OLD DOMINION UNIVERSITY RESEARCH FOUNDATION

DEPARTMENT OF PHYSICS AND GEOPHYSICAL SCIENCES
SCHOOL OF SCIENCES AND HEALTH PROFESSIONS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

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By

G.E. Copeland

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ABSTRACT

Criteria for selection of a mini-computer for use as a core resident acquisition system are developed for the ODU Mobile Air Pollution Laboratory. A comprehensive data acquisition program named MONARCH has been instituted in a DEC-8/E-8K 12-bit computer. Up to 32 analog voltage inputs are scanned sequentially, converted to BCD, and then to actual numbers. As many as 16 external devices (valves or any other two-state device) are controlled independently. MONARCH is written as a foreground-background program, controlled by an external clock which interrupts once per minute. Transducer voltages are averaged over user specified time intervals and, upon completion of any desired time sequence, outputted are: day, hour, minute, second; state of external valves; average value of each analogue voltage (E Format); as well as standard deviations of these values. Output is compatible with any serially addressed media.

INTRODUCTION

The need for development of a computer based data acquisition and control system arose during the evolution of a comprehensive Mobile Air Pollution Laboratory at Old Dominion University. This laboratory, housed in a mobile trailer (see figure 1), monitors at four different heights the following environmental parameters: wind speed and direction; temperature; concentrations of ozone (O_3); nitrogen oxides (NO, NO_2, NO_x); carbon monoxide (CO); total hydrocarbons (THC); and sulfur compounds (H_2S, SO_2). Additionally measurements at one height are: relative humidity; insolation; atmospheric pressure; and the b-scattering coefficient (visibility). All of these analog voltage instruments were initially measured sequentially by a multipoint recorder which produced 14,000 data points per level per day. Transcription and averaging of this data base required more effort than maintenance of the instruments during the course of month-long field experiments. It soon became obvious that a computer based data acquisition and control system must be installed to provide near real time analysis of the environmental parameters and to provide convenient expansion and modification via software when additional instrumentation became available. This system was named MONARCH.

A detailed analysis of present and future requirements for MONARCH suggested the following hardware configuration.

1. Data acquisition. A mixture of analog voltage, bridges, and digital BCD input channels must be available. The software must select order and frequency of scanning for a high precision low-speed A/D. All inputs to the A/D are set in the range -10.00 to +10.00 volts, so that each input slot has its own amplifier to change the incoming voltages to this range. Cost constraints prohibited use of a programmable gain amplifier.

2. All data averaging is done in software.

3. Master Control. A crystal controlled clock provides interrupts once per minute. Software design is based upon counting clock interrupts. When read, the clock provides Julian date, hour, minute, and second in three 12-bit BCD words.

4. Control Functions. Computer must initiate all scans of instruments, read the clock, and be able to control external valves for level shifting as well as inserting scrubbers, span and zero gases at appropriate times into air pollution instruments.

5. Input/Output. The entire systen should work in a conversional mode so that field personnel may control its actions. Output medium should be versatile so that changes from paper tape to cassette tape or to tele-communications is possible.

Criteria were established for selection of a computer for MONARCH. Realizing that none of the investigators had ever dealt with minicomputers or assembly languages, one of the major criteria for selection was the existence of clearly worded comprehensible software documentation. Other criteria were: ease of interfacing, possibility of future expansion, cost, availability of service and software personnel, and our in-house hardware capability. The final selection of the minicomputer was a PDP8/E with 8K 12-bit word core memory.

HARDWARE CONFIGURATION

A block diagram of the hardware system is shown in figure 2. All I/O is handled by a 33ASR teletype. The clock was built in-house and interfaced to the PDP8/E. The clock (device code 13) interrupts once per minute and provides day (000-365), hour (00-24), minute and second (00-60) in three 12-bit words. It can be reset manually to $000^d10^h00^m00^s$.

The valve control unit (device code 15) accepts from the PDP8/E one 12-bit word. Each bit (0 or 1) controls the state of one valve system. Once a valve is set via software command it maintains that state until it is reset. This device is expandable to 36 valve states.

Since MONARCH can control measurements at four levels (15, 25, 50, 75 feet) three of the valve states are used (figure 3). Four glass and teflon manifolds are brought into the trailer where each molecular instrument is attached to each manifold via 1/4" I.D. teflon tubing. Switching is accomplished by valves A, B, C which are solenoid activated teflon 3-way divert valves. This arrangement leaves eight unused states for cycling of scrubbers. If zero air or span gases are desired, they are easily incorporated with these additional valve states.

Device 14 is the A/D scanner and input level shifters for 14 input data channels. It is expandable up to 18 additional analog channels. Channel selection is via transfer of a positive binary number from the accumulator to the decoder where the appropriate channel is selected and its mercury relay is closed and data conversion begins. Upon finish of data conversion this device interrupts and one 12-bit BCD number can be read by the computer. Thus this device both accepts and sends information. If digital information is available from any instrument, they can be assigned their own device codes as needed.

DATA ACQUISITION SOFTWARE

MONARCH operates with the interrupt enabled, and a background program which endlessly rotates one bit through the link and accumulator of the PDP8/E. When the indicator selector switch is in the AC setting, one light moves across the display at a rate and direction dependent upon the switch registers (1). Any similar program can be substituted.

An initial start up sequence, START, operates with interrupt off and a dialogue takes place between the operator and MONARCH (figure 4). This sequence sets the number of levels, instruments, samples per instrument per minute, the length of time MONARCH spends per level and time periods between zero and span cycles. At the end of START all software counters are initialized. MONARCH gives messages to the operator, sets the valves and then halts.

MONARCH operates using a Digital Equipment Corporation 23-bit floating point package (FPP) (2), series of teletype service routines, and a BCD-binary conversion subroutine. Use of the FPP enables accuracy of six significant digits and greatly enahances the ease of arithmetic and data manipulation as well as I/O operations. Figures 5 through 10 give the flow diagram for MONARCH. A listing of MONARCH in PAL III assembly language constitutes Appendix A.

After the operator has interacted with MONARCH and supplied the required information, the computer halts. Upon pressing the CONTINUE switch, all flags are cleared, the interrupt is turned on and the background program is entered. At this point we will assume four levels, 14 instruments, five minutes per level and 100 samples per instrument per minute. At the first clock interrupt (Zeroth minute) MONARCH goes to location 0000 and executes the instruction stored in location 0001 which is an effective jump to the Service routine. The Service routine stores the current value of the accumulator and link. Location 0000 has stored in it the next instruction that was to be performed before interrupt occurred. The SERVE routine is a skip chain which tests to see which device needs attention. At this moment the clock is determined and a jump to CLKSER occurs. Since this is the first clock interrupt, the clock is not read. Several counters are incremented (counted up to zero), and the scanner is instructed to start conversion on instrument 14. Then the program jumps to EXIT where the accumulator and link are restored, and program control is returned to background.

The next interrupt is the scanner signalling that instrument 14 has finished conversion. A jump to SERVE occurs where the scanner is detected and a jump to SCNSER happens. SCNSER clears the scanner interrupt flag, sends one 12-bit BCD word to the accumulator. Since the A/D has been designed to accept -10 to +10 volt signals, it is necessary to determine the algebraic sign of the data. This is implemented in hardware. If the least significant digit (LSD) is 0, then the number is negative. If 1, it is positive. This means valid outputs from the A/D are even numbers (negative); odd numbers (positive) over the range -998 to +999. Over range is signalled by all bits zero and must be differentiated from real zero by software if needed.

SCNSER checks the LSD and converts BCD to binary via a service routine, BCDBIN. The floating point package (FPP) is entered and the one word binary data is converted to floating point (3 words). This data is level shifted to all positive (range 0 to 2000) and added indirectly to the 14th floating point buffer location. The Buffer was set to zero in START. Next the scanner is sent instructions to process instrument 13 and control is passed to background.

This process continues until SCNSER detects the fact that each instrument has been read the specified number of times (100, in this example). At that point the scanner is not sent a start conversion signal and program returns to background to wait for the second clock interrupt.

This procedure (clock interrupt, read sequentially each instrument 100 times, wait until clock interrupts) continues until the fourth clock interrupt. At that time a valve in the NO_x instrument is energized and the same procedure continues.

At the fifth clock interrupt a new sequence is initialed. First, the valve state (level) is changed. The clock is now read (BCD 3 words). The clock words are masked and converted to binary, and then to 12-bit words corresponding to units of seconds, minutes, days, tens of seconds, minutes, days, and hundreds of days. Next the state of the NO_x valve is changed. Data output is now indicated via the routine DTAOUT. An example output is shown in table 1. Extensive use is made of the FPP and teletype routines for output and format control (may be FORTRAN E or F format). Output is sequentially printed on three TTY lines; Line 1: DAY, HOUR, MIN., SEC., VALVE LEVEL CODE. Line 2: DATA FROM INSTRUMENT ONE TO SEVEN. Line 3: DATA FROM INSTRUMENT EIGHT TO FOURTEEN. Each outputted value is a decimal number and each are separated by blanks except carriage return line feed at the end of lines. The values are the arithmetic mean of the voltages of each instrument averaged over the number of times it was read. DTAOUT then zeroes all the data storage buffer and returns to background via EXIT. Since the output is to TTY paper tape, a maximum of 600 characters may be punched before the next interrupt occurs. DTAOUT operates with the interrupt off, so that no confusion is possible.

Included in the SERVE Skip Chain are two other service routines. TTYSER gives a warning to the operator if the TTY keyboard is struck. This can be used to input and modify future states of the program. ERROR is a routine at the bottom of the skip chain which can only be entered if interrupt occurs when no real device has caused such. This routine gives an error message and returns to background. It is of importance in cases where the electromagnetic environment is noisy.

FUTURE EXPANSION PLANS

Even though MONARCH presently resides in an 8K machine, it is entirely contained in Field ϕ (Lower 4K memory). The upper 4K memory is not used. Thus, MONARCH can be used with only minor modification in any 4K PDP 8 system. Since the instruction set utilized is shared by the PDP/5 system, MONARCH will work in these older machines if the interrupt service routine is modified. If mass storage devices are incorporated for I/O operations, then the TTY service routines and FPP FOUT function must be modified.

The present version of MONARCH is fixed to a previously existing four-level value structure shown in figure 3. If the number of external levels are increased, additional value routines are necessary. Decreasing from four levels requires no change. If zero and span cycles are desired, they may be inserted in the ZERO routine or they may be assigned levels five and six and thus will automatically be cycled through in the same time intervals as the first four levels.

Many of the instructions used in the floating point package are not currently used. Additional storage may be obtained by deleting these. Examples would be the floating trig and log functions. One modification that would be desirable, from a data analysis viewpoint, would be the incorporation of statistical variances of the quantities being measured. This could be implemented without greatly increasing data storage requirements (it would double - 14 × 3 × 2 = 84 - 12 bit words). Presently, the data storage buffer has stored in each location (3 word) the sum of the data from each instrument over the sample interval. Using the FSQU instruction and doubling the size of the buffer, one could have stored

$$\sum_{i=1}^{N} x_i$$

and

$$\sum_{i=1}^{N} x_i^2$$

where Xi is the measurement, N is the number of times the quantity is measured. At output, it is a simple matter to output (already done)

$$\langle X \rangle = \frac{1}{N} \sum_{i=1}^{N} X_i$$

and also

$$\sigma^2 = \langle X^2 \rangle - \langle X \rangle^2 = \frac{1}{N} \sum X_i^2 - \left(\frac{1}{N} \left(\sum X_i\right)\right)^2$$

The variances have physical interpretations for meteorological quantities (wind speed, temperature, etc.) which are related to turbulence. Variances should be known so that estimates of the reliability and validity of the data may be obtained.

If reliable calibration equations are available, the floating point package can be used to provide output in engineering units directly. Although this may appear to be a desired goal in design of MONARCH, it can easily produce invalid results if calibration of any instrument changes. As a check against this happening for the computer hardware, it is suggested that at least one data port be used to monitor a fixed voltage (Standard cell).

Table 1. Example of MONARCH output.

Line 1	Day	Hour	Min	Sec	Valve State		
Line 2	Inst # 1	2	3	4	5	6	7
Line 3	8	9	10	11	12	13	14
	+401.0	+14.0	+53.0	+0.0	+5.		
	+75.4	+75.3	+75.3	+75.2	+75.3	+75.3	+75.3
	+75.3	+75.3	+58.9	+69.7	+64.7	+67.0	+1874.9
	+401.0	+14.0	+58.0	+0.0	+4.		
	+76.9	+78.6	+77.2	+78.8	+77.3	+78.8	+77.3
	+78.8	+77.3	+62.1	+73.2	+69.0	+70.2	+1872.8
	+401.0	+15.0	+3.0	+0.0	+2.		
	+77.5	+77.4	+77.5	+77.6	+77.6	+77.7	+77.6
	+77.7	+77.6	+60.8	+71.9	+69.1	+69.3	+1872.9
	+401.0	+15.0	+8.0	+0.0	+0.		
	+74.7	+76.0	+74.9	+76.1	+74.9	+76.2	+75.0
	+76.2	+74.9	+59.4	+69.7	+66.7	+67.1	+1871.6
	+401.0	+15.0	+13.0	+0.0	+5.		
	+77.2	+78.6	+77.5	+79.0	+77.6	+79.0	+77.8
	+79.0	+77.6	+62.3	+73.0	+69.8	+70.1	+1869.1
	+401.0	+15.0	+18.0	+0.0	+4.		
	+73.4	+75.9	+73.6	+76.1	+73.7	+76.1	+73.8
	+76.1	+73.7	+59.5	+69.5	+65.1	+66.6	+1868.8
	+401.0	+15.0	+23.0	+0.0	+2.		
	+75.8	+79.4	+76.0	+79.5	+76.1	+79.7	+76.2
	+79.6	+76.0	+62.9	+71.0	+70.2	+68.2	+1870.2

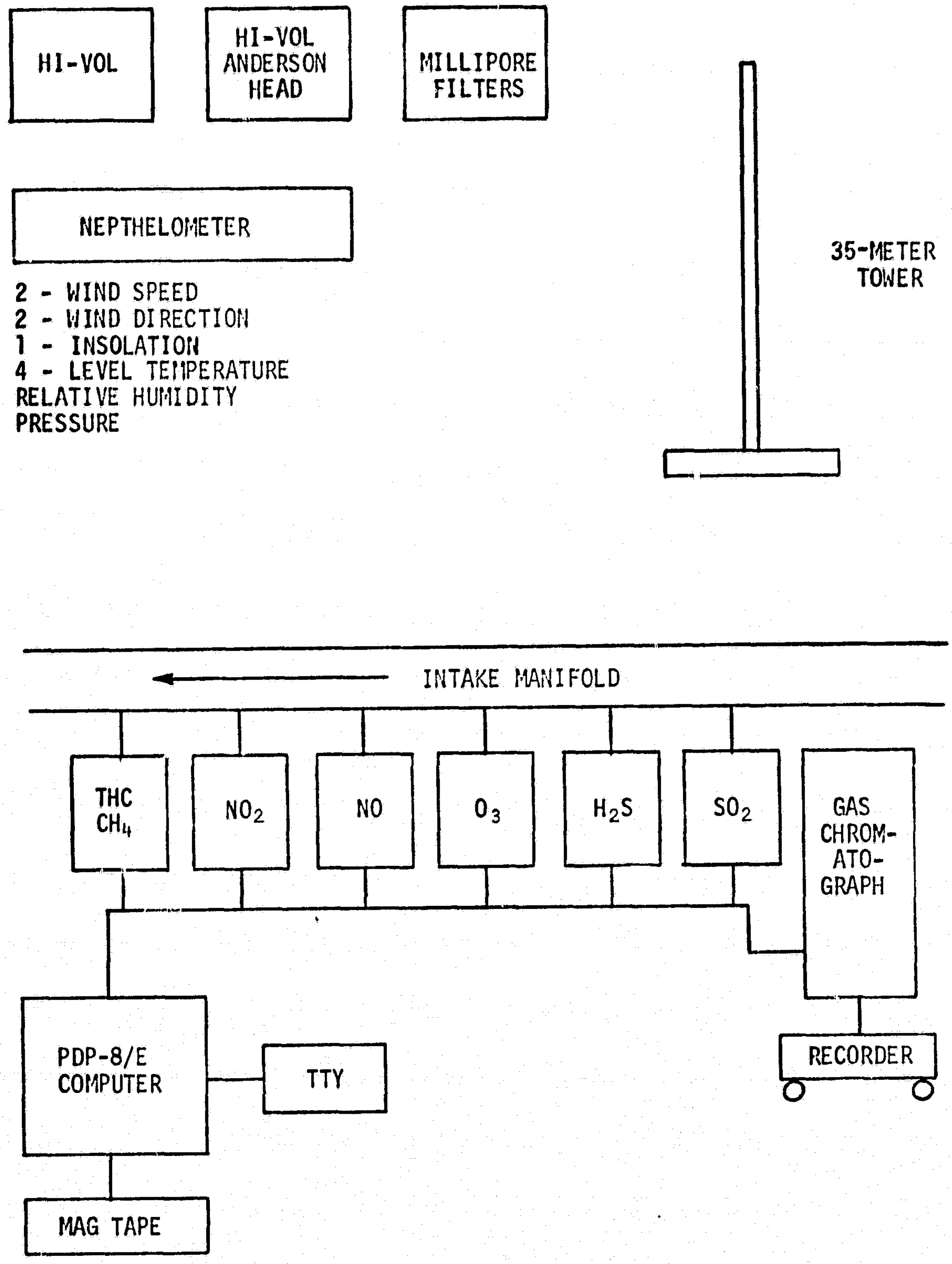

Figure 1. ODU Mobile Air Pollution Laboratory.

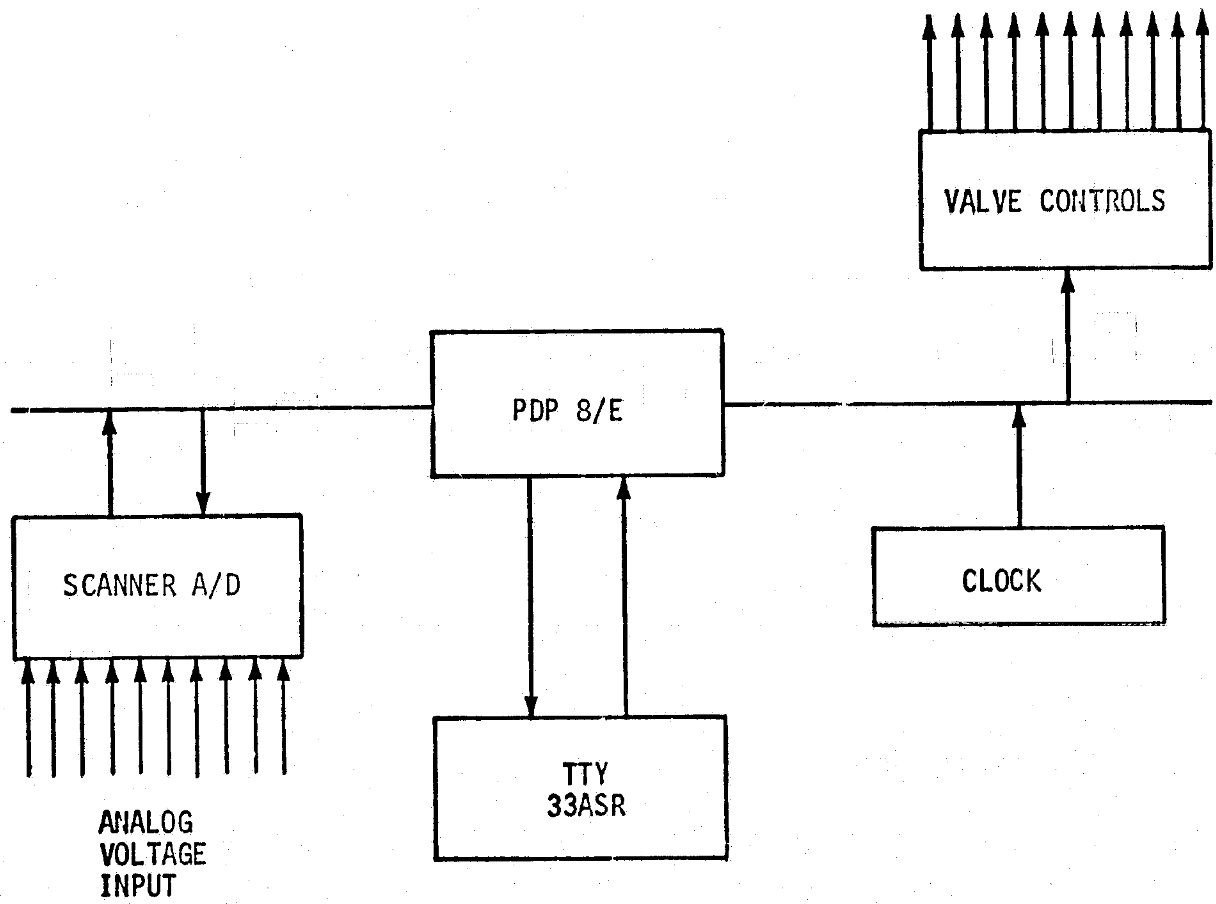

Figure 2. Block diagram of the hardware configuration of MONARCH.

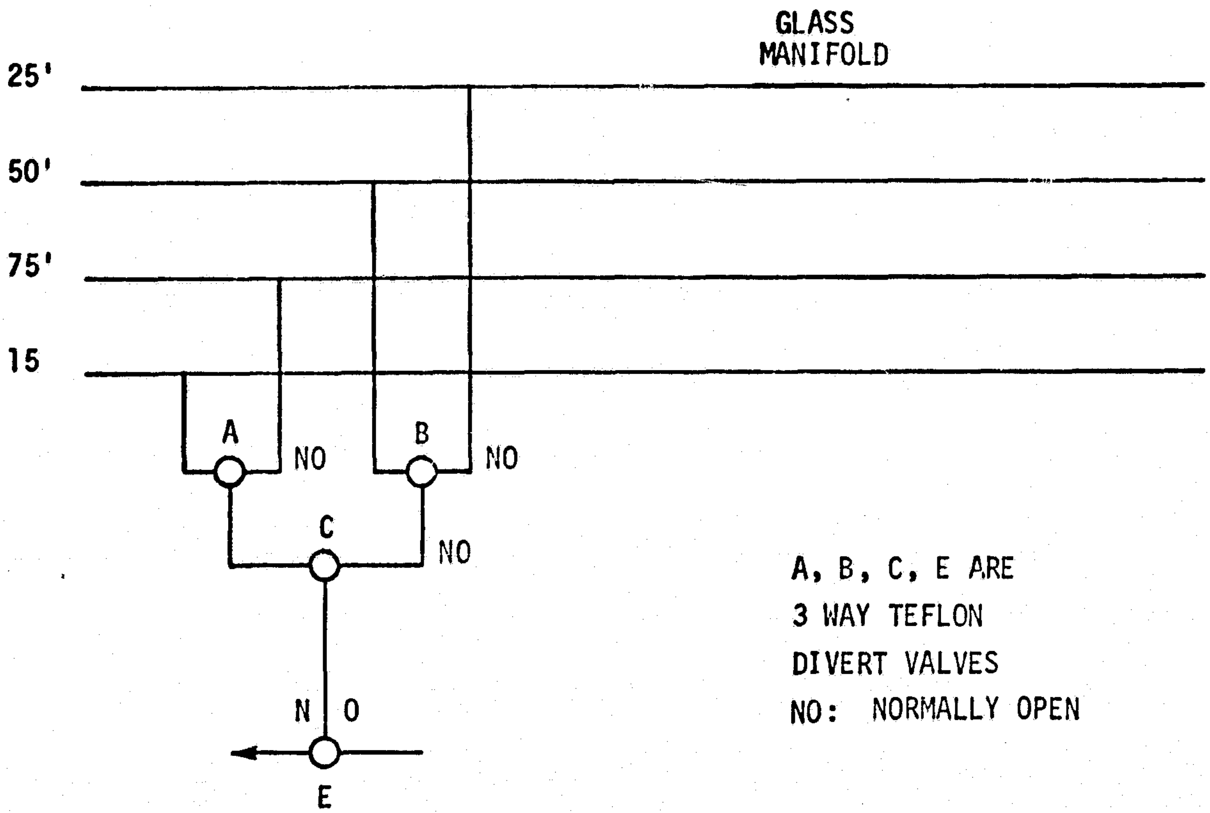

Figure 3. Four level valve configuration.

```
    I AM MONARCH
INPUT THE NUMBER OF DATA PORTS
14
INPUT THE NUMBER OF LEVELS
4
INPUT THE TIME(MIN) SPENT PER LEVEL
5
INPUT NUMBER OF SAMPLES TAKEN
BY EACH INSTRUMENT PER LEVEL
100
INPUT THE NUMBER OF TIMES UP TOWER
BETWEEN ZERO CYCLES
3

CLOCK CAN BE RESET ONLY AT

 000 DAYS
10HR
00MIN
00SEC
WHEN I STOP TURN ON PUNCH AND HIT CONTINUE
```

Figure 4. Initial Dialogue between MONARCH and OPERATOR.

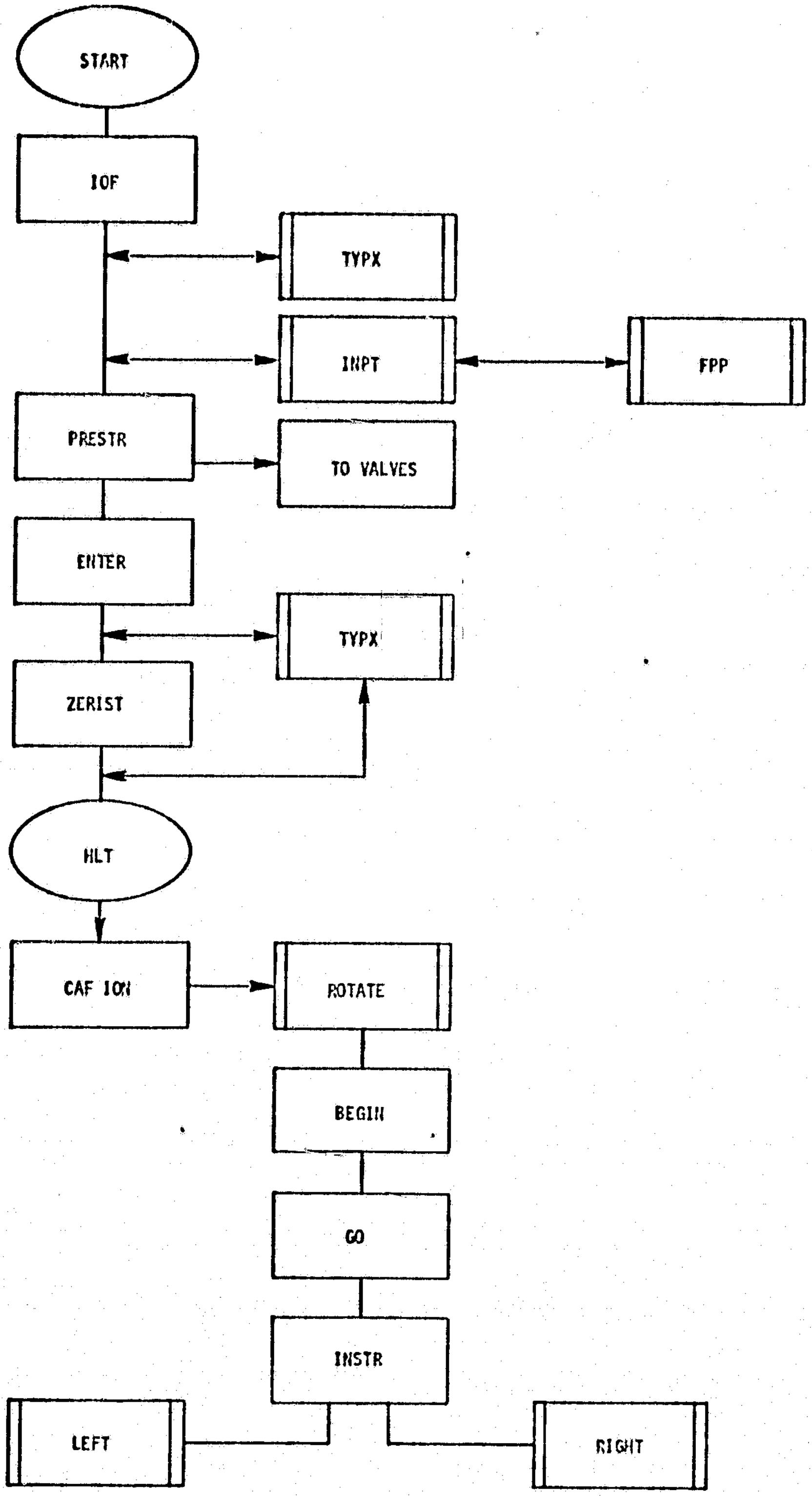

Figure 5. MONARCH flow diagram - start up and background.

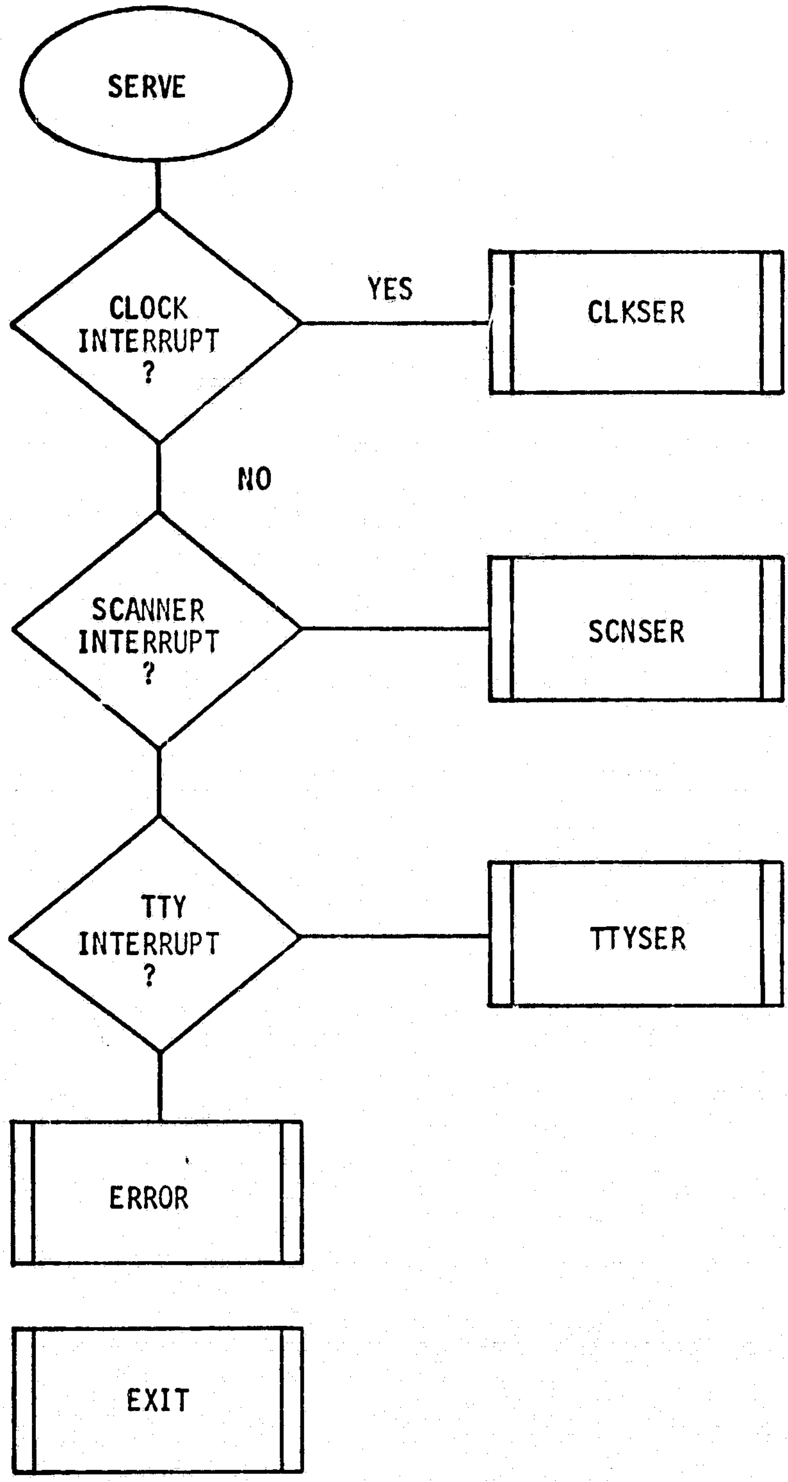

Figure 6. MONARCH - interrupt routines.

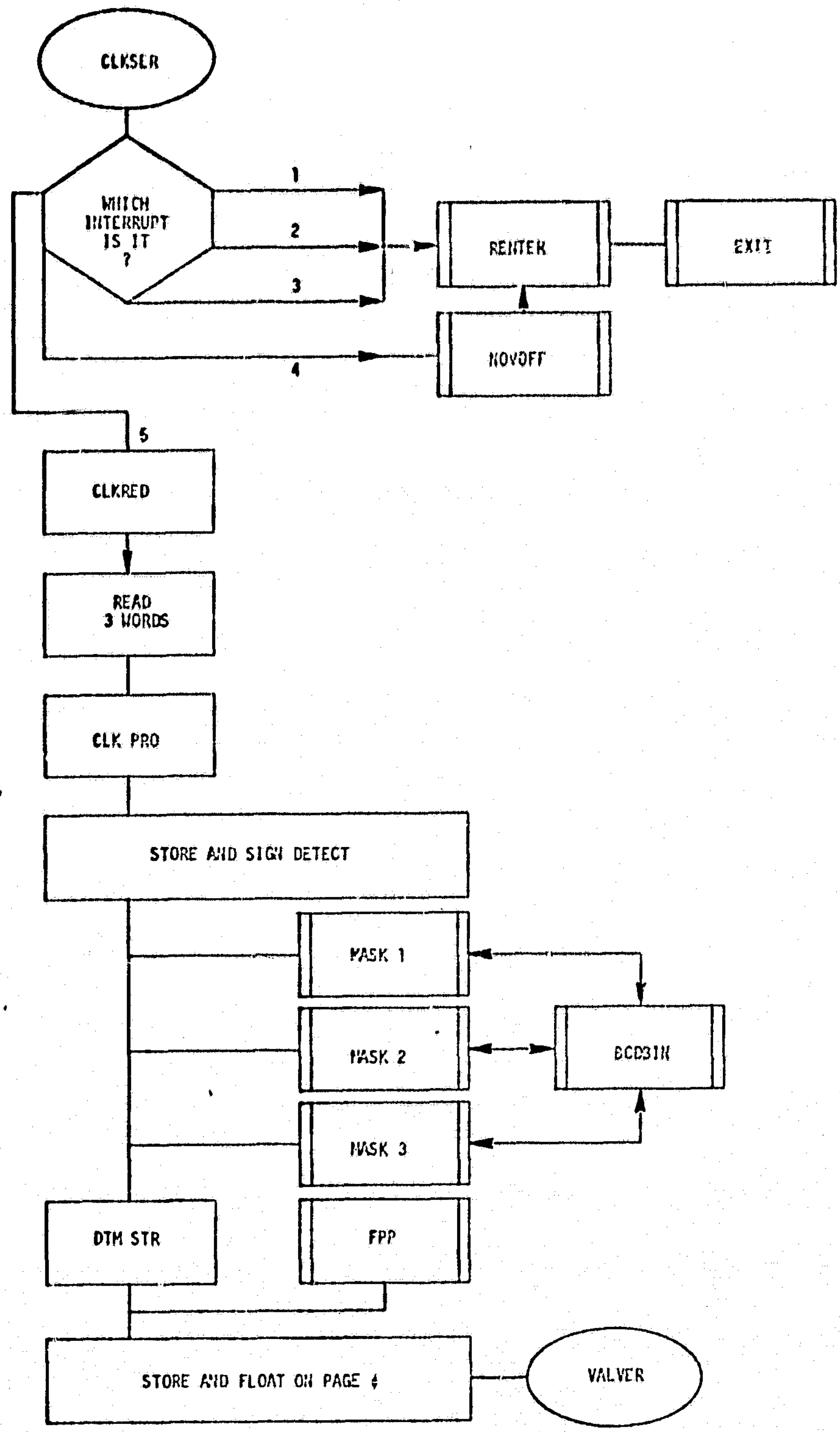

Figure 7. CLKSER (clock service) routine.

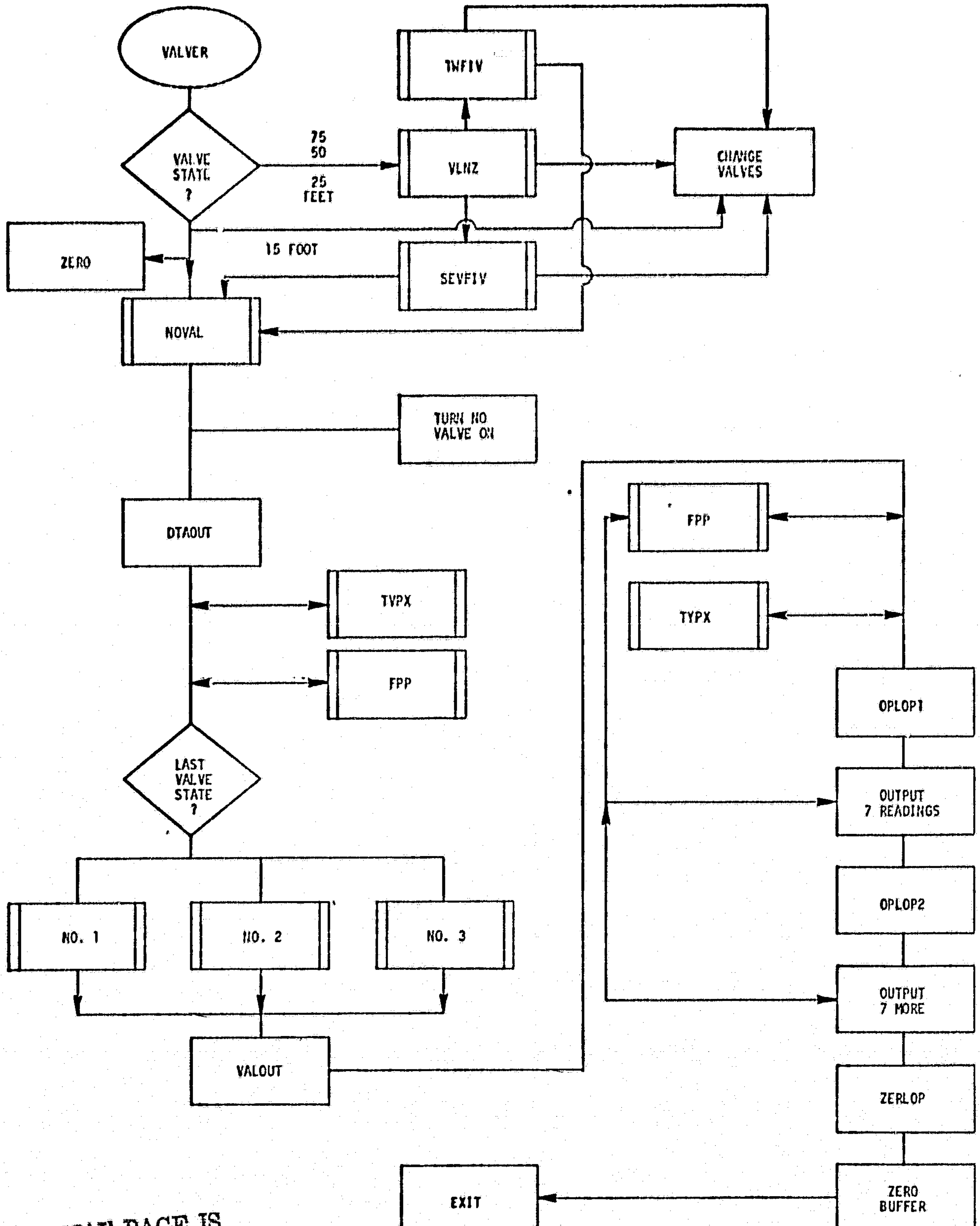

Figure 8. Valve switching and output.

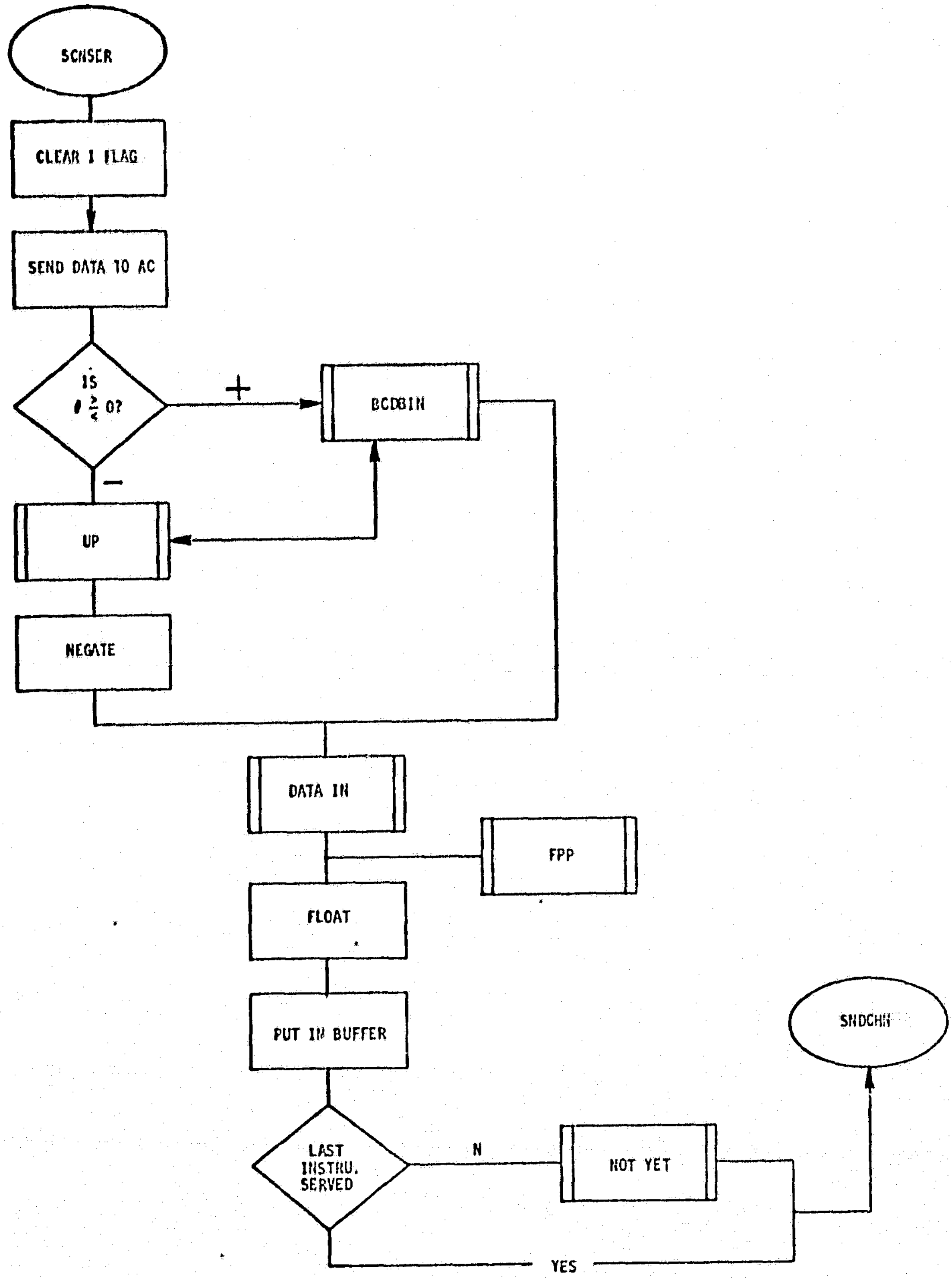

Figure 9. Service routines.

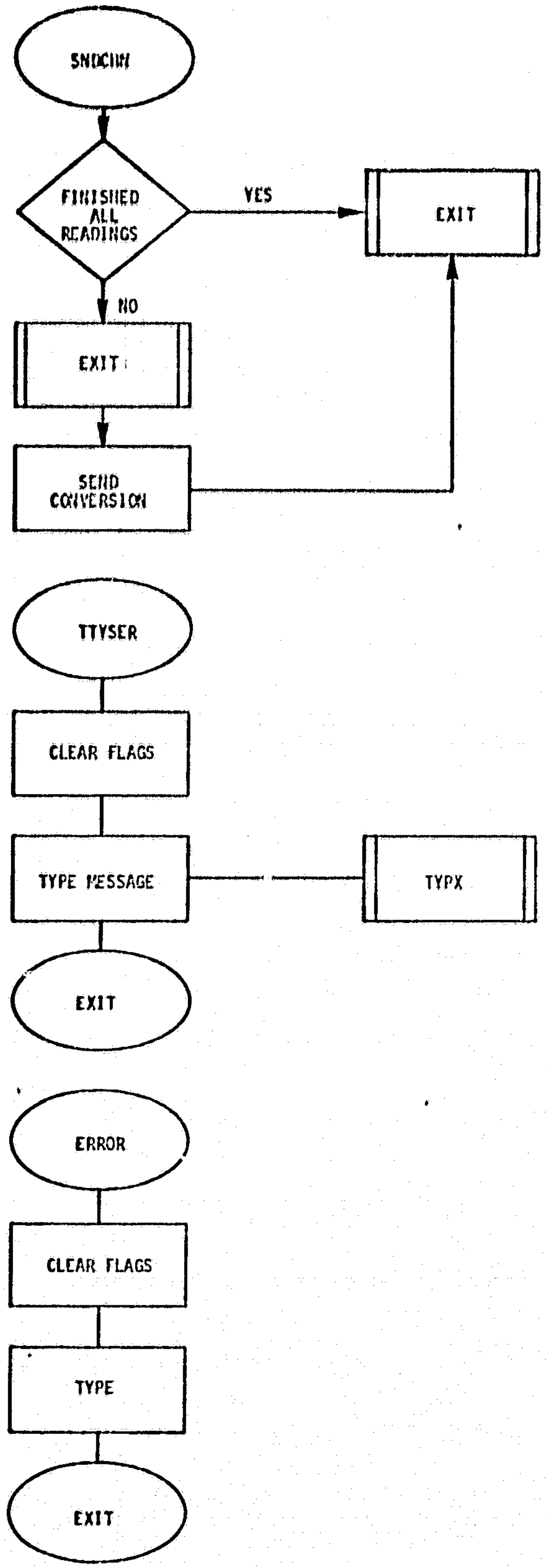

Figure 10. Service routines.

REFERENCES

1. Introduction to Programming, Digital Equipment Corporation, Third Edition, May 1972, p. 3-36.

2. DEC-08-NFPPA-A-PA1.

APPENDIX

MONARCH Written in PAL III

```
BUFF=4000
        *200
ENTER,  CLA CLL
        TLS
        CLA CLL
        DCA AC
        JMS I PTYPX
        ENTMS3
        CLA CLL
        TAD CHAN
        DCA  INDXR3+2
        CLL
        JMS I 7
        FGET INDXR3
        FPUT R16
ZERIST, FGET   ZER000
        FPUT I R16
        FISZ R20  /ALL DONE?
        FJMP ZERIST  /NO
        FGET INDXR3   /SET UP R16
        FPUT R16
        FEXT
        CLA CLL
        TLS
        JMS I PTYPX
        ENTMS1
        CLA CLL
        JMS I PTYPX
        ENTMS2
        HLT   /STOP BEFORE ROTATE CHECK PAPER TAPE
        CAF
        ION
        JMP I PROTAT
ENTMS3,   3700 /CR-LF@
ENTMS2,   2710 /WH
        0516 /EN
        4011 / I
        4023 / S
        2417 /TO
        2040 /P
        2425 /TU
        2216 /RN
        4017 / O
        1640 /N
        2025 /PU
        1603 /NC
        1040 /H
        0116 /AN
        0440 /D
        1011 /HI
        2440 /T
```

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OF POOR QUALITY

```
        0317 /CO
        1624 /NT
        1116 /IN
        2505 /UE
        3700 /←@
ENTMS1,   3737 /←←
        0314  /CL
        1703 /OC
        1340 /K
        0301 /CA
        1640 /N
        0205 /BE
        4022 / R
        0523 /ES
        0524 /ET
        4017 / O
        1614 /NL
        3140 /Y
        0124 /AT
        3737 /←←
        4060 / O
        6060 /00
        4004 / D
        0131 /AY
        2337 /S←
        6160 /10
        1022 /HR
        3760 /←0
        6015 /OM
        1116 /IN
        3760 /←0
        6023 /OS
        0503 /EC
        3700 /←@
        *110
PENTER,ENTER
PROTAT,ROTATE
        *2200
TTYSER,  KCF
        CLA CLL
        TLS
        JMS I PTYPX
        TTYME1
        CAF
        JMP I PEXIT
TTYME1,  1305 /KE
        0520  /EP
        4031 / Y
        1725 /OU
        2240 /R
        1001 /HA
        1604 /ND
        2340 /S
        1706 /OF
        0640 /F
        2410 /TH
        0540 /E
        2424 /TT
        3140 /Y
        3700 /←@
```

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```
        *400
DTAOUT,  CLA CLL
        TLS
        JMS I PTYPX    /+2LF/CR
        OPMS1
        CLA CLL
        IAC    /PUT >0 IN AC
        DCA 56    / TAKE OUT OF E FORMAT
        TAD FORONE  / F7.0
        DCA 57
        TAD DECONE
        DCA  60
        DCA  55   /0 LEFT IN AC,PUT IN 55 SUPPRESS CR/LF
        JMS I 7
        FGET  DAYS
        FOUT
        FGET  HOURS
        FOUT
        FGET   MINS
        FOUT
        FGET SECS
        FOUT
        FEXT
        CLA CLL
        TAD CVS
        SZA   /-0?
        JMP NO1   /NO
        IAC   /YES
        IAC   /2 IN AC
        JMP VALOUT
NO1,    CLA CLL   / IS IT 2?
        CLA CLL CMA RAL    / -2IN AC
        TAD CVS
        SZA    /IS CVS=2?
        JMP NO2   /NO
        CLA CLL   /YES
        CLA CLL IAC RTL    / PUT 4 IN AC
        JMP VALOUT
NO2,    CLA CLL
        CLA CLL IAC RTL
        CIA
        TAD CVS
        SZA    /IS=4?
        JMP NO3   /NO =5 STATE
        CLA CLL   /YES
        TAD CVS
        IAC
        JMP VALOUT
NO3,    CLA CLL
        JMP VALOUT
VALOUT,  DCA 44   /ENTER WITH VALVE STATE IN AC
        JMS I 7
```

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```
        FLOT
        FOUT   /OUT PUT LEVEL IN OCTAL VALVE CODE
        FEXT
        CLA CLL
        JMP I POUTDT
FORONE,  0007
DECONE,0000
        *76
POUTDT, OUTDT
        *3000
OUTDT,   CLA CLL
        TLS
        JMS I PTYPX
        OPMS2  / 1CR-LF
        CLA CLL
        TAD FORTWO
        DCA  57
        TAD DECTWO
        DCA  60    / F8.1
        TAD LSN
        DCA 44
        JMS I 7   /# OF SAMPLES PER LEVEL PER INSTR.
        FLOT
        FPUT FPLSN
        FGET INDXR1
        FPUT R16
OPLOP1, FGET I R16
        FDIV  FPLSN
        FOUT
        FISZ R20   /DONE 1ST HALF?
        FJMP OPLOP1    /NO
        FEXT   /YES
        CLA CLL
        JMP I PTYPX
        OPMS2
        CLA CLL
        JMS  I  7
        FGET  INDXR2
        FPUT R16
OPLOP2,  FGET  I  R16
        FDIV FPLSN
        FOUT
        FISZ  R20
        FJMP OPLOP2    /NO
        FEXT   /YES ; LAST HALF DONE
        CLA CLL
        JMP I PTYPX
        OPMS2
        JMP I PTYPX
        OPMS1
        CLA CLL
        JMS I 7
        FGET INDXR3
        FPUT R16
ZERLOP,   FGET   ZERO00
```

```
         FPUT I R16
        FISZ  R20  /DONE ALL  INSTR?
        FJMP ZERLOP  /NO
        FEXT
        CLA CLL
        JMP I PEXIT
OPMS1,  3737 /2CR-LF
        0000  /@@
OPMS2,  3700  /CR-LF@
FORTWO,  0010
DECTWO,  0001/  F8.1 FORMAT
FPLSN,   0;0;0
INDXR1,   BUFF-3;0;-7
INDXR2,   BUFF+22;0;-7
        *16
R16,0
R17,0
R20,0

        *30
INDXR3,  BUFF-3; BUFF-3; -16
PAUSE




CSIF=6145
SDTAC=6146
        *600
SCNSER,  CLA CLL
        CSIF       /CLEAR SCANNER INTERRUPT FLAG
        CLA CLL
        SDTAC
        DCA TEMDAT
        TAD TEMDAT
        AND MASLSD       /CK TO SEE IF <0,MASLSD=0001
        SZA    /SKIP IF AC=0 ONLY
        JMP  UP
        CLA CLL          /YES NUM<0
        TAD TEMDAT
        JMS I PBCDBN
        CIA     /CONVERT AND NEGATE
        DCA TEMDAT
        JMP DATAIN
UP,     CLA  CLL   /NO IT IS >0
        TAD TEMDAT
        JMS I PBCDBN
```

```
        DCA TEMDAT
        JMP DATAIN
TEMDAT,0
MASLSD,0001
DATAIN,  CLA CLL
        TAD TEMDAT
        DCA 44
        JMS I 7
        FLOT
        FMPY NCSLOP       / SLOPE IS ONE TO ONE FOR NUMBER SCALE
        FADD NCZERO       / INTERCEPT IS +998(USED 1000 TEMP)
        FADD I R16
        FPUT  I R17
        FISZ R20          /FINISHED ALL, INST?
        FJMP NOTYET
        FGET INDXR3       /YES RESET INDEX REG.
        FPUT R16
        FEXT
        JMP  SNDCHN
NOTYET,   FEXT
        JMP  SNDCHN
NCSLOP,    0001; 2000; 0000
NCZERO,  0012; 3720; 0000
SNDCHN, CLA CLL
        ISZ CHAN  /IS CHAN -0?
        JMP EX1  /NO
        TAD NI  /YES, SO RESET CHAN
        CIA  /NEGATE
        DCA CHAN
        ISZ NSL  /IS NSL=0?
        JMP EX1  /NO
        CLA CLL  /YES, RESET  NSL
        TAD LSN
        CIA
        DCA NSL
        NOP /WAIT FOR LAST CLOCK INTERUPT
        JMP I PEXIT
EX1,  CLA CLL
        TAD CHAN
        CIA
        CNTSN  / SEND TO SCANNER
        JMP I PEXIT
EXIT,  CLA CLL
        CAF
        TAD FLAGS
        RTF
        CLA
        TAD AC
        JMP I 0
ERROR,   CLA CLL
```

```
         CAF  /CLEAR ALL FLAGS
        TLS
        JMP I PTYPX
        ERRME1
        CLA CLL
        CAF
        JMP I PEXIT
ERRME1,  0522 /ER
        2217 /RO
        2240 /R
        1116 /IN
        4023 / S
        1311 / KI
        2040 /P
        0310 /CH
        0111 /AI
        1640 /N
        3700 /←@

        *115
PEXIT,EXIT
PERROR, ERROR
PAUSE
```



```
SICFS=6137
SISFS=6147
CNTSN=6141
CCIF=6135
RCW1=6131
RCW2=6132
RCW3=6133
        *1000
SERVE,  DCA AC
        GTF
        DCA FLAGS
        CLL  /SKIP CHAIN
        SICFS   /SKIP IF CLOCK FLAG SET
        SKP
        JMP CLKSER
        SISFS  / SKIP IF SCANNER FLAG SET
        SKP
        JMP  I PSCNSR
        KSF   /KEYBOARD SET FLAG?
        SKP
        JMP I PTTYSR
        JMP I PERROR
        CAF
        JMP I PEXIT / SHOULD NEVER GET HERE
CLKKSER,  CLA CLL
```

```
         CCIF   /CLEAR CLOCK INTERRUPT FLAG
        ISZ CIC  /IS CIC-0?
        SKP  /NO
        JMP CLKRED  /YES
        CLA CLL
        IAC  /PUT 1 IN AC
        TAD CIC
        SMA
        JMP NOVOFF
RENTER,  CLA CLL
        JMS I 7
        FGET INDXR3
        FPUT R16
        FEXT
        CLA CLL
/ THIS RESETS INDEX FOR ADDING TO THE DATA FILES
        TAD NI
        CIA
        DCA CHAN
        TAD CHAN
        CIA
        CNTSN   /START CONVERSION ON 1ST INST
        CLA CLL
        JMP I PEXIT
NOVOFF,  CLA CLL
        TAD CVS
        SACTV  / SEND TO VALVES
        JMP RENTER
CLKRED,  CLA CLL
        CCIF    /CLEAR CK INTR. FLOG
        RCW1    /READ 1ST CLK WORD
        DCA FSTWRD
        RCW2    /READ 2ND WORD
        DCA SNDWRD
        RCW3
        DCA THRWRD
        TAD MINS5
        CIA  / NEGATE
        DCA CIC           / RESET THE CIC COUNTER
        JMP CLKPRO
FSTWRD,0
SNDWRD,0
THRWRD,0
CLKPRO,  CLA CLL
        TAD FSTWRD
        JMS MSK1   /SAME PAGE
        DCA UNSSEC
        TAD FSTWRD
        JMS MSK2   /SAME PAGE
        DCA TNSSEC
        TAD FSTWRD
        JMS MSK3    /SAME PAGE
```

```
        DCA UNSMIN
        CLL
        TAD SNDWRD    /2ND WRD PROCESSOR
        JMS MSK1
        DCA TNSMIN
        TAD SNDWRD
        JMS MSK2
        DCA UNSHRS
        TAD SNDWRD
        JMS MSK3
        DCA TNSHRS
        CLL
        TAD THRWRD    /3RD WORD
        JMS MSK1
        DCA UNSDYS
        TAD THRWRD
        JMS MSK2
        DCA TNSDYS
        TAD THRWRD
        JMS MSK3
        DCA HNDDYS
        CLL
        JMP I PDTMSR
MSK1,0
        AND MASKT1
        CLL
        RTR
        RTR
        RTR
        RTR
        JMS I PBCDBN
        JMP I MSK1
MSK2,0
        AND MASKT2
        CLL
        RTR
        RTR
        JMS I PBCDBN
        JMP I MSK2
MSK3,0
        AND MASKT3
        CLL
        JMS I PBCDBN
        JMP I MSK3
MASKT1,7400
MASKT2,0350
MASKT3,0017
        *72
CVS,0
        *70
AC,0
        *101
PBCDBN,BCDBIN
        *160
UNSSEC,0
TNSSEC,0
```

```
UNSMIN,0
TNSMIN,0
UNSHRS,0
TNSHRS,0
UNSDYS,0
TNSDYS,0
HNDDYS,0
        *102
PSCNSR,SCNSER
PTTYSR,TTYSER
PDTMSR,DTMSTR
PVALVR,VALVER
        *1
        JMP I PSERVE
        *5
PSERVE, SERVE
        PAUSE



        *1200
DTMSTR,  CLA CLL
        TAD UNSSEC
        DCA  44
        JMS I 7
        FLOT
        FPUT  SECS
        FEXT
        CLA CLL
        TAD TNSSEC
        DCA  44
        JMS I 7
        FLOT
        FMPY  TEN
        FADD  SECS
        FPUT  SECS
        FEXT
        CLA CLL
        TAD UNSMIN
        DCA  44
        JMS I 7
        FLOT
        FPUT  MINS
        FEXT
        CLA CLL
        TAD TNSMIN
        DCA  44
        JMS I 7
        FLOT
        FMPY  TEN
        FADD  MINS
        FPUT  MINS
        FEXT
        CLA CLL
        TAD UNSHRS
        DCA  44
```

```
        JMS I 7
         FLOT
         FPUT  HOURS
         FEXT
         CLA CLL
         TAD UNSDYS
         DCA  44
         JMS I 7
         FLOT
         FMPY  TEN
         FADD  HOURS
         FPUT  HOURS
         FEXT
         CLA CLL
         TAD UNSDYS
         DCA  44
         JMS I 7
         FLOT
         FPUT  DAYS
         FEXT
         CLA CLL
         TAD TNSDYS
         DCA  44
         JMS I 7
         FLOT
         FMPY  TEN
         FADD  DAYS
         FPUT  DAYS
         FEXT
         CLA CLL
         JMP I PYEARS
TEN,    4; 2400; 0
BCDBIN,  0
         DCA TEMPH
         TAD TEMPH
         AND LDIGIT
         CLL RTR
         DCA CUNT
         TAD CUNT
         RAR
         TAD CUNT
         CMA IAC
         TAD TEMPH
         DCA TEMPH
         TAD TEMPH
         AND MDIGIT
         CLL RTR
         DCA CUNT
         TAD CUNT
         RAR
         TAD CUNT
         CMA IAC
         TAD TEMPH
```

```
        JMP I BCDBIN
LDIGIT, 7400
MDIGIT, 7760
CUNT, 0
TEMPH, 0
        *76
PYEARS, YEARS
        *3200
YEARS,   CLA CLL
        TAD HNDDYS
        DCA   44
        JMS I 7
        FLOT
        FMPY  HUN100
        FADD  DAYS
        FPUT  DAYS
        FEXT
        CLA CLL
        JMP I   PVALVR
HUN100,    7; 3100; 0
        *123
SECS,0;0;0
MINS,0;0;0
HOURS,0;0;0
DAYS,0;0;0
        PAUSE
```

```
        *120
ZERO00,   0 ;0 ;0
        *2400
ZERO,     CLA CLL
        TAD NCLUT
        CIA
        DCA TULCN
        JMP I PNOVAL
/ THIS ROUTINE WILL BE WRITTEN LATER(MAY 23,1974)
/ CURRENT SYSTEM WILL NOT  ZERO BUT ONLY A SMALL CHANGE IS
/ NEEDED.
        *112
PNOVAL, NOVAL
        *71
FLAGS, 0
        PAUSE
```

```
SACTV=6151
        *1400
VALVER, CLA CLL
        ISZ VL   /IS VL=0?
        JMP VLNZ          /NO
        TAD NLV           /YES,NLV=+4=# LEVELS
        CIA
        DCA VL   /RESET VL
        CLA CLL
        IAC
        RTL
        IAC
        DCA CVS
        TAD CVS           / CURRENT VALVE STATE(A,B,C)
        SACTV    /PUT 101 ON AC, SEND TO VALVES
        ISZ TULCN         /READY TO ZERO?
        JMP NOVAL         / NO; NCLUT=# CYCLES UP TOWER
        JMP I PZERO    /YES
VLNZ,    CLA CLL          /VL=-1,-2,-3
        IAC
        IAC
        TAD VL            /PUT +2 IN AC, TAD VL, RES +,0,-
        SPA
        JMP SEVFIV  /VL=-3,75 FOOT
        SZA
        JMP TWFIV  /VL=-1,25 FEET
        CLA CLL
        IAC
        IAC
        DCA CVS
        TAD CVS
        SACTV  /SET 010 IN AC, SEND TO VALVES,50 FEET
        JMP NOVAL
SEVFIV,  CLA CLL
        IAC
        RTL  / 100 IN AC
        DCA CVS
        TAD CVS
        SACTV  /75 FEET
        JMP NOVAL
TWFIV,   CLA CLL
        DCA CVS
        TAD CVS
        SACTV  /000 IN AC , SEND TO VALVES, 25 FEET
        JMP NOVAL
NOVAL,  CLA CLL
        IAC   /NO VALVE TURN ON
        RTL
        RAL   / MAKE 1000 IN AC
        TAD CVS  / ADD CURRENT VALVE STATE
        SACTV
        CLA CLL
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
        JMP I PDATOT
ROTATE,     CLA CLL CML
        NOP
BEGIN,  DCA SAVEAC
        RAL
        DCA SAVEL
        TAD MASK
        OSR
        DCA COUNT
        OSR
        RAL
        SZL CLA
        JMS LEFT
        JMS RIGHT
        CLL
GO,     TAD SAVEL
        RAR
        TAD SAVEAC
INSTR,   RAR
        ISZ COUNTR
        JMP .-1
        ISZ COUNT
        JMP .-3
        JMP BEGIN
SAVEAC,0
SAVEL,0
MASK,7000
COUNTR,0
COUNT,0
LEFT,0
        ISZ LEFT
        TAD KRAL
        DCA INSTR
        JMP I LEFT
RIGHT,0
        TAD KRAR
        DCA INSTR
        JMP I RIGHT
KRAR, 7010
KRAL, 7004

        *73
NCLUT,0
TULCN, 0
        *106
PZERO,ZERO
        *107
PDATOT, DTAOUT
PAUSE
```

```
        *1600
START,    IOF
        KCC     /CLEAR KEYBOARD FLAG
        CLA CLL
        TLS
        JMS I PTYPX
        MESG01
        JMS I PTYPX
        MESG02
        JMS INPT
        CLA CLL
        TAD 150
        DCA NI
        TAD NI
        CIA
        DCA CHAN    / SET CHAN=-NI
        CLA CLL
        JMS I PTYPX
        MESG03
        JMS INPT
        CLA CLL
        TAD 150
        DCA NLV    / SET UP NLV(#OF LEVELS)
        TAD NLV
        CIA
        DCA VL    /SET UP VL=-NLV
        CLA CLL
        JMS I PTYPX
        MESG04
        JMS INPT
        CLA CLL
        TAD 150
        DCA MINS5   / SET UP TIME / LEVEL(MINS=5 TYPICAL)
        TAD MINS5
        CIA
        DCA CIC   / SET UP CIC
        CLL
        JMS I PTYPX
        MESG05
        JMS INPT
        CLA CLL
        TAD 150
        DCA LSN
        TAD LSN
        CIA
        DCA NSL    /SET NSL
        CLA CLL
        JMS I PTYPX
        ZERCYM
        JMS INPT
        CLA CLL
        TAD 150
```

```
        DCA NCLUT
        TAD NCLUT
        CIA
        DCA TULCN
        CLL
        JMP PRESTR
INPT,   0    /THIS PAGE INPUT OF NUMERICAL CONSTANTS
        CLA CLL
        JMS I 7
        FIN
        FFIX
        FPUT 150
        FEXT
        CLA CLL
        JMP I INPT
MESG01,3737     /←←
        4040
        4040
        1140 /I
        0115 /AM
        4015 / M
        1716 /ON
        0122 /AR
        0310 /CH
        3700 /←@
MESG02, 1116 /IN
        2025 /PU
        2440 /T
        2410 /TH
        0540 /E
        1625 /NU
        1502 /MB
        0522 /ER
        4017 / O
        0640 /F
        0401 /DA
        2401 /TA
        4020 / P
        1722 /OR
        2423 /TS
        3700 /←@
MESG03, 1116 /IN
        2025 /PU
        2440 /T
        2410 /TH
        0540 /E
        1625 /NU
        1502 /MB
        0522 /ER
        4017 / O
        0640 /F
```

```
        1405 /LE
        2605 /VE
        1423 /LS
        3700 /←@
PRESTR,  CLA CLL
        IAC
        RTL
        IAC
        DCA CVS
        TAD CVS
        SACTV  /SET UP 15 LEVEL
        CLA
        IAC
        RTL
        RAL
        TAD CVS
        SACTV
        CLA CLL
        JMP I PENTER
        *2700
ZERCYM,  1116  /IN
        2025 /PU
        2440 /T
        2410 /TH
        0540 /E
        1625 /NU
        1502 /NB
        0522 /ER
        4017 / O
        0640 /F
        2411 /TI
        1505 /ME
        2340 /S
        2520 /UP
        4024 / T
        1727 /OW
        0524 /ER
        3702 /←B
        0524 /ET
        2705 /WE
        0516 /EN
        4032 / Z
        0522 /ER
        1740 /O
        0331 /CY
        0314 /CL
        0523 /ES
        3700 /←@
        PAUSE
```

```
    *2000
TYPX,   0
        CLA CLL
        TAD I TYPX
        DCA TYPNT
        ISZ  TYPX
TYPX1, TAD I TYPNT
        RTR
        RTR
        RTR
        JMS  TYPY
        TAD I TYPNT
        ISZ  TYPNT
        JMS  TYPY
        JMP  TYPX1
TYPNT,  0
TYPY,  0
        AND TK77
        SNA
        JMP I TYPX
        TAD TKM37
        SZA
        JMP TYPY1
        TAD TK215
        JMS  TLSX
        TAD TKM125
TYPY1, SPA
        TAD  TK100
        TAD TK237
        JMS TLSX
        JMP I TYPY
TK77,  77
TKM37,  -37
TK215, 215
TKM125, -125
TK100, 100
TK237, 237
TLSX,   0
        TSF
        JMP .-1
        TLS
        CLA
        JMP I TLSX
KRBX,  0
        KSF
        JMP  .-1
        KRB
        JMP I KRBX
KREAD,   0
        CLA CLL
        TAD I KREAD
        ISZ   KREAD
        DCA  KRPNT
        TAD I KREAD
        DCA   KRCNT
KRB1,   JMS    KRBX
        DCA I KRPNT
        TAD   KRTAB
```

```
        DCA   KRBKS
KRB3,  TAD I KRPNT
        ISZ KRBKS
        SNA CLA
        JMP I KRBKS
        ISZ KRBKS
        TAD I KRBKS
        SZA
        JMP   KRB3
        JMS   KRBKS
        ISZ   KRCNT
        JMP   KRB6
        TAD   TK207
KRB5,   JMS TLSX
        CLA CMA
        TAD   KRCNT
        JMP KRB1-1
KRB6,  TAD I KRPNT
        ISZ   KRPNT
        JMS TLSX
        JMP KRB1
KRUB,  CLA CMA
        JMS   KRBKS
        ISZ   KRFLAG
        TAD I KREAD
        CIA
        TAD   KRCNT
        SNA CLA
        JMP KRUB1
        CLA CMA
        TAD KRPNT
        DCA KRPNT
        TAD I KRPNT
        JMP   KRB5
KRUB1,  TAD TK237
        JMS TYPY
        JMS KRBKS
        JMP KRB1
KRCR,   JMS   KRBKS
        TAD   TK237
        JMS TYPY
        DCA I KRPNT
        ISZ   KREAD
        JMP I KREAD
KRBKS,  0
        TAD   KRFLAG
        SZA CLA
        TAD   TK334
        SZA
        JMS   TLSX
```

```
        DCA   KRFLAG
        JMP I KRBKS
KRFLAG, 0
KRPNT=TYPNT
KRCNT=TYPX
TK207, 207
TK334,334
KRTAB,  .
        JMP KRB1
        -200;
        JMP KRB1
        -212;
        JMP KRB1
        -215;
        JMP KRCR
        -377;
        JMP KRUB
        0
PAUSE



      *2600
MESG04, 1116 /IN
        2025 /PU
        2440 /T
        2410 /TH
        0540 /E
        2411 /TI
        1505 /ME
        5015 /(M
        1116 /IN
        5140 /)
        2320 /SP
        0516 /EN
        2440 /T
        2005 /PE
        2240 /R
        1405 /LE
        2605 /VE
        1440 /L
        3700 /←@
MESG05, 1116 /IN
        2025 /PU
        2440 /T
        1625  /NU
        1502 /MB
        0522 /ER
        4017 / O
        0640 /F
        2301 /SA
        1520 /MP
        1405 /LE
        2340 /S
        2401 /TA
        1305 /KE
```

```
        1637 /N←
        0231 /BY
        4005 / E
        0103 /AC
        1040 /H
        1116 /IN
        2324 /ST
        2225 /RU
        1505 /ME
        1624 /NT
        4020 / P
        0522 /ER
        4014 / L
        0526 /EV
        0514 /EL
        3700 /←@


        *100
PTYPX,TYPX
        *140
NI,0
CHAN,0
NLV,0
VL,0
MINS5,0
CIC,0
LSN,0
NSL,0
PAUSE
```

```
        FIXMRI FJMP=0000
        FIXMRI FJMS=7000
        FISZ=0000
        FEXT=0000
        FSQU=0001
        FSQR=0002
        FSIN=0003
        FCOS=0004
        FATN=0005
        FEXP=0006
        FLOG=0007
        FNEG=0010
        FIN =0011
        FOUT=0012
        FFIX=0013
        FLOT=0014
        FNOR=7000
        FCDF=7001
        FSW0=7002
        FSW1=7003
        FHLT=7004
        FSMA=7110
        FSZA=7050
        FSPA=7100
        FSNA=7040
        FNOP=7010
        FSKP=7020
        PAUSE
```