+1} is the accumulation of counts for 1 second. CALC subtracts the zero offset for the current range from ϕ_{i+1} and places this adjusted value in IX. The old 1 second flux, ϕ_i is called FUXX. After all calculation, FUXX is updated; that is, IX → FUXX.

The quantity ϕ_{i+1}/ϕ_i is added into a running ratio sum called RAT--this is used to calculate the high accuracy omega every 8 seconds. A one second omega, $\omega = \left(\phi_{i+1}/\phi_i\right) - 1$ is calculated--if ω is ≤ 0, a transfer is made to program tag C.50 where the power calculation is done. If $\omega > 0$, it is stored in TAU for LOG11 routine, if requested. In addition, ω is added in with the running sum, WD. Recall that WD is used in the display update.

The power calculation is handled in the following way. The conversion or K factor has been estimated and will be more accurately determined after the reactor has been loaded with fuel. The current equation used is,

$$P = K_j \, C \, 2^{2r} \qquad j = 1,2$$

where

C = current raw digitizer counts

r = range (1, ...11)

$K_1 = 1.43 \times 10^{-7}$

$K_2 = 3/5 \, K_1$

The flux, ϕ, is proportional to ion chamber amps/chamber sensitivity,

$$\phi = \frac{\text{amps}}{\text{sensitivity}}$$

The raw counts-amperes relation is

$$\frac{C}{\text{amps}} = \frac{10^5}{2^{2r} \times 10^{-10}}$$

Therefore,

$$\phi = (2^{2r})(C)(10^{-15}) \, \text{SENS}^{-1}$$

and since,

$$P = k\phi \,,$$

we have,

$$P = \left[(k)(\text{SENS}^{-1})(10^{-15}) \right] C \, 2^{2r}$$

where the bracketed expression represents the K_j estimates given above.

The K_1 constant is 23142_8 scaled at B-36. An integer (in the accumulator) is understood to have the binary point after BIT 17 and hence is scaled at B-0. As a further example, the octal fraction, .003666 is said to be scaled B-18. The absolute value of the scale factor is used to shift the AC into the Q register and thereby split off fractional parts of a number for the BCD conversion routine.

Now, consider the factor, 2^{2r}, in the power equation. When multiplying, this has the effect of decreasing the scale factor by a factor of 2r. More significant bits can be gained by a pseudo-normalization (in this case--a long left shift 6 bits). This, of course, has the effect of further decreasing the scale factor by 12 (2 x 6). Therefore, the power scale factor is calculated in the program as,

$$\text{Scale factor} = 36 - 12 - 2r = 24 - 2r.$$

This factor is stored in PS1 and PS2 for Channel 1 and 2, respectively.

Using the same estimate for K and power - 2000 watts (the high level trip point), it can be seen that this is roughly equivalent to 13,000 counts on range 10.

HIACC. This routine is called twice in succession (for channel 1 and 2) every 8 seconds. The two functions performed are to (1) calculate a high accuracy period and store in a data table (for output) if a storage request has been received and (2) sum both 8 second omegas if neither digitizer is busy.

If a digitizer is busy and if the storage request flag is set, a BCD "XXX" is stored in the STAB table. (See description of flux value outputs in the DATA routine).

The period is calculated using the second order approximation to the exponential. Thus,

$$\phi_{i+1}/\phi_i = \text{EXP}\ (T/\tau) \simeq 1 + T/\tau + .5T^2/\tau^2$$

Let ϕ_{i+1}/ϕ_i, for the j^{th} second, equal R_j, then

$$\omega = \sum_{j=1}^{8} R_j/8 - 1$$

$$\text{and} \quad \omega \simeq 1/ + .5/\tau^2$$

$$\text{where } T = 1 \text{ second.}$$

$$\text{Thus, } \tau = [1 + \text{SQRT}(1 + 2\omega)]\ /2\omega$$

The above calculation is performed in HIACC, using a B-12 scaling. Tau is not mentioned explicitly in the program--rather it is stored in location HI10 for use if the store request flag is set. If $\omega < 0$, the BCD "NEG" is stored in HI10 and if $\omega = 0$, "INF" (∞) is stored in HI10 and all calculations are bypassed. If $\omega > 0$, the counter, INUM is incremented by one. INUM is always 1 or 2--the latter case, of course, occurs when neither channel is busy and the counter signals the main program to calculate,

$$\omega = (\omega^1 + \omega^2)/2,$$

which is used for display updating purposes.

RCS. Whenever the safety circuit is made up, this routine is called ten times a second from TIME--thus, RCS is always executed just before entering the NU2 program. The location, CLOO, is immediately checked to determine if there has been a core load request--indicated by CLOO $\neq$ 0. If a request has been made, two checks are made before honoring the request. All HCR's must be closed. The subroutine, HCR, performs this check. Secondly, two VSR's must be in and two must be all the way out. This condition is checked in the VSR subroutine. If either or both conditions are not true, control passes to N.0 or the nuclear mode section. If the two conditions are true, the program entry is set to C.2 and CLOO is set to a 740000 (used in case of a scram). In addition, "COR" is printed out. As long as the core load mode exists, all the HCR's must be out or a scram will occur--the programmed scram calls the routine, SCRAM2. The VSR condition must remain true--if not, the howler is blown and a scram does not occur. However, a scram will occur if the basement door is opened.

At location, C.30, the flag, CLOO is re-examined to see if a nuclear mode has been requested (CLOO = 0). The request is honored if both doors (reactor and basement) are closed. The program entry is set to nuclear check so that control passes to N.0. Also the word "NUC" is typed out to inform the operator.

In the nuclear mode, a scram occurs (call subroutine, SCRAM2) if any of the VSR's come off the upper limit (checked in subroutine, VSRO) or if either door is open. (Checked in subroutine, DOOR).

GAS PURITY (GAP)

The GAP routine is a permanent core resident which is entered once every second. Its primary function is to read and calculate engineering units for the gas system moisture monitors and gas chromatographs. It also switches the moisture monitor sample streams and sets the gas purity alarm valves as a function of reactor temperature. Each second, GAP determines the instrument range settings from the watch channels. These are then used to obtain the proper range multiplier used in the engineering routine.

When not within a gas chromatograph cycle, GAP checks each second for the flag indicating the gas chromatographs have started a new sample cycle. This flag initiates a timing cycle which alternately reads peak values and waits for the next peak. The time settings for each peak and each wait are determined by the gas chromatograph self-programmed timers. The program times are adjusted by the operator to agree. The program reads, calculates, and stores the values for hydrogen, carbon dioxide, oxygen, and carbon monoxide for each of two sample streams. The gas chromatograph timer initiates the stream switching. Since the ADC scans the gas chromatograph signals at about once per second, and some of the contaminant peaks are rather short lived (< 10 seconds), the program estimates the peak value from the highest readings.

$$V_p = V_1 + \frac{V_2 - V_3}{2}$$

where,

V_p = estimated peak value.

V_1 = maximum value read.

V_2 = second highest value read.

V_3 = third highest value read.

This value is then used to calculate the engineering units (volume parts per million).

The program also reads the nitrogen peak in order to determine if the gas chromatograph is functioning or if the program timing is in error. If GAP doesn't detect a nitrogen peak, it outputs an error message "GCE". When all contaminants have been read, the program again checks for the new sample flag. The timing sequence is reinitiated for each cycle.

Every four minutes, GAP reads, calculates, and stores the values for the two moisture monitors. It also switches one moisture monitor (1 M12) to the next sample point. The gas impurity alarm limits are wet every four minutes according to the following list.

Gas Impurity Alarm Limits (vppm)

Impurity	Stack Average Temperature				
	< 200°C	> 200°C < 250°C	> 250°C < 500°C	> 500°C < 750°C	> 750°C
H_2O	None	9,000	4,000	3,000	1,000
H_2	"	None	10,000	8,000	5,000
CO_2	"	"	1,000	1,000	1,000
O_2	"	"	5,000	5,000	5,000
CO	"	"	10,000	8,000	5,000

REACTOR RODS (ROD, RODM, VMON)

The three programs, ROD, RODM, and VMON were written to facilitate the manipulation of the control rods (HCR's) and the vertical safety rods (VSR's). There is a close interrelation between these routines--which are all entered via automatic interrupt driven programs. While the operator is responsible for making rod selection requests, the programs have a great deal of decision making type of control. Detailed examination of program functions reflect detailed operations specifications. A certain amount of program complexity is due to the hardware associated with the rods (limit switches, drive motors, cables, etc.) and the safety requirements.

ROD. This is the selection routine--entered from the keyboard interrupt routine (KEP) upon completion of a legal command. See table 27 for a list of vertical and horizontal rod commands. The major program functions are listed below:

(1) Determine if the reactor is in the core load mode (CLOO < 0) and if so, return to KEP's error exit. (Question mark is printed on the command Teletype).

(2) Determine if the rod maintenance (MRD) program is in core and if so, bypass the special HCR limit test which is entered when the safety circuit is made up.

(3) Analyze the operator's command for rate request, VSR up or down, HCR shutdown or inch request, and VSR deselection.

(4) Allow deselection of all VSR's if any or all four were selected.

(5) Allow VSR selection if and only if all HCR's are out or closed and if no rods are selected.

(6) Select designated HCR's if no VSR's are selected (all VSR's must be out) and only if the safety circuit is made up--unless the rod maintenance program is being used.

(7) Convert inches to HCR drive motor pulses and store for the rod monitor routines.

(8) When appropriate (as in (7) above) set selection flags and signals for the rod monitor routines.

All recognizable selection commands will negate previous selection commands. Thus, if HCR's 1, 2, 8, are selected first and if a request for #6 is honored, 1, 2, 8, are deselected. All error exits go to EXXIT which returns to KERR in KEP. Actually, ROD is a subroutine called by KEP as follows:

```
JMS   ROD     /Jump to ROD
LAC   KEPB    /argument used by ROD
JMP   KERR    /error return
JMP   KEP5    /normal return from ROD
```

A VSR request is analyzed in the program section beginning at RD.20. If a "VSO" command (deselect all VSR's) is received, control passes to RD.26 where the selection word, RSEL, is examined. If any HCR's are selected or if the VSR's are already deselected, an error exit occurs; otherwise, the request is honored. Actual deselection occurs by sending the function code, 320000, to the Astrodata register. The vertical rod monitor program is bypassed by setting RSEL = 0.

On the VSR selection options (some or all rods can be requested to move up or down and a shutdown request, which moves rods down, can be made) the appropriate limits are examined and selection is made only for those <u>not</u> on the desired limits. RSEL (selection word) is constructed, in part, in the routine, SELECT, where the rod numbers are extracted from the number buffer, NBUF. The proper bit in the RSEL word is generated by setting the bit (for example, BIT17 = 1, BIT16 = 2) in RSEL. Thus, BIT = 2^{n-1}, where n = rod number. Each time through a loop, which extracts the rod number, the bit is calculated and OR-ed into RSEL. The HCR section also uses the SELECT routine to build RSEL.

The HCR requests are analyzed at section RD.30. If the conditions in (6) above are met, either shutdown command (8 or all 9 HCR's) may be honored. If a normal command is received, the SELECT subroutine is called. In addition, the flag, PASS, is set (PASS $\neq$ 0) to signal entry into RODM, the horizontal rod monitor program. Further, R.C. and RODTAB + 4 are set (R.C. $\neq$ 0, RODTAB + 4 $\neq$ 0) - the former flag tells RODM that the operator has changed his mind and the latter flag is used if rod maintenance is in core.

When a HCR inch request (desired inches of travel) is received, control passes to RD.40, where NBUF is modified. In all other cases where numbers are input, the prescribed format is L_1 L_2 N_1 N_2 XXX..., where N_1 and N_2 are identifying numbers only and XXX represents the actual input value. Hence,

N_1 and N_2 are placed in NBUF + 1 and 2, respectively. The BCD to binary conversion routine, BIN, only uses NBUF + 3 through NBUF + 9. Rod inches are placed in NBUF + 1 and 2, therefore, all entries must be pushed down two entries before calling BIN.

Since 4000 stepping motor pulses are equivalent to one inch of travel, the required number of pulses are calculated and placed in the location, RODTAB; thus,

$$\text{RODTAB} = \text{Inches} * 4000.$$

The value in RODTAB is used in the monitor routine, RODM.

RODM. This routine is entered from TIME every .1 second, if any HCR's are selected. The purposes of RODM are to make sure selected rods are traveling in the right direction if an inch request has been received and to deselect rods when the correct number of inches have been traveled or when a wrong direction is detected and/or when an open or closed limit is reached. In general, the routine will detect a limit switch failure and not allow the operator to drive rods further against a limit. RODM will acknowledge special shutdown modes, repositioning or inch requests and any operator selection change made via the ROD program.

Initial entry or entry after the operator has changed his mind is at RM1. The limit status is obtained from watch channel 1 and placed in RMASK and the change of mind indicator, R.C., is set to zero. If the rods are being moved without any inches of travel request, control passes to RM9. When inches are to be monitored, the current rod count for the last rod selected is placed in a location called, TREND. Recall that every .1 of a second, the 9 HCR rod counters are read and placed in the table, RODCUR. Let requested counts (inches) equal y and current counts equal x, then if

$$y - x > 0$$

the rod counter must increase or deselection occurs and conversely if

$$y - x < 0 .$$

At location RM9, the flag, R.C. is checked. When R.C $\neq$ 0, the operator has made a new request and transfer is made back to RM1. If R.C = 0, the watch channel is read and the limit bits are compared with the old status word, RMASK. If no change in limit status has occurred, the word, RSEL is examined for selected rods. When any rod is selected and inches are to be monitored, the direction check is performed--using TREND. If inches are not to be monitored, a check is made to see if a shutdown request has been received. If so, control passes to RM59, where the HCR deadman switch is monitored. If the operator is trying to open the rod (after a request to close) all HCR's are deselected, RM1 entry is reset and an error message is printed.

Whether inches of travel are being monitored or not, a check is always made to make sure the rods are not being driven beyond a limit. This check monitors the limit trips, even if any limit switches should fail. (When a change in watch channel 1 occurs or RMASK does not match, a limit has either cleared or made up. In the later case, if the made up limit appears four consecutive times--thus taking care of flutter--the correct rod(s) are deselected). The rod counters, if adjusted with respect to rod limits before start of operations, are normally in the range,

$$24612 > C > 412$$

Usually, because of the 512 count offset, C will be greater than 512. The bandwidth has been carefully chosen from operating experience. If C (counts) for any rod fall outside this range, an error message is printed, all HCR's are deselected and a monitor switch (BYPASS) is set, so that the rods can be repositioned without repeated deselection caused by the rod count check.

VMON. The vertical rod monitor is entered every .1 second if any VSR's are selected--indicated by RSEL $\neq$ 0 and PASS = 0. Recall that HCR's and VSR's cannot be selected at the same time.

VMON uses the indicator flags, R.C., for new selection and RMASK for the initial limit status word to be used for comparison with limit bits in watch channel 12. Figure 13 shows the various limits associated with a VSR. The "jet" limit is made up when the rod is in or all the way down. An N_2 gas stream is directed at a pressure switch composed of a diaphragm. The other down limit and the intermediate limit switch are dependent upon the position of the drum which is capable of one revolution as the cable winds or rewinds. The upper limit switch is set by actual contact with the rod.

Initially, RMASK is set to the rod limit status. When no new selection has been made, control passes to V66 where RMASK is compared with the current watch channel status word. If no change has occurred, the in or down limits

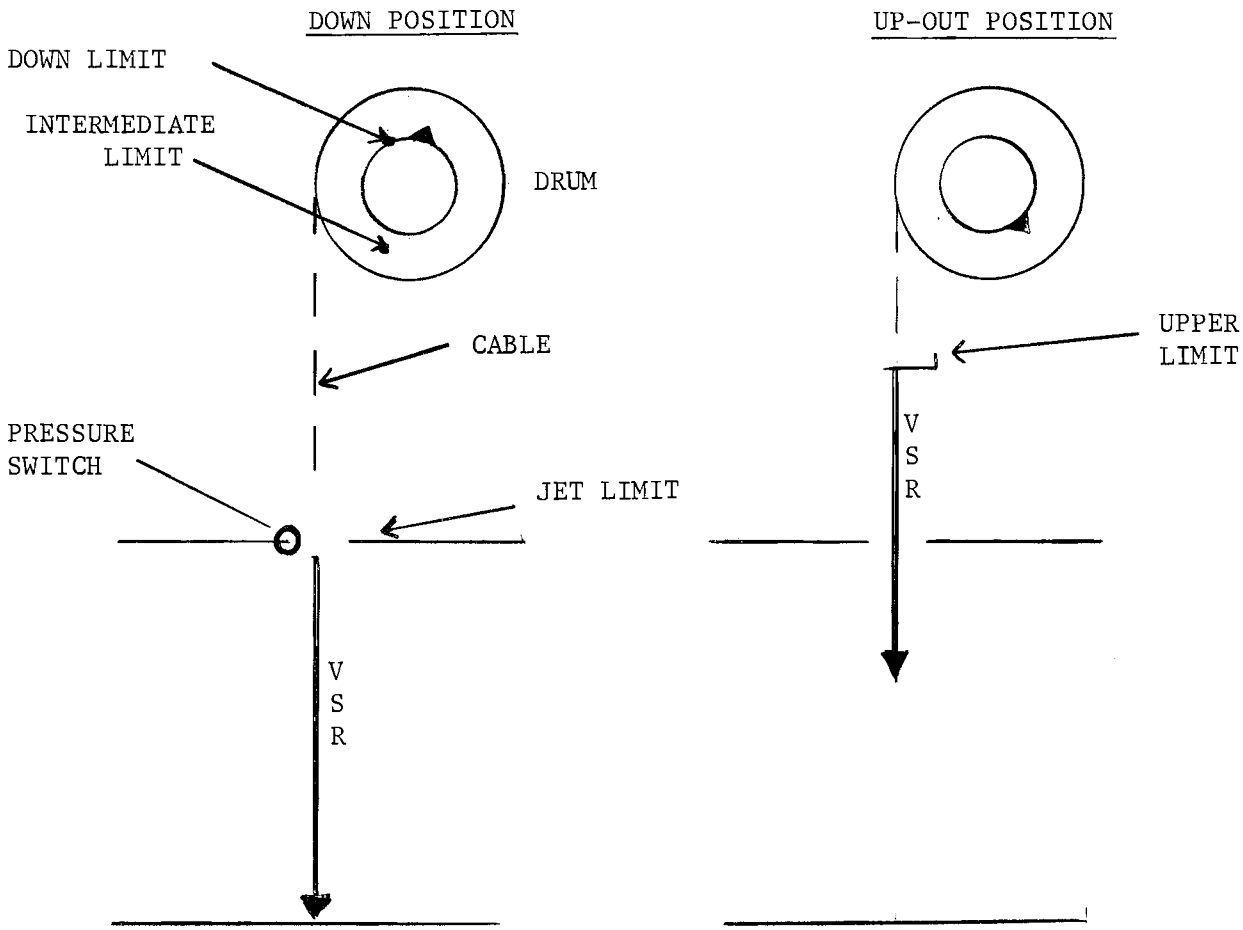


FIGURE 13. SCHEMATIC OF VSR LIMITS

are checked to see if any rod reversal occurred. When this occurs, the rod is deselected.

When the rod limit status changes and the change has been observed three consecutive times, a check is made to determine if a limit made up or cleared. If the later condition is true, RMASK is updated with the new status bits and the rod reversal test is done at V.5.

If a limit has made up, the proper rod(s) are deselected. In addition, if all rods are deselected, the message "VOF" is printed.

SCRAM SYSTEM (SCRAM1, SCRAM2, SCRAM3)

There are three general types of reactor scrams and accordingly, three separate programs have been written. All three scram programs may call on a general subroutine. The programs (discussed in the named order) are SCRAM1, SCRAM2, SCRAM3 and the general subroutine, SCRAM.

SCRAM1. This routine is entered when the computer has executed an illegal command. An illegal command is defined as one with zeros in the operation portion of any word which is placed in the instruction register. The common expression for this occurrence is to "CAL OUT". When the computer executes a zero or CAL, control is automatically passed to location 21_8. At location 21, a transfer to the SCRAM1 program occurs. The SCRAM1 program saves the address (from which the computer executed a CAL) and causes it to be printed if the address was not in the scratch pad area. If the safety circuit was made up, the routine SCRAM is called. Recovery is tried by always returning to the main executive loop, MLOOP. If a scratch pad program caused the CAL, that program is turned off. If 3 CALS occur, the computer halts with the offending CAL address. Then, the only recovery is by reinitialization.

SCRAM2. This routine is called by either the RCS safety check program or the nuclear program, NU2. The SCRAM routine is immediately called because the safety circuit is always made up by NU2. The RCS program and NU2 have the scram code (cause of the programmed scram) in the MQ register. See table 18 for a listing of these codes. This code is printed out; however, the message address is not sent to TELOUT because entry to SCRAM2 was via the TIME interrupt. Therefore, HODPOD is given a signal to output the message (SMESS + 5 $\neq$ 740000). SCRAM2 exits back to the TIME routine at location T.20 (Note: the first 6 instructions in TIME must never be changed without changing SCRAM2)!

SCRAM3. This is the hardware driven interrupt which may be caused by (a) operator depressing the scram button, (b) power failure, (c) non-regular updating or failure to update the two safety circuit deadmen or activity sensors, (d) independent EG & G trips.

When this interrupt occurs, the LIMIT routine is turned on so that any off-normal conditions may be observed. The SCRAM subroutine is called and "API" is printed--this signifying that "0" priority interrupt was entered. If NU2 was the program running at time of interrupt, control is returned to TIME at T.20 location; otherwise, the AC is restored and a normal interrupt exit is executed.

SCRAM. In this routine, the message, "NUC OUT!!!" is printed and the nuclear program, NU2 is turned off. For display purposes, the period is set to a BCD

"INF" (∞) and POWER is set to zero. The API channel 0 is disabled, the C.1 switch is set in RCS program and all horizontal and vertical rods are deselected. If the core load mode was "on", the howler is blown.

IX. MAINTENANCE ROUTINES

These four programs are part of the PMACS "on-line" system and are requested by the operator. The first two can be classified as calibration routines--the valve calibrate and a routine which tests the RTD circuitry and the analog-digital converter. The third program (rod maintenance) can be used when PMACS is in the non-nuclear mode. The fourth program allows read out and calibration of the two flux digitizers when not in the nuclear mode.

VALVE CALIBRATION (VLVC)

The three main functions of VLVC are: (1) initialization, (2) calibration and (3) restoration. During initialization, VLVC erases the inactive display area, checks for proper operating conditions and modifies VMOVER. During calibration, VLVC calibrates a valve in the full open or full closed position. While calibrating, VLVC continually monitors an abort flag that may be set by the operator at any time. During restoration, VLVC restores all changes it made to other programs and then shuts itself off.

The valve calibration program, VLVC, uses the subroutine, VMOVER, which is in the gas system program package. Since the analog display program also uses VMOVER, VLVC must not operate whenever the gas system programs are not active. VMOVER must acknowledge valve positions commands, move valves and compare valve stem-motor positions. VLVC bypasses these features for the valve which is to be calibrated.

Detailed Description (VLVC). The five areas described are: (1) the features of VMOVER (a subroutine in the gas system programs), (2) tasks accomplished during the initialization phase of VLVC, (3) the details of the method of calibrating a valve, (4) the details of how VLVC shuts itself off and (5) the program action when the operator requests VLVC to shut off.

VMOVER uses two tables to move the digital motor in the digital pneumatic valve positioner. The first table is set to the desired motor position, while the second table keeps track of the current motor position. The motor position is stored as a number between zero and 1000. The table which receives the desired motor position may be set by the operator via the Teletype or by the automatic control routine. VMOVER compares the desired position with the current position and pulses the digital motor in the direction which makes the tables agree. Another section of VMOVER continually compares the analog, valve stem position, signal and the current digital motor position. When these two position indicators disagree, an error message is typed on the Teletype at 15 second intervals.

Since VLVC is called into the core scratch area, the first task of the initialization segment is to erase the demand display program. If the gas system program is active, VMOVER is then modified to allow the operator to use the normal keyboard command for moving a valve and to inhibit the position check. If the gas system program is not active, an explanation message is typed ("GAS OFF" or "VLOGA ON") and VLVC is shut off. When all conditions are satisfied for correct operation, the message, "Calibrate One Valve", is typed and the program moves to the calibration stage.

Once the message, "Calibrate One Valve", is typed, the operator may make one of two choices: he may shut off the calibration program during any stage of its execution, or he may calibrate a single valve. To calibrate a valve, the operator types the command,

*SKV0α N

where α is one of the digits 1, 2, 3,...,7 (corresponding to the valves 1PCV12, 2PCV12, 1TCV12, 2TCV12, 3TCV12, 1FCV12 and 2FCV12) and N is the number zero or 1000. If N is any number other than zero or 1000, the command is ignored and the message, "Position Error, Use 0 or 1000, is typed. The operator may then try again. When the proper calibration command is given, the auto flag for that valve is cleared, and the proper limit switch flag, relay word bit and direction are chosen. The valve motor is then pulsed once every 0.1 second until the limit switch is hit. After the limit switch is closed, the entries for the calibrated valve in the desired position and current position tables of VMOVER are changed to the calibration valve. When this last calibration step is performed, the message, "Calibration Complete" is typed and the calibration exit stage of VLVC is entered.

Just before VLVC shuts itself off by jumping to the main routine, EXIT, it normally performs three functions. First, it must wait until all program messages have been typed. Second, the demand display is restored--the display which was active before VLVC was called. Finally, the subroutine VMOVER in the gas system program core area is restored to its normal condition.

The operator may wish to stop VLVC after he has started calibrating a valve. He would do this by inserting a zero into GA10 with the command *SGA00. In this case, the new position and current position tables in VMOVER would be modified with the pulse position equivalent of the analog, valve stem position signal before performing the normal exit functions. The VMOVER tables are not modified when VLVC shuts itself off because the gas system programs are not active.

ANALOG-DIGITAL CALIBRATION (ADCC)

The four types of inputs scanned by the analog-to-digital converter (ADC) are: (1) low level voltages, (2) high level voltages, (3) low precision resistance temperature detectors (RTD's), and (4) high precision RTD's. A cursory reliability check is made by calibrating one analog channel from each of these groups whenever ADCC is requested by the time routine. Presently the calibration is performed when the operating system is started and at three and one-half hour intervals thereafter. A zero and full scale check is made on the low and high level voltages, while only a full scale check is made on the RTD channels. The operator is notified of the results of each of these checks on the logging typewriter with a log having the code, "WA". If a calibration error is detected, the raw counts are included with the error message, otherwise a channel ok message is typed. Whether there is an error or not, the channel number and the type of calibration is typed. When ADCC is called, it enters the scratch area. Since a demand display may have been active before the ADCC call, ADCC erases the demand display and then restores it after the calibration is complete. ADCC does not release the scratch area until all the calibration status messages are typed.

Detailed Description (ADCC). Table 4 indicates the channels calibrated by ADCC. The calibration procedure is similar for all types of calibration: the calibration is considered satisfactory if the ADC counts are within five counts of the expected calibration values.

The program ADCC handles raw counts as if they were signed. The ADC range is -5 volts through 0 volts to +5 volts. The raw counts run from zero

TABLE 4

ADC CHANNELS CALIBRATED BY ADCC

Input Type	Channel Number (Octal)	Type of Calibration
Low level voltage	15	Zero and full scale
High level voltage	160	Zero and full scale
Low precision RTD	6	Full scale
High precision RTD	1	Full scale

to 3777 (octal) for the voltage range -5 volts to 0^- volts and 000 (octal) to 7777 (octal) for the voltage range 0^+ volts to +5 volts. ADCC converts the raw counts to signed integers in the range 0 to 2047 (decimal), so the raw counts from ADCC are -2047 to 0 for the voltage range -5 volts to 0^- volts and 0 to +2047 for the voltage range 0^+ volts to +5 volts.

The expected value for zero calibration on channels 15 and 160 is zero. Raw counts from -5 to +5 are acceptable and any other values are considered errors. The expected values for full scale calibration on channels 15 and 160 are 1228 and 828, respectively. Raw counts in the ranges 1223 to 1233 and 823 to 833 are acceptable. The expected calibration value for the low precision RTD channel depends on the latest value that was converted. When channel six is calibrated full scale, the calibration raw counts should be 197 counts higher than the previous normal conversion counts. Acceptable values are 192 to 202 counts above the previous value.

The high precision RTD channel also depends on the previous normally converted signal, but the relation is more complex. There are ten ranges for the high precision RTD's, and there are ten different possible calibration values. The full scale calibration counts should be lower than the previous normally converted value by the amount R, where R is different for each of the ten ranges. Table 5 shows the values of the variable R for each of the ten high precision RTD ranges.

Six calibration functions (zero on 15, full scale on 15, zero on 160, full scale on 160, full scale on 1 and 6) are performed, and six status messages must be typed. If the calibration is satisfactory, the address of the appropriate message address is transferred to the status message table. If the calibration is not satisfactory, the appropriate message address is transferred, and the raw calibration counts are saved as a decimal integer. In case of an error in the high precision RTD channel, the scale or range number is also added to the status message. Tables 6 and 7 list the messages for satisfactory and erroneous calibration messages for each channel that is calibrated.

TABLE 5

EXPECTED DIFFERENCE BETWEEN CALIBRATION AND PREVIOUS NORMAL RAW COUNTS FOR RTD CHANNELS.

Range	Expected Difference	Allowable Difference
0	403	398-408
1	451	446-456
2	499	494-504
3	542	537-547
4	584	579-589
5	624	619-629
6	663	658-668
7	701	696-706
8	737	732-742
9	771	766-776

TABLE 6

MESSAGE IF CALIBRATION IS SATISFACTORY

Channel Number	Message
15	CH15 ZERO OK
15	CH15 FULL OK
160	CH160 ZERO OK
6	LO RTD 5 OK
1	HI RTD 2 OK

TABLE 7

MESSAGES FOR CALIBRATION ERROR

Channel Number	Message
15	CH15 ZERO ERROR αN^1
15	CH15 FULL ERROR αN^1
160	CH160 ZERO ERROR αN^1
160	CH160 FULL ERROR αN^1
6	LO RTD 5 ERROR αN^1
1	HI RTD 2 ERROR αN^1
	SCALE = M^2

[1] α is the sign + or - and N is a decimal integer in the range 0 through 2047.
[2] M is a decimal integer in the range 0 through 9.

ROD MAINTENANCE

The ROD MAINTENANCE (MRD) program will accomplish the following:

(1) Make up the safety circuit and drive one rod for testing, calibrating, or maintenance.

(2) Check the independent channels in conjunction with the safety circuit.

(3) Make up the safety circuit and drive a vertical rod down, after a down or scram limit has failed to make up; (caused if a scram occurs when a VSR is between its down and intermediate limits). MRD also provides the operator with a continually updated display of all vertical and horizontal rod limits switches. This display will be green

when the safety circuit is made up and red when in a scram condition. The safety circuit automatically opens (scrams) when any one of the following conditions occur.

(a) Rod limit watch channel is in error.

(b) Safety Circuit keylock switch is turned off.

(c) A manual scram button is punched.

(d) Two or more scram limits clear.

(e) A trip on either independent flux channel.

MRD is called by MAIN and control passes to the program section called STATUS. The first time through, MRD outputs the message, "MRD ON", sets LW00 + 1 to initialize four alarms (S C Trip A, S C Trip B, S C Switch, and S C Ground) and then enables API 17. Each time thereafter STATUS checks to see if KEP has cleared the program "ON" flag, (RODTAB + 1). If the flag has been cleared, STATUS disables API 0 and API 17, turns off the four alarms previously turned on, outputs, **MRD OFF**, erases the rod limit display, and then shuts off MRD. If the "ON" flag has not been cleared, control passes to the display section (Tag, R1) of the program. Whenever MRD is in core, the rod limits will be displayed when the area is not occupied by alarms or a demand display. The display heading is deposited on the screen from the FRMAT table. The actual limits are displayed by routine, R2, which calls into the accumulator the correct watch channels. It sends this information to DISP which converts it to the correct display codes and in turn deposits them on the display screen. After the display has been updated or if the display was occupied, the program proceeds to SAFE.

SAFE checks out all conditions related to the safety circuit. The following conditions have to be met before the safety circuit logic can be set, unless the "VSR Recovery Mode" flag (BYP) is set by DEADM: (1) The safety circuit power supply must be on. (2) There can be no more than one scram limit cleared. (3) All watch channel bits, related to rod limits, must check with their complements. (This prevents the circuit from being made up when a rod is disconnected). (4) One through eight horizontal drive motors must be in their closed positions. (This prevents tripping individual circuit breakers). (5) All four VSR down limits must be made up. After these five conditions have been met, LGIC5 will prevent the circuit from being made up for five seconds. This five second delay protects the VSR's from being damaged after a scram; otherwise, the circuit could possibly make up while the rod is still decelerating. After the time delay is up, the safety circuit logic is set and after another short time delay, API 0 is enabled and the display is made green. The delay allows the logic relays to make positive contact before API 0 is enabled, otherwise, an API 0 interrupt trips the safety circuit. If the "VSR Recovery Mode" flag (BYB) is set, SAFE only makes two checks. The safety circuit keylock switch must be on and all horizontal toggle switches must be in their up position. If they are not, SAFE outputs "PLACE ALL HCR TOGGLE SWITCHES UP." If they are, SAFE outputs "VSR Recovery Mode." SAFE then bypasses the five second time delay and immediately sets the safety circuit logic. The "VSR Recovery Mode" will be described in greater detail in the section covering DEADM.

Two program switches (SA1 and SW2) are made in SAFE as soon as the safety circuit logic has been set. The SA1 switch (part of the "VSR Recovery Mode") causes bypassing of all SAFE checks and sends control to SW2.2. The SW2 switch causes the bypassing of the drive motor position checks. All other checks made in SAFE are capable of tripping the safety circuit. There are two exits from SAFE. If the safety circuit is made up, the exit is through SW2.2, which sets a flag (DEAD) telling DEADM to pulse the deadmen. If the conditions in SAFE are not met, the exit is through SW3, which turns the display red and signals DEADM not to pulse the deadmen. Control now passes to VVENT.

VVENT monitors the following conditions: (1) The manual scram button is continually monitored and at any time is pushed, COUNT is zeroed out. (COUNT is incremented by one, sixty times a second by the real time clock (API 17), and is used as a timer throughout the program.) The flag, RAWUP, is set to signal SCRM, that the scram is to be timed and was not a spurious safety circuit trip. (2) If VVENT determines that the scram button has not been pushed, it checks RODTAB + 4. (Set in the program ROD). If a new rod selection has been made, it is saved in VFLAG ("VSR Recovery Mode" flag). If it was a vertical selection, COUNT is set to zero and timing is started immediately since the rod begins moving upon selection. If it is a horizontal rod selection, VVENT sets switch V.ENT to VV1 and then exits. Upon entry into VV1, the HCR drive toggle switch is checked and as soon as it is found to be in a drive position, COUNT is zeroed out and timing is started. When a new drive timing cycle starts, control passes to DRV which sets two mask words, SHUTM, (HCR closed and VSR down limits), and OPENM, (HCR open and VSR up limits). DRV then sets the entry switch to DRV2. DRV2 compares the mask words with the current limit status words. As soon as a limit changes, control goes to DRV3 (HCR opening or VSR going up) or DRV4 (HCR closing or VSR going down) depending on the direction of travel. DRV3 initializes the HCRVSR table (type out format) to output a "D+" indicating the movement causes the reactor to become more reactive. DRV4 initializes the HCRVSR table to output a "D-" indicating the movement causes the reactor to become less reactive. In either case, the limits are continually checked in DRV5 or DRV6 until one makes up. Then program control is given to DRV.1, which deposits the bit corresponding to the rod number into NO. The raw counts from COUNT are stored in RAW. DRV.1 checks RAWUP (set in VVENT) to see if it was a manual scram. If not, subroutine LNP is called to convert information for log out. After the log out is completed, the program exits. If RAWUP indicates a scram, HCRVSR table is initialized to output "CD" for circuit delay time and subroutine LNP is called to output the circuit delay time. (Time interval between the initiated scram and actual rod release.) When this is complete, HCRVSR is initialized to output "S" for scram and the subroutine LNP is called to output the scram time. When the log out is completed, an exit is made.

When the safety circuit is tripped, API 0 interrupt immediately gives program control to SCRM which disables API 0 and checks to see if there was a manual scram. If so, SCRM deposits the circuit delay time in RAWUP, sets the entry switch V.ENT to SCRAM, deselects all rods, turns off the rod monitor program, (zeros out RSEL) turns the display red, restores the AC and returns to the interrupted program in progress. If it was not a manual scram, it sets the entry switch to exit and completes the functions listed above.

The SCRAM entry is set by SCRM after a manual scram. SCRAM sets a mask word, LMASK, which consists of the HCR scram limits and VSR down limits. LMASK is compared continually with HCR scram and VSR down limits. When a change is noted, program control is taken over by DRV.1.

Subroutine, LNP, determines which rod is being tested by examining NO. It then sets HCRVSR table to output the correct number. The drive time and the scram time are obtained from RAW. The circuit delay time is retrieved from RAWUP. All times are converted to decimal and stored in TTAB table for output. An example of the completed data output is as follows:

MR296T13:02	CD HCR #3	.12 SECONDS
MR296T13:02	S HCR #3	.87 SECONDS

The circuit delay time is .12 seconds. The total scram time (including CD) was .87 seconds.

DEADM entry is via the real time clock interrupt (API 17)-60 times a second. On each entry it increments COUNT. It then examines the accumulator switches for the "VSR Recovery Mode" code (531642). If the code is not found, D3 look at all HCR and VSR scram limits and a check is made to insure that no more than one limit is cleared at a time. If this check is OK, a flag, SCLM, is set which signals SAFE. If more than one scram limit is clear, exit is made without pulsing the deadmen. The flag, DEAD (set depending on checks made in SAFE) is checked and if set, both deadmen are pulsed. If the "VSR Recovery Mode" code was in the accumulator switches, VLFAG (set by VVENT) is checked for a VSR down command. If the code is in the AC and a VSR down command has been executed, the flag BYP (checked in SAFE for "VSR Recovery Mode") is set and both deadmen are pulsed. If the "VSR Recovery Mode" code is set, and a rod command other than a VSR down command is found in VFLAG, the flag, BYP, is cleared and exit is made without pulsing the deadmen.

DIGITIZER MAINTENANCE (MAN)

The nuclear maintenance program (MAN) is called from microtape into the nuclear area (7400 - $10{,}000_8$) by the operator and turned off by operator request.

The main functions are to read and display both flux digitizers (counts per second) and range settings. Through the accumulator switches, the operator can manipulate the different functions of the flux digitizers. This involves changing ranges, opening and closing the data relays and turning the calibration signal on or off. This program allows the operator to read the PMACS neutron flux without making up the safety circuit. It also provides a means to check all zero offsets and to allow adjustments to the digitizer units. The first entry from MAIN allows MAN to set a flag so that it can be entered from TIME once every tenth of a second. When the program is turned off, the data relays are opened, if closed, and the calibration signal is turned off.

The following messages are used by the program:

"NUC MAINTENANCE ON" is typed out when the program is turned on.

"SET ACS" is typed to remind operator to set the accumulator switches.

"ACS ERROR" or "ACS ERR" is typed out when an invalid command is received.

"MOF" is typed out when the operator turns the program off.

X. INITIALIZATION AND SHUTDOWN

There are two programs associated with PMACS start up. (1) A pre-initialization program, PNIT and (2) an initialization program, INIT. The shutdown, FINAL, is part of an operational shutdown procedure. FINAL is not a PMACS system program and is read into the computer with the paper tape "read in" switch.

INITIALIZATION (PNIT AND INIT)

PNIT. This program is on paper tape and is read in using the "read in" switch. All interrupt flags are cleared and the flux digitizer data relays are opened so that no signal is received. PNIT types out a mesaage if the accumulator switches are not all cleared, halts and waits for the operator. When the AC switches are clear the memory diagnostic program, CHECKERBOARD, is allowed to execute for about two minutes. (Noise conditions will cause error halts in this program). If the computer passes this test, PNIT prints out "KEY" and rings a bell. The operator must lock out the console--when this is accomplished, the rest of the PNIT tape is read in by program and transfer is made to the absolute location 17400_8. At this point the program loads the system programs (including INIT) from the microtape on unit 4. When loading is complete, transfer is made to INIT at 7000_8.

INIT. This program performs its functions and is overlayed by the gas and nuclear system programs. The major functions are listed below:

(1) Turn on the demand display; that is, set up calling sequence so the display program can be called into the scratch area.

(2) Turn off the gas system programs.

(3) Turn on the DATA routine.

(4) Initialize all queue tables.

(5) Clear rod counters for those rods which are "on limits."

(6) Deselect all VSR's and HCR's.

(7) Type out a row of asterisks and ring bells to insure both Teleyypes are connected.

(8) Transfer the CTAB table to upper core.

(9) Initialize the GAP program.

(10) Place proper alarm values into a table for the program, LIMIT.

(11) Set power trip point to two watts.

(12) Set period trip point to 15 seconds.

(13) Blank out alpha-numeric display to get rid of any garbage.

(14) Set power = 0 and period to a BCD "infinite" for display purposes.

(15) Check if the auto register switch is on and if not, print "AUTO" and halt.

(16) Deselect all tapes and rewind units #4 and #8.

(17) Cause the first analog-digital conversion <u>interrupt</u> by requesting a scan of channel zero.

(18) Enable the automatic priority interrupt (API) for the selected channels.

(19) Transfer command to the main loop (MAIN).

<u>SHUTDOWN</u>

The shutdown program, FINAL, is used to insure operations that computer interfaced equipment is left in a safe condition. Further checks are made to inform the operator of the reactor and basement door status. The following specific things are done:

(1) Disable the API.

(2) Deselect all VSR's and HCR's.

(3) Type out "BAD" if rod scram limits are not set and "OK" if they are set.

(4) Type out "BAD" or "OK" -- depending on the operational safety status (watch channel input) of:

   (a) Civil defense siren.

   (b) Radiation monitors.

   (c) Safety circuit power switch.

   (d) PMACS output switch.

   (e) Howler circuit.

   (f) Service and basement sumps.

   (g) Break tanks (low or high).

(5) Type out "CLOSED" or "OPEN" depending on the door status. Final control is transferred to a program which continually tests for "noise" in the computer accumulator. Control will remain in this program until the computer is halted or until PNIT is used.

XI. PROGRAM PREPARATION AND MODIFICATION PROCEDURES

Core Areas and Corresponding Tape Programs. There are six fixed arbitrary core partitions or areas for the HTLTR programs. Five of the areas are allotted for programs and the sixth area is reserved for the alpha-numeric display. Preparing and updating programs for these specific areas depends on the use of specific tapes and procedures as outlined below.

Core Area 1 ($0 - 6077_8$). This area is used by MAIN, HODPOD, DATA, KEP, ENGR, LIMIT, and RCS. All of these programs (plus INIT and HIGHWR) are filed, in both symbolic and binary form on the magnetic tape labeled MAINSYS. INIT (initialization program) and HIGHWR (high core writer) temporarily reside in areas two and five, and are overlayed by other programs which are read in from storage tape four during run time. If any changes are desired on any of the programs on MAINSYS (HIGHWR excluded), the edit, assemble, and load procedure[4] are executed. When MAIN load is complete, type a "T" to obtain the absolute beginning core address of all routines. Save this print out in the master program (listing) book. Place the magnetic storage tape--PMACS 4--on unit 4 with write switch on. Place 16100_8 in the address switches (high writer program), hit START and CONTINUE. The loaded core area 1 will be stored on tape 4. A good write is indicated by all ones in the AC lights. Disable the write on #4, dial in the logging tape to unit #8 and go to the start up procedure if desired.

Core Area 2 (6100 - 11057_8). This area is used by the Gas-Heat programs, NU1 and NU2 (nuclear), the rod maintenance and the digitizer maintenance programs. These programs can be called into specific parts of area 2 by MAIN during run time. The symbolic and binary files for these programs are stored on separate DECSYS tapes. GASCYC is stored on a magnetic tape labeled GAS-SYS. NU1 and NU2, the rod maintenance and the flux digitizer program are stored on a tape labeled NUCSYS. When any changes are necessary, the appropriate tape is loaded and the edit, assemble and load procedure is followed. The load procedure for each of these programs causes a low tape writer to be loaded in lower memory beginning at octal 400. Place PMACS 4 tape on unit 4 with the write on. Place 400_8 in the address switches and hit CONTINUE. When the computer halts, place the correct beginning storage block number in the AC switches. See Table 15 for program-block correspondence. Next, press CONTINUE and after a halt occurs, place the absolute starting address of the program in the AC switches. The program will be stored on PMACS 4. A special procedure will now be described for GAS-SYS programs.

Procedure for Changing Programs on GAS-SYS Tape. The DECSYS-7 system is used to edit, assemble and load the programs on the GAS-SYS tape. Furthermore, of the eight programs on this tape, seven of them are interdependent.

General Editing Procedures. Table 8 lists the programs on the GAS-SYS tape that may be retrieved by the DECSYS editor. Also included in the table are the gas and heat systems states in each program, the magnetic tape link assignments, and the present core assignments.

TABLE 8

PROGRAMS ON GAS-SYS TAPE

Programs	Gas and Heat System States	Link Member	Core Assignment
GASCYC	Initialization	Link 1	6400 - 6477
SUBS	Subroutine package and "emergency cool" (ECO)	Link 1	6500 - 7377
VINIT	Initialization	Link 2	6100 - 6477 and 11000 - 11047

TABLE 8

PROGRAMS ON GAS-SYS TAPE

Programs	Gas and Heat System States	Link Member	Core Assignment
EVA	"evacuate" (EVA), "fill" (FIL), "recirculate" (REC), "vent" (VEN), "cool" (COO), "standby" (STA)	Link 3	6100 - 6477
GHE	"gas heat" (GHE), "heat"	Link 4	6100 - 6477
VLVC	Valve calibration		16100 - 17100
VLOGA	Analog display		7400 - 10777
ADCC	ADC calibration		16100 - 17100

Core Assignments. The present core assignments for the programs on the GAS-SYS tape are listed in Table 8. It is impossible to define a general procedure for a change in core assignments. The first seven programs in Table 8 are interconnected, so an assignment change for any one of these would effect them all. The programs VLVC and ADCC are in the present scratch area, so they overlay the demand display programs and inactivate the demand display area of the three color display. VLVC and ADCC have routines to erase the demand display screen area and then restore the displays just before they shut themselves off. Figure 14 shows the relative core positions of all the programs on the GAS-SYS tape. These relative positions must be maintained no matter what the absolute core assignments are. The upper limit in the scratch area is strictly for convenience. The DECSYS system may still be used to load if the scratch area programs extend no higher than about 17100.

FLTAB Locations. The words to call the four magnetic tape links on the PMACS 4 tape depend on the core assignments and the FLTAB assignments. Presently the locations FLTAB + 12, + 13, and + 14, are assigned to the gas and heat systems programs that are on the four magnetic tape links. Table 9 lists the FLTAB words that are presently used by the gas heat program links. The other programs are called via the keyboard (VLVC and VLOGA) or by the time routine (ADCC) and the proper FLTAB words must be found in those routines which are external to the GAS-SYS tape.

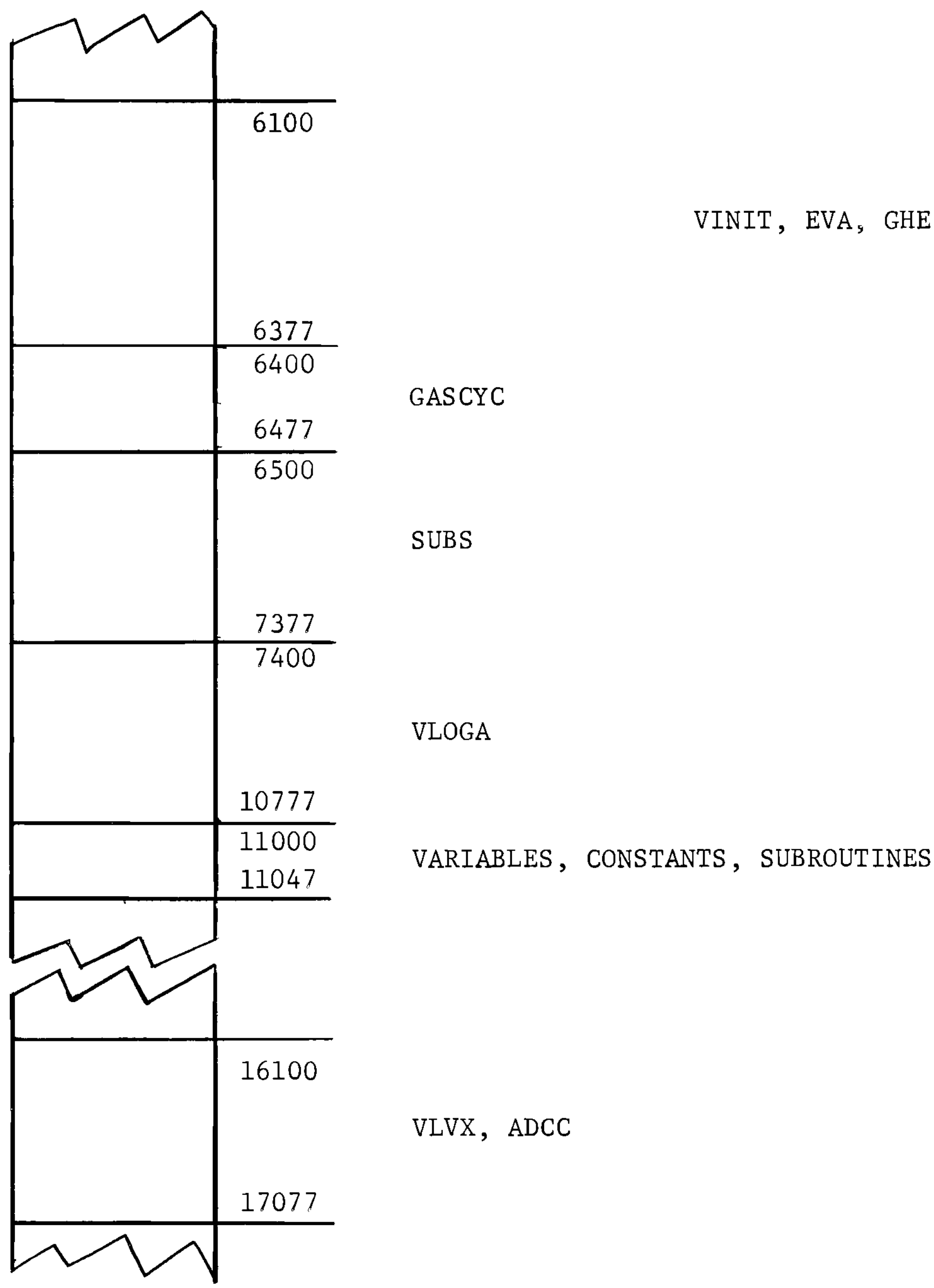


FIGURE 14. RELATIVE CORE ASSIGNMENTS FOR GAS-SYS PROGRAMS

TABLE 9

CURRENT FLTAB WORDS FOR GAS-HEAT LINKS

Link	FLTAB+12	FLTAB+13	FLTAB+14
Link 1	ISZ 6400	122210	DAC 6377
Link 2	ISZ 6100	122214	DAC 6077
Link 3	ISZ 6100 or ISZ REC	122220	DAC 6077
Link 4	ISZ 6100	122224	DAC 6077

Writing Onto PMACS 4 Tape. All programs on the GAS-SYS tape may be loaded with DECSYS. Each of the four tape links and the programs VLVC, ADCC, and VLOGA also have a core-to-tape writing routine that is loaded with them. The first address in a program, PMACS 4 block assignments for the GAS-SYS tape programs and the load request program, are listed in Table 10.

TABLE 10

STARTING ADDRESSES AND BLOCK ASSIGNMENTS

Link or Program	PMACS 4 Block Assignment	First Address	Load Request
Link 1	210	6400	GASCYC
Link 2	214	6100	VINIT
Link 3	220	6100	EVA
Link 4	224	6100	GHE
VLVC	240	16100	VLVC
VLOGA	244	7400	VLOGA
ADCC	250	16100	ADCC

A step-by-step procedure for writing one of the seven links or programs is given below:

(1) Load link or program with the request name in the last column of Table 10. The only confusion that could arise here is with link 1. Loading GASCYC loads both the programs, GASCYC, and the subroutine package, SUBS.

(2) Set address switches to 400 and START.

(3) After halt, set first address of program or link (column 3 of Table 10) into AC switches and CONTINUE.

(4) After halt, set block number (column 2 of Table 10) into AC switches and CONTINUE.

(5) All one's in the AC at the next halt indicates that the writing was concluded satisfactorily.

Program Interdependence. The seven interdependent programs on the GAS-SYS tape are: GASCYC, SUBS, VINIT, EVA, GHE, VLVC and VLOGA. If any one of these programs is changed, one or more of the others has to be rewritten onto the PMACS 4 tape, or edited and then rewritten onto PMACS 4. The extent to which GASCYC is dependent on the others has already been covered in the previous section. The interdependence of the remaining six programs is explained by Table 11. Page 5 of the program listings gives the reference, if any, to other programs. If other programs are not referenced directly, the EXTERNAL-INTERNAL pseudo instructions available with the DECSYS system are used. If a program X references program Y in an EXTERNAL statement, and program Y is changed, then program X has to be written onto the PMACS 4 tape.

TABLE 11

INTERDEPENDENCES OF PROGRAMS ON GAS-SYS TAPE

Primary Program	Programs that are effected by changes in primary programs	Programs that effect primary program when changed
SUBS	VINIT (see table of subroutines, constants and variables loaded in 11000 - 11047); EVA and GHE have to be reloaded. VLVC and VLOGA reference locations in SUBS.	EVA may change if the location for the "recirculate" state changes.
VINIT	None	GHE uses subroutines loaded by VINIT. SUBS is used to enter states in EVA.
EVA	SUBS needs absolute addresses for "evacuate" and "recirculate" state. GHE needs absolute addresses for "cool" and "standbys" states.	SUBS is used by the EVA program.

Primary Program	Programs that are effected by changes in primary programs	Programs that effect primary program when changed
GHE	VINIT loads subroutines in 11000 to 11047.	GHE uses addresses for the "cool" and "standby" states in EVA.
VNVC	None	Certain locations in SUBS are modified by VLVC.
VLOGA	Any program that uses AC switches 0, 1, 2, 14-17	Any program that uses AC switches 0, 1, 2, 14-17. SUBS has locations that are modified by VLOGA.

Core Area 3 (11000 - 14001). This is the common area which is cross-referenced by all other programs. It contains the constant pool, FLTAB, queue tables, buffers, current analog value table and many other locations used by functional programs. In addition, several conversion routines and the analog to digital interrupt service routine reside in area 3. All these tables and programs are treated as one program, labeled UPCON--which stands for upper constant core. UPCON is stored in symbolic and binary form on the magnetic tape called UPSYS.

The equivalence table (EQCON), used by every program in the system, is generated from the assembly of the program, UPCON. This equivalence table is at the beginning of all symbolic programs and necessary for their correct assembly. Therefore, if UPCON is changed, a new EQCON is generated and every program in the system must be updated with the new EQCON. This is about a four day job if everything goes well. Hence, very careful consideration must be made before initiating any change to the upper "constant" core.

Although UPCON is stored on a magnetic tape, the assembly and loading procedures are a completely paper tape--non-DECSYS operation. This is because the Digital Equipment Corporation software or the DECSYS system loader cannot load programs into the core locations 11000_8- 16077_8. Part of this area is used for DECSYS tape routines. This is the reason for assigning core area 3 to UPCON.

Thus, one can update and assemble the UPCON program using the DECSYS system, but actual incorporation into the system demands the following procedure.

(1) Use EDIT! and punch the symbolic paper tape for UPCON1. Do the same for UPCON2. (For paper tape handling and convenience, UPCON has been divided into the above two tapes with the pseudo-code START punched as the last line on each).

(2) Place the magnetic tape labeled DSD on unit 4. Set the AC switches to 040207_8. Set the address switches to 017600_8. Place the mylar paper tape (marked DSD) in the optical reader and press the READ IN toggle switch. (The assembler will now read into core). A halt will occur.

(3) Place UPCON1 in the optical reader and press CONTINUE. Some tape will punch out and the computer will halt with all ones in the AC lights.

(4) Set address switches to 20_8, put UPCON2 into the reader and press START. The computer will again halt with all AC lights on.

(5) Press CONTINUE for completion of normal assembly. Computer will halt again with AC = 777777.

(6) Remove the assembled tape from the punch hopper and label it with R, UPCON and date.

(7) Change the following core locations, using the DEPOSIT switch.

700206	address	2625
602613	"	2300
700202	"	2614
700062	"	17770
603117	"	17771

(8) Set AC switches to 000202 and address switches to 17770.

(9) Press CONTINUE--paper tape list of symbols will punch out in slow motion.

(10) Read in the RIM loader at 17763, then put tape marked FQ MAKER into the reader.

(11) Set address switches to 17770 and press START.

(12) Load, into the reader, the paper tape which was generated at step 9.

(13) Set address switches to 22 and press START. The new symbolic EQCON will now punch out.

(14) Edit the EQCON tape carefully, deleting all references to EAE

commands, and adding (as the first page) the symbolic tape marked A, EAD and ASTRODATA STUFF. The Fortran assembler doesn't recognize EAS commands and understandably, any ASTRO I/O commands. Check all tags and numbers for their proper range--they must be between 11060 and 14402_8. Punch out the corrected tape and label it A, EQCON.

(15) Repeat the following sequence for all DECSYS tapes--MAINSYS, GAS-SYS, NUCSYS, LOG1 SYS, LOG2 SYS and UPSYS.

(a) Punch out all programs on the SYS tape and label each with A, NAME--month/day/year. (On the UPSYS tape, only punch out the UPVAR program). Do not punch the first four pages of the programs because this is the old equivalence table.

(b) Throw away all old paper tape backups.

(c) Prepare a new SYS tape--either by copying from the STRIPPED DECSYS MASTER tape or by going through the update procedure to delete old program.[4]

(d) Execute the update--append procedure for each program. When appending to MAINSYS, one must add the programs in the exact order as before. In addition when a program is on tape, assemble it before adding the next. Place the EQCON tape in the reader and follow the steps outlined in reference 2, but PRESS STOP quickly after the last line has read in. This is necessary only because one large tape tends to jam in the read hopper, otherwise, the EQCON tape could have been added to all program tapes. Next, place the program tape in the reader, press CONTINUE and complete the normal procedure.

(e) Go through the edit, assemble and load sequence as described for programs in area 1 and area 2.

Core Area 4 (14404 - 16077). This area is used by MICRO, IN, OUT, OUTIME, ROOT, and GAP. All of these programs are assembled together and treated as one program which is labeled, UPVAR--upper variable core. UPVAR is stored in symbolic and binary form on the magnetic tape labeled UPSYS. This is merely a convenience so that editing can be done. The assembling and loading procedures are completely paper tape oriented. UPVAR with EQCON is assembled by placing the paper tape in the reader and using the assembler from the DSD maintenance tape. The assembled tape is loaded with the RIM loader. Next, the assembled tape R, UPCON is loaded. At this point, area 3 and area 4 of core contains all necessary programs for start up. However, it is necessary to store area 3 and 4 on PMACS tape. Do the following:

(1) Place PMACS 4 on unit 4 with write enabled.

(2) Read in the special low writer (SPLOWR) at 400_8.

(3) Press CONTINUE. If the lower core (MAIN) has already been stored, the PMACS 4 system is ready for use. See start up procedure.

Core Area 5 (16100 - 17477_8). This is the scratch area--used by all the logging, demand display, calibrate and maintenance routines. All of these programs are assembled with the absolute (octal) beginning address of 16100. The PMACS 4 loading procedure for most of these programs is identical to that given in the description of CORE AREA2. With the exception of the AD calibrate program (on GAS-SYS tape) all of these scratch area programs are stored on two tapes called LOG1 SYS and LOG2 SYS. These tapes contain all 14 logs and the demand display, DNDISP. Logs 1, 12, 13 and DMDISP must be assembled and loaded using the paper tape operation. This includes using the P-T writer to store the program on Tape 4.

Core Area 6 (17500 - 17714). This area is used exclusively for the alphanumeric display. See listing of INIT for allocation of locations 17715 to 17777.

TABLE 12

ASTRODATA COMMANDS

(Special IOT Assignments)

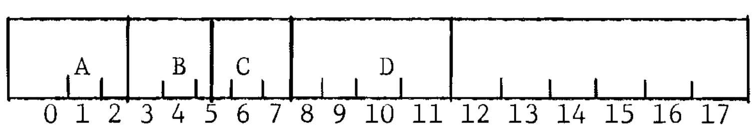
OCTAL CODE	OPERATION
703511	CDskp - Skip if CDR register is not busy
703512	OSC.
703514	TACDR - Transfer contents of Accumulator to CDR
703611	Skip if Analog Input is not busy
703612	Transfer flux digitizer accumulator #1 to Storage R_1
703614	Transfer flux digitizer accumulator #2 to Storage R_2
703711	OSC.
703712	OSC.
703714	OSC.
704011	Input Rod Counter (HCR 1) into Accumulator
704012	(HCR 2)
704014	(HCR 3)
704111	(HCR 4)
704112	(HCR 5)
704114	(HCR 6)
704211	(HCR 7)
704212	(HCR 8)
740214	Input Rod Counter (HCR 9) into Accumulator
704311	Input Watch Channels #1 into Accumulator
704312	#2
704314	#3
704411	#4
704412	#5

OCTAL CODE	OPERATION
704414	Input Watch Channels #6 into Accumulator
704511	#7
704512	#8
704514	#9
704611	#10
704612	#11
704614	#12
704711	#13
704712	#14
704714	Input Watch Channels #15 into Accumulator
705011	Input ADC into Accumulator
705012	Input Flux Digitizer #1 into PDP-7 Accumulator
705014	Input Flux Digitizer #2 into PDP-7 Accumulator

(TACDR 18 Bit Commands)

1. FLUX DIGITIZER

18-Bit Instruction Word



A: Device Selection. (Must be 0)

B: Function Code

0 = Reset flux accumulator reg.

1 = Close pre range relay

2 = Close input relay. Start count into Flux AC

3 = Open input relay. (Zero offset) stop count

4 = Set scale of digitizer from bits 8-11

5 = Calibrate on

6 = Calibrate off

7 = Open pre range relay

C: Digitizer Selector

Bit 7 = Flux Digitizer Channel #2

Bit 6 = Flux Digitizer Channel #1

Bits 6, 7 = Flux Digitizer Channels #1 and #2

D: Scale

B = 4, bits 8-11 are scale

2. ANALOG INPUT

A	B	C	D
0 1 2	3 4 5	6 7 8 9	10 11 12 13 14 15 16 17

A: Device Selection. (Must be 1)

B: Function Code

0 = Normal digitize

1 = Calibrate zero } Normal input only

2 = Calibrate Full }

4 = Repeat digitize

C: Scale

0 = Normal High gain input

$0\text{-}11_8$ = Precision RTD scales

17_8 = Low precision RTD, low gain amplifier

D: Channel Selection

0-1 = High precision RTD

$2\text{-}13_8$ = Low precision RTD

$14_8\text{-}177_8$ = Normal inputs

3. ROD POSITION COUNTERS - Set to 1000_8 offset

									ROD								
									9	8	7	6	5	4	3	2	1
A			B						C								
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

A: Device selection. (Must be 2)

B: Function code. (Must be 0)

C: Rod selection to be reset

Bit 9 = rod counter #1

Bit 10 = rod counter #9

4. STEPPING MOTOR OUTPUTS

									HCR AND VCR									
									9	8	7	6	5	4	3	2	1	
A			B					C	D									
											1	2	3	4	5	6	7	← valves
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	

A: Device Selection. (Must be 3)

B: Function code

1 = horizontal rods - No direction selection

2 = vertical rods & misc. group

3 = valve output & misc. group

0 = rod stepping rate

7 = enable valve interrupt

C: Direction Selector

0 = reverse } Out - Operate

1 = forward } In - Poisen

Vertical Only

If B = 0 or 1, no function

D: Rod selector

Bit 9 = rod #9

Bit 17 = rod #1

If B = 0, bits 16-17 determine pulse rate.

E: HCR Pulse Rate

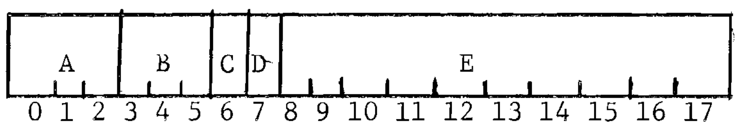
300000 for 100 pps

300001 " 20 pps

300002 " 10

300003 " 7

5. ANALOG OUTPUTS



A: Device selection. (Must be 4)

B: Channel selection

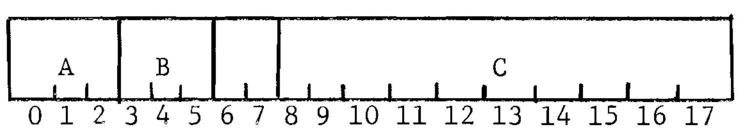
C: CRT Channel selection. 1 = CRT

D: CRT axis selection. 0 = X Axis 1 - Y Axis

E: Data. If C = 0 uses 8 bits.

If C = 1 uses 10 bits.

6. CONTACT OUTPUTS



A: Device Selection. (Must be 5)

B: Function Code 0 Select Relays 0 - 9

1 Select Relays 10 - 19

2 Select Relays 20 - 29

3 Select Relays 30 - 39

C: Bit 8 Select Relay 0, 10, 20, 30

Bit 9 Select Relay 1, 11, 21, 31

Bit 10 Select Relay 2, 12, 22

Bit 11 Select Relay 3, 13, 23

Bit 12 Select Relay 4, 14, 24

Bit 13 Select Relay 5, 15, 25

Bit 14 Select Relay 6, 16, 26

Bit 15 Select Relay 7, 17, 27

Bit 16 Select Relay 8, 18, 28

Bit 17 Select Relay 9, 19, 29

To enable relays 0-4

A: Device selection must be 6

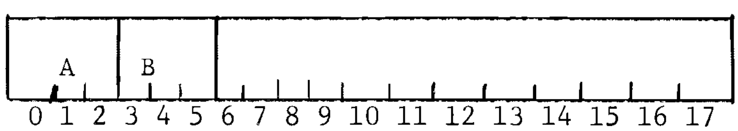
B: Function code must be 0. This must be repeated at .1 second intervals.

To reset lockout

A = 6

B = 1

7. SAFETY CIRCUITS



A: Device selection. (Must be 7)

B = 0 Activity sensor pulse #1

B = 1 Reset (false off) lock out flip-flops AS_1, and AS_2

B = 2 Set (ON) logic level #1

B = 3 Reset logic level #1 Program Scram

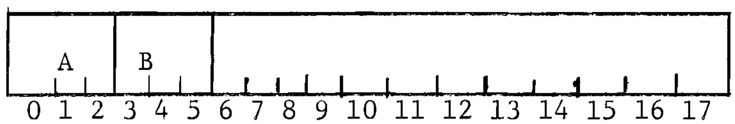
B = 4 Set logic level #2

B = 5 Reset logic level #2

B = 6 Not Used

B = 7 Activity Sensor Pulse #2

8. NEUTRON ANALYSIS



A: Device Selection. (Must be 6)

B: Function Code

2 = Start analysis

3 = Stop analysis

TABLE 13

PMACS GENERAL MESSAGE MNEMONICS

These messages may be printed by the Command Teletype.

Message	Definition
API	Scrams External to PMACS
ARB	Core Memory Scratch area is busy
AUTO	Automatic Index Register switch not on
BOF	Gas Blower and its alarm Turned Off
BON	Gas Blower On
COO	COOL program entered
COR	CORE load mode entered
DNC	Door(s) not closed
DMO	Rod Drive Motor operable
DPF	CRT Display full of alarms
ECO	EMERGENCY COOL program entered
ENG	Wrong Equation Index in Engineering routine
EVA	EVACUATE program entered
FIL	FILL program entered
FX1	Storage table for HIGH ACCURACY Nuclear Data is full
FX2	Storage table for Nuclear Power and Period Data is full
GCE	Gas Chromatograph timing error
GHE	GAS-HEAT program entered
GOF	GAS programs off
HOB	Heat off from failed stack TC
HOF	Reactor heater breakers opened (Heat Off)
HT	Reactor heater breakers closed (Heat On)

Message	Definition
LOG	Process identification complete
NHI	High Gas Blower inlet pressure
NUC	NUCLEAR mode entered
NTB	Requested symbol not found (LOG 13)
RDW	HCR Rods going in wrong direction
REC	RECIRCULATE program entered
RSF	Drive against limit:Rod deselected (can also indicate Rod Limit Switch failure)
SCN	Safety Circuit not made up when asked for
SIC	Same as above & rods not scrammed (down or closed Limit Switch open)
SER	Operator setpoint error
STA	STANDBY program entered
TP1	Tape timing track error (bad tape)
TP2	Tape block not found (try again)
TP3	Check sum error (try again)
TP4	Spurious tape interrupt (try again)
TP5	Write request for tape other than #8 or 6 (#8 tape is full)
TP6	Tape block 0 requested (could not find itself - try again)
TP8	End of tape error
VEN	VENT program entered
VER	Vertical rod error going wrong direction
VIB	Gas Blower vibration alarm
VLV	Valve position error (check valve calibration)
VOF	Vertical rods all deselected

Message	Definition
VOK	Valve position correct for RECIRCULATE program
VPE	Operator valve position error
WC1 - WC6	Watch channel complements disagree
?	Illegal keyboard command

TABLE 14

WATCH CHANNEL ALARM MESSAGES

These messages are typed on the Logging Teletype.

BASE COOLING	Low cooling flow to reactor base	**
BASEMENT DOOR	Reactor basement shield door open	*
BLDG HI RAD	High level alarm on building area radiation monitor	
BLDG INT RAD	Intermediate level alarm on building area radiation monitor	
CD AREA SRN	Loss of power to Civil Defense Area siren (circuit D-20)	
CD BLDG SRN	Loss of power to Civil Defense building sirens (circuit D-18)	
CHOPPER VIBR	High vibration on neutron spectrometer chopper	
GAS BLOWER	Gas Blower Off	**
G B SEAL LP	Low pressure on gas blower seal gas	**
HTR FLOW B	Low cooling flow to bottom heater connector	**
HTR FLOW C	Low cooling flow to core heater connector	**
HTR FLOW N	Low cooling flow to neutral heater connector (check both)	**
HTR FLOW S	Low cooling flow to side heater connector	**
HTR FLOW T	Low cooling flow to top heater connector	**
MANUAL SCRAM	Manual scram pushbutton actuated	*
N INCID CKT	Loss of power to nuclear incident monitor circuit (A-20)	

N INCID MON	High level (or failure trip) on nuclear incident monitor
N2 TANK LOW	Low level alarm on nitrogen storage tank
PMACS SWITCH	PMACS output keylock switch off *
PPW TANK HI	High level alarm on protected process water tank
PPW TANK LOW	Low level alarm on protected process water tank
PURGE HI RAD	High level or failure trip on purge filter γ monitor
REACTOR DOOR	Reactor shielding door open *
REACTOR SUMP	High level in reactor basement sump
S C GROUND	Safety circuit ground detector trip
S C HORN FAIL	Loss of power to safety circuit horns (circuit A-24)
S C SWITCH	Safety circuit keylock switch off *
S C TRIP A	Safety circuit trip from independent channel "A" *
S C TRIP B	Safety circuit trip from independent channel "B" *
SERVICE SUMP	High level in service basement sump
XFMR FLOW B	Low cooling flow to bottom heater transformer **
XFMR FLOW C	Low cooling flow to core heater transformer **
XFMR FLOW S	Low cooling flow to side heater transformer **
XFMR FLOW T	Low cooling flow to top heater transformer **

MNEMONIC FOR BAD COMPLEMENTS

WC1	WATC1 $\neq \overline{\text{WATC2}}$
WC2	WATC3 $\neq \overline{\text{WATC4}}$
WC3	WATC5 $\neq \overline{\text{WATC6}}$
WC4	WATC7 $\neq \overline{\text{WATC8}}$
WC5	WATC9 $\neq \overline{\text{WATC10}}$
WC6	WATC12 $\neq \overline{\text{WATC13}}$
DPF	Display full of alarm messages and at least one additional.

Commands preceded by a "#" indicate a new alarm. Commands preceded by a "!" indicate alarm is reset.

* Indicative of safety circuit trip

** Will cause heaters to be turned off

TABLE 15

TAPE 4 STORAGE ALLOCATION

BLOCK NUMBER (OCTAL)	PROGRAM
1 - 5	NEVER USED
6 - 15	SPARE
16 - 21	NU1 (Part 1 of Nuclear)
22 - 25	NU2 (Part 2 of Nuclear)
26 - 35	SPARE
36 - 41	DEMAND DISPLAY
42 - 45	LOG 1
46 - 51	LOG 2
52 - 55	LOG 3
56 - 61	LOG 4
62 - 65	LOG 5
66 - 71	LOG 6
72 - 75	LOG 7
76 - 101	LOG 8
102 - 105	LOG 9
106 - 111	LOG 10
112 - 115	LOG 11
116 - 121	LOG 12
122 - 125	LOG 13
126 - 131	LOG 14
132 - 135	LOG 15 (RETR)
142 - 163	MAIN BACKUP
164 - 171	CONSTANT & VARIABLE POOL
204 - 207	SPARE

BLOCK NUMBER (OCTAL)	PROGRAM
210 - 213	GASCYC
214 - 217	LINK 1 (GASCYC)
220 - 223	LINK 2 (GASCYC)
224 - 227	LINK 3 (GASCYC)
230 - 233	SPARE
234 - 237	ROD MAINT.
240 - 242	VALVE CALIBRATE (VLVC)
244 - 247	NUC MAINT. (MAN)
250 - 253	AD CALIBRATE (ADDC)
254 - 1100	SPARE

TABLE 16

AUTO REGISTER ASSIGNMENT

REGISTER	PROGRAM
1	GASCYC
2	GASCYC & VALVE MAINT.
3	TIME
4	GASCYC
5	LIMIT
6	ROD MAINT.
7	ENGR
10	MAIN
11	MICRO
12	UNPAC
13	TIME
14	BINBTB
15	KEP & ROD
16	GASCYC
17	SCRATCH PROGRAMS

TABLE 17

ANALOG ALARM MESSAGES

These messages are typed on the Logging Teletype. (These also show on the CRT and an alarm bell rings.)

Format:

In this order:

(1) # = New Alarm
or
! = Previous Alarm Reset

(2) XXX = Identifying Mnemonic

(3) XXX = System Engineering Units

Example:

#	20T56	100.5
(1)	(2)	(3)

New alarm, stack T/C measures 100.5° C

Identifying Mnemonic	Alarm Condition	High Limit
1T12	Main heat exchanger exit (1) gas temperature	260°C
2T12	Reactor exit gas temperature (1)	750°C
3T12	Purge cooler exit gas temperature (1)	100°C
4T12	Main heat exchanger temp exit water (1)	50°C
5T12	Rod cooling heat exchanger gas temp exit (1)	40°C
6T12(2)	Gas blower bearing temperature (1)	50°C
7T12	Rod cooling heat exchanger temp exit water (1)	50°C
8,9T12	Gas dryer tower temperature (1)	300°C
1T54	Flux chamber compartment temperature (1)	50°C
1T36(2)	Neutron chopper bearing temperature (1) future	50°C

Identifying Mnemonic	Alarm Condition	High Limit
3-34T56	Reactor graphite temperature (2)	100°C
1-24T60	Reactor heater temperature (1)	1500°C
1,2H60	Reactor core and side heater power (1)	132 kW
3,4H60	Reactor top and bottom heater power (1)	66 kW
1P12	Main filter differential pressure (1)	.2 psi
1P12	Gas blower outlet pressure (1)	4.0 psig
1H12	Gas blower amperage (1)	75 amps
		Low Limits
2D12	Gas blower differential pressure (3)	2.8 psi
3F12	Rod cooling gas flow (3)	85 scfm
2P12	Gas blower inlet pressure (3)	.25 psig
		High and Low Limits
1A12	Reactor absolute pressure (3)	14.9 ≤ P ≤ 17.0 psig
3P12	Gas mockup pressure (1)	3.0 ≤ P ≤ 4.4 psig
1,2L12	Alpha monitor (4)	1 % ≤ C ≤ 75% full scale
1,2M12	Moisture Monitor range (4)	10% ≤ C ≤ 75% full scale

(1) limits are set by INIT

(2) limit is initially set by INIT. GASCYC will automatically reset limit to the temperature setpoint plus 50°C

(3) low limit is controlled by GASCYC, e.g., it is set when gas blower is on

(4) low limit is manually inserted by keyboard command

GAS PURITY ALARM MESSAGES **

IN	MM	Reactor inlet (Dryer exit) moisture
MHX	MM	Main heat exchanger exit moisture
EX	MM	Reactor exit (Purge cooler) moisture
RHX	MM	Rod cooling heat exchanger moisture
IN	H2	Reactor inlet hydrogen
IN	CO2	Reactor inlet carbon dioxide
IN	O2	Reactor inlet oxygen
IN	CO	Reactor inlet carbon monoxide
EX	H2	Reactor exit hydrogen
EX	CO2	Reactor exit carbon dioxide
EX	O2	Reactor exit oxygen
EX	CO	Reactor exit carbon monoxide

** Limits are automatically set by GAP according to the graphite temperature

TABLE 18

SCRAM MESSAGE MNEMONICS

The following messages appear on the Command Teletype when the rod hold circuit opens.

Scram code is ___ ___.

SAFETY CIRCUIT TRIPS

R 1	=	HCRs Not Closed
R 2	=	Reactor Room Door Not Closed
R 3	=	Reactor Basement Door Not Closed

NUCLEAR SAFETY CIRCUIT TRIPS

A	=	Trip from Flux Digitizer #1
B	=	Trip from Flux Digitizer #2
0	=	Period Trip: One-tenth Second Calculation < Trip Point
1	=	Period Trip: One Second Calculation < Trip Point
2	=	Period Trip: Period < 8 Seconds
3	=	Nuclear Power Trip: Power Exceeds Setpoint
4	=	Nuclear Power Trip: Power Exceeds 2 kW
5	=	Program Trip: Digitizer Not On Scale (Low Level Trip)
6	=	Nuclear Power Trip: Power Exceeds 3 kW
7	=	Program Trip: #1 and #2 Flux Digitizers Differ By More Than 4 Ranges
9	=	Program Trip: Digitizer Range Change Failed (Counts Exceed 100 k)

For Example:

A 2 Means period < 8 seconds from digitizer #1.

TABLE 19

ERROR MESSAGES FROM NUCLEAR PROGRAMS #1 AND #2

These messages appear on Command Teletype.

"NUC1 OK" indicates NUCLEAR Program #1 is complete and has called NUCLEAR Program #2.

The following messages indicate that NUCLEAR Program #1 has found trouble with a digitizer and has turned the NUCLEAR program off.

"DIGITIZER 1 OFFSET" = |Reading-Limit|
"DIGITIZER 2 OFFSET" = |Reading-Limit|
} 3000 > Reading > 20 Must Be Satisfied

"DIGITIZER 1 NOT ON SCALE"

"DIGITIZER 2 NOT ON SCALE"

"DIGITIZER 1 CAL HIGH" = |Reading-Limit|
"DIGITIZER 2 CAL HIGH" = |Reading-Limit|
"DIGITIZER 1 CAL LOW" = |Reading-Limit|
"DIGITIZER 2 CAL LOW" = |Reading-Limit|
} 11000 > Reading > 9000

The following messages indicate that NUCLEAR Program #1 has found the indicated condition and has turned the NUCLEAR Program off.

"HCR DRIVES NOT OUT"

"HCR NOT CLOSED"

"VSR NOT DOWN" (Jet)

"DOORS NOT CLOSED"

"SAFE CKT. PWR. OFF"

The following message is received whenever NUC 2 is turned off, by typewriter command or scram.

"NUC"

"OUT"

"!!!"

TABLE 20

NUCLEAR COMMANDS

*NUC	=	TURN ON NUCLEAR PROGRAM AND MAKE UP SAFETY CIRCUIT
*NUC OFF	=	TURN OFF NUCLEAR PROGRAM AND SCRAM (NUC OUT !!! typed when program is turned off)
		TO STORE HIGH ACCURACY NUCLEAR DATA (8 sec)
*SND ØØ Ø	=	Stop Storing
*SND ØØ 1	=	Start Storing
		TO STORE NUCLEAR POWER AND PERIOD DISPLAY DATA (1 min)
*SND Ø1 Ø	=	Stop Storing
*SND Ø1 1	=	Start Storing
		TO SET NUCLEAR POWER LEVEL TRIP POINT
*SND Ø2 (1-2ØØØ)	=	Sets Power Level Trip Point (1-2ØØØ watts)
		TO SET NUCLEAR PERIOD TRIP POINT
*SND Ø3 (1-999)	=	Sets Period Trip Point (1-999 sec)
		TURN ON/OFF CORE LOAD MODE
*SCL ØØ Ø	=	Turns Off
*SCL ØØ 1	=	Turns On
		STOP/START HIGH ACCURACY NUCLEAR DATA (8 sec) TYPEOUT
		Before Typeout is called, storing of High Accuracy Nuclear Data should be called in.
*STN ØØ Ø	=	Start Typing
*STN ØØ 2Ø6	=	Stop Typing
		STOP/START NUCLEAR POWER AND PERIOD (1 Min) TYPEOUT
		Before Typeout is called, storing of Power and Period Display Data should be called in.
*STF ØØ Ø	=	Start Typing
*STF ØØ 198	=	Stop Typing

TABLE 21

LOGGING COMMANDS

SET LOGGING CLOCK TIME (At Time of Computer Initialization)

(1) *T

(2) Insert Day of Year (ØØØ-366)

(3) Insert Hour of Day (ØØ-24)

(4) Insert Minute of Hour (ØØ-6Ø)

Example:	(1)	(2)	(3)	(4)
	*T	273	08	30

REQUEST LOGS

*L Ø1 = Select General 128 Analog Channel Typeout

*L Ø2 = Select Gas System Temperature Log

*L Ø3 = Select Heater Temperature Log

*L Ø4 = Select Graphite Stack Temperature Log

*L Ø5 = Select Heater Power Log (Hall Effect Devices)

*L Ø6 = Select System Flow and Pressure Log

*L Ø7 = Select Gas Purity Log

*L Ø8 = Select Valve Position Log

*L Ø9 = Select Rod Position Log

*L 1Ø = Select High Precision RTD Log

*L 11 = Select Flux-Power, Period, Setpoint Log

*L 12 = Select Specific Input Channel
Commands for Log 12
*SAN ØØ Channel Number (ØØ1-128)

*L 13 = Computer Location Log
This Log is used to interrogate the Core Memory
Location or Current Setpoint

*L 14 = Watch Channel Log

*STY ØØ = STOP LOG CURRENTLY ON LOGGING TYPEWRITER
(next logging command will be automatically accepted)

STOP/START ALL LOGGING ON LOGGING TYPEWRITER

*STL ØØ Ø = Start Typing

*STL ØØ 2Ø4 = Stop Typing

LOG 13 OPTIONS

(1) Type Octal Address

(2) Type Symbolic Address (Name)

(3) Type Symbolic Name, Plus Symbol and 0, 1, 2, etc.

(4) Consecutive Locations Can Be Dumped By Depressing Line Feed for Each

(5) Type Symbolic Name, Plus Symbol and 0, 1, 2, etc. Comma and the Decimal Number of More Locations Desired To Be Consecutively Dumped.

Each Log (except #12 and #13) has been programmed to produce an 8 1/2 by 11 inch sheet of paper for storage purposes. If Logs are desired for information only, the setting of (bit 11) on accumulator switches on the PDP-7 console will stop this paper sizing function, and therefore conserve paper.

TABLE 22

DEMAND DISPLAY COMMANDS

ALL DEMAND DISPLAYS

*D 1	=	Select Gas Purity Display
*D 2	=	Select Valve Position, Pressures, Flow Display (Gas and Water Temperature Display)
*D 3	=	Select Heater Power, Highest Heater and Graphite Stack Temperature Display
*D 4	=	Analog Rod Position Display

SELECT WATCH CHANNEL DISPLAYS

*DW 1	=	Watch Channels 1 & 2
*DW 2	=	" " 3 & 4
*DW 3	=	" " 5 & 6
*DW 4	=	" " 7 & 8
*DW 5	=	" " 9 & 10
*DW 6	=	" " 12 & 13
*DW 7	=	" " 14 & 15
*DW 8	=	" " 11 only

*E	=	ERASE DEMAND DISPLAYS
*LS	=	CLEAR OR FREE SCRATCH AREA

TABLE 23

LIMIT COMMANDS

SET ALARM LIMITS AND BAD T/C ROUTINE

Select Bad T/C Check Routine

*SLT ØØ Ø	=	Turn Routine On
*SLT ØØ 1	=	Turn Routine Off
*SLT Ø1 (number)	=	Select 1T12 (High Limit)
" Ø2 "	=	Select 2T12 " "
" Ø3 "	=	Select 3T12 " "
" Ø4 "	=	Select 4T12 " "
" Ø5 "	=	Select 5T12 " "
" Ø6 "	=	Select 6T12 " "
" Ø7 "	=	Select 7T12 " "
" 1Ø "	=	Select 8,9 T12 (High Limit)
" 11 "	=	Select 3-34 T56 " "
" 12 "	=	Select 1-24 T6Ø " "
" 13 "	=	Select 1,2 H6Ø " "
" 14 "	=	Select 3,4 H6Ø " "
" 15 "	=	Select 1T54 " "
" 16 "	=	Select 1D12 " "
" 17 "	=	Select 1P12 " "
" 2Ø "	=	Select 1H12 " "
" 21 "	=	(Spare)
" 22 "	=	(Spare)
" 23 "	=	Select 3P12 " "
" 24 "	=	Select 1A12 " "
" 25 "	=	Select 1,2 L12 " "

*SLT	26	(number)	= Select 1,2 M12 (High Limit)
"	27	"	= (Spare)
"	3Ø	"	= Select 3F12** (Low Limit)
"	31	"	= Select 2D12** " "
"	32	"	= Select 2P12** " "
"	33	"	= Select 3P12 " "
"	34	"	= Select 1A12 (Low Limit) **
"	35	"	= Select 1,2 L12 (Low Limit)
"	36	"	= Select 1,2 M12 " "
"	37	"	= (Spare)
(Number)			= ØØØØ to 4Ø95

SET MASK FOR WATCH CHANNEL LIMIT

*SLW ØØ Ø (Mask Word) = Select Watch Channel #5

*SLW Ø1 Ø " " = Select Watch Channel #9

Mask Word is a 6 octal number (18 bit) word.

**Denotes set by GASCYC Program

TABLE 24

GAP TIMING COMMANDS

TO SET GAP TIMING

*SPS	Ø1 Ø	=	Select Hydrogen
"	Ø2 Ø	=	Wait 1
"	Ø3 Ø	=	Select Carbon Dioxide
"	Ø4 Ø	=	Wait 2
"	Ø5 Ø	=	Select Oxygen
"	Ø6 Ø	=	Wait 3
"	Ø7 Ø	=	Select Nitrogen
"	1Ø Ø	=	Wait 4
"	11 Ø	=	Select Carbon Monoxide
			and Set Time (negative) in Seconds (octal)

TABLE 25

GAS SYSTEM COMMANDS

*GAS	=	TURN-ON GAS PROGRAM
*SGA ØØ Ø	=	Start EMERGENCY COOL (ECO)
" ØØ 1	=	Start EVACUATE (EVA)
" ØØ 2	=	Start FILL (FIL)
" ØØ 3	=	Start RECIRCULATE (REC)
" ØØ 4	=	Start VENT (VEN)
" ØØ 5	=	Start GAS HEAT (GHE)
" ØØ 6	=	Start COOL (COO)
" ØØ 7	=	Enter STANDBY (STA)
*GAS OFF	=	TO SHUTDOWN (SHU)

TO SET VALVE POSITION MANUALLY

*SKV Ø1 (Ø-1ØØØ)	=	Select 1 PCV 12
" Ø2 "	=	Select 2 PCV 12
" Ø3 "	=	Select 1 TCV 12
" Ø4 "	=	Select 2 TCV 12
" Ø5 "	=	Select 3 TCV 12
" Ø6 "	=	Select 1 FCV 12
" Ø7 "	=	Select 2 FCV 12

(Ø-1ØØØ) Select valve position 0-100%

*SLT 1Ø Ø	=	Close 3 FCV 12
" 1Ø 1	=	Open 3 FCV 12
" 11 Ø	=	Close 4 FCV 12
" 11 1	=	Open 4 FCV 12
" 12 Ø	=	Close 6 FCV 12
" 12 1	=	Open 6 FCV 12

TO CONTROL VALVES MANUALLY OR AUTOMATICALLY

*SAV Ø1 Ø	=	Manual control of 1 PCV 12
" Ø1 1	=	Automatic control of 1 PCV 12
" Ø2 Ø	=	Manual control of 2 PCV 12
" Ø2 1	=	Automatic control of 2 PCV 12
" Ø3 Ø	=	Manual control of 1 TCV 12
" Ø3 1	=	Automatic control of 1 TCV 12
" Ø4 Ø	=	Manual control of 2 TCV 12
" Ø4 1	=	Automatic control of 2 TCV 12
" Ø5 Ø	=	Manual control of 3 TCV 12
" Ø5 1	=	Automatic control of 3 TCV 12
" Ø6 Ø	=	Manual control of 1 FCV 12
" Ø6 1	=	Automatic control of 1 FCV 12
" Ø7 Ø	=	Manual control of 2 FCV 12
" Ø7 1	=	Automatic control of 2 FCV 12

*MVL = TO CALIBRATE ONE VALVE IN GAS SYSTEM
(This program automatically turns off when valve is calibrated and types "CALIBRATION COMPLETE" on the Command Teletype.

*SGA	=	TO SET GAS SYSTEM VALUES
= Ø	=	Select Setpoint (γ = Ø-3ØØØ)
= 1	=	Select Proportional Constants (γ = Ø-128ØØ)
= 2	=	Select Integral Constants (γ = Ø-131Ø71)
= 3	=	Select Sample Intervals (γ = Ø-6ØØØ)
= 1	=	Choose 1 PCV 12
= 2	=	Choose 2 PCV 12

= 3	=	Choose 1 TCV 12
= 4	=	Choose 2 TCV 12
= 5	=	Choose 3 TCV 12
= 6	=	Choose 1 FCV 12
= 7	=	Choose 2 FCV 12
	=	To set constant in deciman (See following pages)

The setting of Proportional and Integral Constants (*SGA 1 β γγγγγγ and *SGA 2 β γγγγγγ) will be set permanently on magnetic tape during initial system operation and should normally not require changing. However, adjustments can be made during any operating cycle to improve stability and response.

Upon reinitialization of this computer for the next run, these adjusted settings will be automatically replaced by the permanent tape settings.

CONTROL LOOP SETPOINTS

Controlled Valve	Setpoint as Typed at Keyboard	Measured - Variable: Transducer Identification	Measured - Variable: Description
1 PCV 12	0-260 (0 to 260°C in steps of 1°C)	1 TE 12	Temperature of outlet gas from reactor heat exchanger
2 PCV 12	0-500 (0 to 5 psig in steps of .01 psig)	2 PT 12	Pressure at the blower inlet
1 TCV 12	0-90 (0 to 90°C in steps of 1°C)	4 TE 12	Temperature of outlet water from reactor heat exchanger
2 TCV 12	0-40 (0 to 40°C in steps of 1°C)	5 TE 12	Temperature of outlet gas from rods heat exchanger
3 TCV 12	0-90 (0 to 90°C in steps of 1°C)	3 TE 12	Temperature of outlet gas from purge heat exchanger
1 FCV 12	0-70 (0 to 70 amperes in steps of 1 ampere)	1 H 12	Current drawn by blower motor
2 FCV 12	0-40 (0 to 40 cfm in steps of 1 cfm)	2 FE 12	Flow in purge line

Variables Associated With the Gas-Heat Systems Programs

Example: The desired blower inlet pressure in Ø.4 psig

Type: *SGAØ24Ø ↓

Result: In the automatic mode, valve 2P would move to attain the desired pressure. No reaction in the manual mode.

Entries GA11 through GA17 are the proportional constants for the feedback controller, and GA21 through GA27 are the integral constants. The sampling intervals are entries GA31 through GA37. Normally these three sets of constants are not changed. They determine the controller characteristics and should be evaluated before plant operation begins. The following tables give a few values for each of the three sets of constants. Linear interpolation may be used to obtain values not in the tables.

PROPORTIONAL CONSTANTS (GA11 through GA17)

Desired Value	Value Typed at Keyboard	Octal Value Entered into GA1X
0.1	13	15
0.5	64	1ØØ
1	128	2ØØ
2	256	4ØØ
4	512	1ØØØ
10	1280	24ØØ
20	2560	5ØØØ
30	3840	74ØØ
40	5120	12ØØØ
50	6400	144ØØ
60	7680	17ØØØ
70	8960	214ØØ
80	10240	24ØØØ
90	11520	264ØØ
100 (maximum)	12800	31ØØØ

Example: The desired proportional constant for 1T's control loop is 10.

Type: *SGA13128Ø ↓

Result: 24ØØ (octal) is deposited into location GAØØ+13.

Variables Associated With the Gas-Heat Systems Programs

Integral Constants (GA21 through GA27)

Desired Value	Value Typed at Keyboard	Octal Value Entered Into GA2X
10^{-5}	2	2
10^{-4}	21	25
10^{-3}	210	322
0.002	419	643
0.004	839	15Ø7
0.01	2097	4Ø61
0.02	4194	1Ø142
0.04	8389	2Ø3Ø5
0.1	20973	5Ø755
0.2	41945	121731
0.4	83890	243662
0.5	104863	314637
0.625 (maximum)	131071	377777

Example: The desired integral constant for 1P's control loop is 10^{-3}.

Type: *SGA2121Ø ↓

Result: 322 (octal) deposited into GAØØ+21

TABLE 26

HEAT SYSTEM COMMANDS

TO TURN ON/OFF HEAT PROGRAM

*SHE ØØ Ø	=	Open Breakers - Shut Off Program (20 second delay - watch on D3)
" ØØ 1	=	Close Breakers - Turn On Program (20 second delay - watch on D3)

TO CONTROL HEATING SYSTEM

*SHE Ø 1 (Ø-6ØØØ)	=	To Set Sampling Interval in Tenths of Seconds (Ø-6ØØØ)
" Ø 2 (Ø-1ØØØ)	=	To Set Temperature Setpoint (Ø-1ØØØ°C)
" Ø 3 1	=	To Set Control Mode Flag
" Ø 3 Ø	=	Exit Control Mode
" Ø 4 (Ø-2ØØ)	=	Selects TOP Heater (Ø-2ØØ)
" Ø 5 "	=	Selects SIDE Heater (Ø-2ØØ)
" Ø 6 "	=	Selects BOTTOM Heater (Ø-2ØØ)
" Ø 7 "	=	Selects CORE Heater (Ø-2ØØ)

Control Mode may only be entered while in automatic control. Normal Auto Heat Control will control all 4 banks of heaters with proportional constants. Control Mode turns off the core heaters and controls the other 3 banks of heaters with proportional + integral constants.

Example: *SHE Ø4 15Ø Select Top Heater and Control to 15Ø Counts. The kW for the 150 counts will appear on the CRT display. The kW will be different for any given counts depending on the HEATER and STACK temperatures.

TO AUTOMATICALLY CONTROL HEAT SYSTEM

*SGA 2Ø Ø	=	Turns Automatic OFF
*SGA 2Ø 1	=	Turns Automatic ON

Example: To heat automatically at full power on ALL heaters to a given temperature:

1) *SGA 2Ø 1 (Puts Heaters in AUTOMATIC)

2) *SHE Ø4 2ØØ (Sets Heaters to Full Power)
*SHE Ø5 2ØØ
*SHE Ø6 2ØØ
*SHE Ø7 2ØØ

If heating rate desired is 50 percent for a given heater, then approximately 100 counts should be typed in place of the 200.

*SHE XY NNNNNN	=	<u>TO SET HEATER SYSTEM CONSTANTS</u>
X = 1	=	Select Proportional Constants (γ = Ø-128ØØ)
= 2	=	Select Integral Constants (γ = Ø-131Ø71)
Y = Ø	=	Low Temperature Set - Top Heater (below 400°C)
= 1	=	" " " Side Heater " "
= 2	=	" " " Bottom Heater " "
= 3	=	" " " Core Heater " "
= 4	=	High Temperature Set - Top Heater (above 400°C)
= 5	=	" " " Side Heater " "
= 6	=	" " " Bottom Heater" "
= 7	=	" " " Core Heater " "
NNNNNN	=	To Set Constants in Decimal (See above and refer to HEAT Program write up)

The setting of Proportional and Integral Constants (*SHE 1 β γγγγγγ and *SHE 2 β γγγγγγ) will be set permanently on magnetic tape during initial system operation and should normally not require changing. However, adjustments can be made during any operating cycle to improve stability and response. Upon reinitialization of the computer for the next run, these adjusted settings will be automatically replaced by the permanent tape settings.

Variables Associated With the Gas-Heat Systems Programs

Definitions of Keyboard Variables for the Heat System Program - continued:

Table Locations	Decimal Values of Entries	Purposes
HE1Ø through HE17	Ø to 128ØØ	These are the proportional constants for the automatic heater controls. HE1Ø through HE13 are for low temperature operation and HE14 through HE17 are for high temperature operation.
HE2Ø through HE27	Ø to 131Ø71	HE2Ø through HE23 are high temperature integral constants and HE24 through HE27 are low temperature constants.
GA2Ø	Ø or 1	Ø for manual control and 1 for automatic control of heaters.

Definitions of Keyboard Variables for the Heat System Program

Table Locations	Decimal Values of Entries	Purposes
HEØØ	Ø or 1	If the gas system state is GHE, the heat system program becomes active.
HEØ1	Ø to 6ØØØØ	Controller sampling interval in units of Ø.1 seconds.
HEØ2	Ø to 1ØØØ	Reactor temperature setpoint.
HEØ3	Ø or 1	Ø requests proportional control on four heater banks; 1 requests proportional plus integral control on top, side, bottom, banks.
HEØ4 through HEØ7	Ø to 255	Dual uses. In manual mode: these set the heater outputs for top, side, bottom, core, respectively. In automatic mode these set the maximum heater outputs.

OPERATION IN "GHE" MODE WITHOUT BLOWER

I. While in "FIL" mode:

(1) Set blower inlet pressure setpoint to 0.7 psig (*SGA Ø2 7Ø)

(2) Put 2 PCV12 in automatic control (*SAV Ø2 1)

(3) Open 4 PCV12 (*SKV 11 1)

(4) Adjust 2 FCV12 to attain FLOW setpoint (*SKV Ø7 βββ)

II. When 0.7 psig has been reached (Display D-2)

(1) Call "REC" mode (*SGA ØØ 3)

(2) After message "NHI" is typed on Command Teletypewriter, insert the following changes in core memory:

a) *SAA ØØ Ø ØØ6471
*SBB ØØ Ø ØØ3776

b) *SAA ØØ Ø ØØ6212
*SBB ØØ Ø 774ØØ1

c) *SAA ØØ Ø ØØ6214
*SBB ØØ Ø 346471

d) *SAA ØØ Ø ØØ6216
*SBB ØØ Ø 6Ø6246

III. Drop the blower inlet pressure below 0.5 psig in order for the program to continue.

(1) *SGA Ø2 45

(2) Open 4 FCV12 (*SKV 11 1)

(3) At 0.5 psig, close 2 FCV12 to about 30% (*SKV Ø7 3ØØ)

IV. After receiving the message "REC", then call "GHE" by *SGA ØØ 5.

NOTE: Any alarm that would normally send the program from "GHE" to "COO", will send the program through "COO" to "ECO" because blower is off.

The above changes in core memory are erased upon leaving the "GHE" mode. To return to "GHE" mode again from any other mode, it will be necessary to re-enter these changes.

TO ENTER "COO" MODE FROM "GHE" WITHOUT BLOWER ON

I. Call "REC" mode (*SGA ØØ 3)

1) Make proper valve adjustments to enter "REC" as you would if you were coming from "FIL".

2) Blower will automatically start as pressure drops below the setpoint.

II. Call "COO" mode (*SGA ØØ 6) when ready.

III. Adjust valves for desired gas conditions:

1) Suggested purge flow commands

*SGA 17 64	(K_P to 0.5)
*SGA 27 2ØØØØ	(K_I to 0.1)
*SGA Ø7 1Ø	(2 FCV12 to 10 cfm)
*SAV Ø7 1	(2 FCV12 to automatic)

2) Set *SGA Ø1 βββ to appropriate temperature

3) *SAV Ø1 1 to automatic mode

4) *SGA Ø6 ββ set automatic control of blower to desired amperes

5) *SGA Ø6 1 in automatic mode

6) Set other valves to desired conditions using setpoints and automatic control flags.

TABLE 27

ROD COMMANDS

CONTROL RODS

*RH αααααααα	=	TO SELECT HORIZONTAL CONTROL RODS
α's = 1 through 9 (Selected all or separately or in any combination)		
*RHS	=	TO SELECT ALL HCR DRIVES EXCEPT #9 WHICH ARE NOT ON THE CLOSED LIMIT
*RHF	=	TO SELECT ALL HCR DRIVES WHICH ARE NOT ON THE CLOSED LIMIT
*RI α.ααα	=	REQUEST ROD POSITION
		Select Rods With *RH ααα And Then Insert RI α.ααα To Move to Position
		TO SET HCR PULSE RATE
*RR Ø	=	Set 1ØØ HZ
" 1	=	Set 2Ø HZ
" 2	=	Set 1Ø HZ
" 3	=	Set 7 HZ

VERTICAL SAFETY RODS

*RVU αααα	=	SELECT AND RAISE VSR'S
αααα	=	Rod Number 1 through 4 (selected all or separately or in any combination)
*RVD αααα	=	SELECT AND DRIVE IN VSR'S
αααα	=	Rod Numbers 1,2,3,4
*RVS	=	SELECT ALL VSR'S NOT FULLY DOWN AND DRIVE IN
*RVO	=	DESELECT ALL VSR'S

ROD MAINTENANCE

*MRD	=	TURN ON ROD MAINTENANCE PROGRAM
*MRD OFF	=	TURN OFF ROD MAINTENANCE PROGRAM

Use regular commands for VSRs and HCRs in this mode, only move one unit off limits at a time.

MRD - VSR HANG UP FROM SHORT SCRAM RECOVERY PROCEDURE

This procedure may be useful sometimes when more than one (1) VSR is not fully down or its limit and the safety circuit cannot be made up. This can happen from a short scram.

1) *MRD (call ROD MAINTENANCE Program)

2) *SAAØØØ1Ø255 268T21:23

   *SBBØØØ61Ø262 268T21:23

3) Put Accumulator Switches at 531642

4) *RVS (select all VSRs not fully down and drive in)

Any other ROD command than a VSR down command will open the safety circuit if more than (1) scram limit is open.

TABLE 28

TYPICAL LOG OUTPUTS

L3310T13:58

HEATER TEMPERATURES

CH.	CH.ID.	R.C.	E.U.
TOP THERMOCOUPLES			
014	1T60	004000	0028
015	2T60	004001	0033
016	3T60	004000	0028
017	4T60	004001	0033
SIDE THERMOCOUPLES			
018	5T60	004000	0028
019	6T60	004001	0033
020	9T60	004001	0033
021	10T60	004001	0033
022	15T60	004001	0033
023	16T60	004001	0033
024	19T60	004001	0033
025	20T60	004001	0033
CORE THERMOCOUPLES			
026	7T60	004001	0033
027	8T60	004001	0033
028	11T60	004001	0033
029	12T60	004001	0033
030	13T60	004001	0033
031	14T60	004001	0033
032	17T60	004001	0033
033	18T60	004000	0028
BOTTOM THERMOCOUPLES			
034	21T60	004001	0033
035	22T60	004000	0028
036	23T60	004000	0028
037	24T60	004001	0033

L4310T13:51

GRAPHITE TEMPERATURES

CH.	CH.ID.	R.C.	E.U.
CORE THERMOCOUPLES			
Ø38	3T56	ØØ4123	ØØ91.4
Ø39	4T56	ØØ4Ø3Ø	ØØ44.3
Ø4Ø	5T56	ØØ4Ø12	ØØ33.1
Ø41	6T56	ØØ4Ø1Ø	ØØ31.5
Ø42	7T56	ØØ43Ø2	Ø18Ø.1
Ø43	8T56	ØØØØØØ	ØØ25.1
Ø44	9T56	ØØ6752	1237.3
Ø45	1ØT56	ØØ4Ø7Ø	ØØ69.9
Ø46	11T56	ØØ362Ø	ØØ25.1
Ø47	12T56	ØØ4153	Ø11Ø.6
Ø48	13T56	ØØ4532	Ø3Ø1.1
Ø49	14T56	ØØ4Ø2Ø	ØØ37.9
Ø5Ø	15T56	ØØ4122	ØØ9Ø.6
Ø51	16T56	ØØ4ØØ1	ØØ25.9
Ø52	17T56	ØØ4ØØ1	ØØ25.9
Ø53	18T56	ØØ4Ø62	ØØ65.1
TOP THERMOCOUPLES			
Ø54	19T56	ØØ4ØØØ	ØØ25.1
Ø55	2ØT56	ØØ3772	ØØ25.1
Ø56	21T56	ØØ4ØØØ	ØØ25.1
Ø57	22T56	ØØ4ØØØ	ØØ25.1
SIDE THERMOCOUPLES			
Ø58	23T56	ØØ3772	ØØ25.1
Ø59	24T56	ØØ4ØØØ	ØØ25.1
Ø6Ø	25T56	ØØ4ØØØ	ØØ25.1
Ø61	26T56	ØØ4ØØØ	ØØ25.1
Ø62	27T56	ØØ3772	ØØ25.1
Ø63	28T56	ØØ4ØØØ	ØØ25.1
Ø64	29T56	ØØ4ØØØ	ØØ25.1
Ø65	3ØT56	ØØ4ØØØ	ØØ25.1
BOTTOM THERMOCOUPLES			
Ø66	31T56	ØØ4ØØØ	ØØ25.1
Ø67	32T56	ØØ4ØØØ	ØØ25.1
Ø68	33T56	ØØ4ØØØ	ØØ25.1
Ø69	34T56	ØØ4ØØØ	ØØ25.1

L2310T13:55

GAS SYSTEM TEMPERATURES

CH.		CH.ID.	R.C.	E.U.
003		1T12	004053	0024.12
004		3T12	004050	0043.54
005		4T12	004052	0023.42
006		5T12	004050	0022.03
007		6T121	004042	0017.82
008		6T122	004042	0017.82
009		7T12	004043	0018.53
010	@	1T57	004042	0017.82
011		1T54	004051	0022.71
012		1T36	007773	1759.45
013		2T12	003770	0025.18
094		8T12	004000	0025.18
095		9T12	003772	0025.18

L5310T13:56

HEATER KILOWATTS

CH.	CH.ID.	R.C.	E.U.
070	C1H60	004002	000.15
071	S2H60	004001	000.07
072	T3H60	004001	000.03
073	B4H60	004001	000.03

L6310T14:11

GAS SYSTEM FLOW AND PRESSURE

CH.	CH.ID.	R.C.	E.U.
074	1F12	004002	0132.00
075	2F12	003703	0000.00
076	3F12	004001	0003.00
077	1D12	003771	0000.00
078	2D12	004002	0049.93
079	1P12	004001	0000.00
080	2P12	003773	0000.00
081	3P12	404002	0000.01
093	9F12	004003	0006.00
111	1A12	006751	0014.71

L7310T14:11

GAS PURITY

IN H2	000000
IN CO2	000000
IN O2	000000
IN CO	000000
EX H2	000000
EX CO2	000000
EX O2	000000
EX CO	000000
IN MM	000001
MHX MM	000015
EX MM	000017
RHX MM	000017

L8310T14:12

VALVE POSITION

CH.	CH.ID.	R.C.	E.U.	P.P.
113	1PC12	002052	002.01	0000
114	2PC12	006013	100.43	0000
115	1TC12	001723	000.00	6554
116	2TC12	001712	000.00	3876
117	3TC12	006173	105.90	7701
118	1FC12	006002	100.00	6549
119	2FC12	006022	100.78	5157
	3FC12	CLOSE		
	4FC12	OPEN		
	6FC12	CLOSE		

L9310T14:13

ROD POSITIONS

CH.	CH.ID.	R.C.	E.U.	P.P.	P.I.
120	1R42	000000	0.000	00512	0.000
121	2R42	000000	0.000	00512	0.000
122	3R42	000000	0.000	00512	0.000
123	4R42	000000	0.000	00512	0.000
124	5R42	000000	0.000	00512	0.000
125	6R42	000000	0.000	00512	0.000
126	NR42	000000	0.000	00512	0.000
127	8R42	000000	0.000	00512	0.000
128	9R42	000000	0.000	00512	0.000

LA310T14:15

HI PRECISION RTD

CH.	CH.ID.	R.C.	E.U.
001	1RTD	000453	0007.10
002	2RTD	007773	0053.72

LB310T14:15

FLUX VALUES

	OMEGA	POW.	R.F.
1	.2202	0000.0000	000000
2	.2202	0000.0000	000000

POWER SET = 0002
PERIOD SET = 0015

LD310T14:09

WATCH CHANNEL LOG

BIT #	Ø	1	2	3	4	5	6	7	8	9	1Ø	11	12	13	14	15	16	17
WATC1	1	1	1	1	1	1	1	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
WATC2	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	1	1	1	1	1	1	1	1	1
WATC3	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	1	1	1	1	1	1	1	1
WATC4	1	1	1	1	1	1	1	1	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
WATC5	Ø	Ø	Ø	Ø	Ø	1	Ø	1	1	1	1	1	1	1	1	1	Ø	Ø
WATC6	1	1	1	1	1	Ø	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	1	1
WATC7	1	Ø	1	Ø	1	1	Ø	Ø	Ø	Ø	1	Ø	1	Ø	Ø	1	1	1
WATC8	Ø	1	Ø	1	Ø	Ø	1	1	1	1	Ø	1	Ø	1	1	Ø	Ø	Ø
WATC9	1	Ø	1	Ø	Ø	Ø	1	Ø	Ø	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø
WAT1Ø	Ø	1	Ø	1	1	1	Ø	1	1	Ø	Ø	1	1	1	1	1	1	1
WAT11	1	Ø	Ø	Ø	Ø	1	Ø	Ø	Ø	Ø	Ø	1	Ø	Ø	1	1	1	Ø
WAT12	Ø	Ø	Ø	Ø	Ø	1	1	1	1	Ø	Ø	Ø	Ø	1	1	1	1	Ø
WAT13	1	1	1	1	1	Ø	Ø	Ø	Ø	1	1	1	1	Ø	Ø	Ø	Ø	1
WAT14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Ø	1	1
WAT15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Ø	1	1

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2. PDP-7 Users Handbook, DEC, Maynard, Mass.
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4. R. A. Walker, private communication.

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