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MICROCOMPUTER-BASED PNEUMATIC CONTROLLER FOR NEUTRON ACTIVATION ANALYSIS

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PREPARED FOR THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION UNDER CONTRACT AT(07-2)-1

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by

J. S. Byrd and R. J. Sand

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ABSTRACT

A microcomputer-based pneumatic controller for neutron activation analysis was designed and built at the Savannah River Laboratory. In this system, commercially available microcomputer logic modules are used to transport sample capsules through a network of pressurized air lines. The logic modules are interfaced to pneumatic valves, solenoids, and photo-optical detectors. The system operates from programs stored in firmware (permanent software). It also commands a minicomputer and a hard-wired pulse height analyzer for data collection and bookkeeping tasks. The advantage of the system is that major system changes can be implemented in the firmware with no hardware changes. This report describes the hardware, firmware, and software for the electronics system.

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MICROCOMPUTER-BASED PNEUMATIC CONTROLLER FOR NEUTRON ACTIVATION ANALYSIS

INTRODUCTION

The National Uranium Resource Evaluation (NURE) is a program by the United States Energy Research and Development Administration to locate potential supplies of uranium ore to supply the future needs of the country. Under this program, large numbers of geologic samples are acquired from the entire country, and the samples subsequently are analyzed by radiochemical spectral techniques. The Savannah River Laboratory is responsible for the NURE program in the eastern United States.

A pilot-scale neutron activation facility has been developed by Savannah River Laboratory to analyze the NURE samples with minimal manual operations. The NURE Activation Facility[1] consists of a control center module (CCM) trailer, a pneumatic transport system, and a reactor irradiation chamber (RIC). The CCM houses the pneumatic control system, detectors and spectra aquisition equipment, and half of the pneumatic system valving. The reactor irradiation chamber is mounted against the moderator tank wall of a production reactor at the Savannah River Plant. The other half of the pneumatic system valving is in the reactor tank service area near the RIC. The CCM is located immediately outside the reactor building and is connected to RIC pneumatic piping. The transport time of sample rabbits (or between the CCM and RIC) is approximately 1-1/2 seconds. Samples are contained in devices called rabbits for rapid movement into and out of an irradiation field.

An electronic control system was required to control the transportation of sample rabbits from a loading port, through a series of irradiation cycles in several reactor tubes, through counting intervals at one of two counting ports (D1 and D2), and to an unloading port at the end of the tests (Figure 1). Four activation regimes are defined in Table 1. Figure 2 shows a photograph of the controller. Design criteria for the controller were:

- The system could operate all necessary control valves to transport the rabbits through a schedule of radiation-count cycles defined in Table 1. The regime schedule of any given sample rabbit could be modified based on analysis results of some previous cycle.

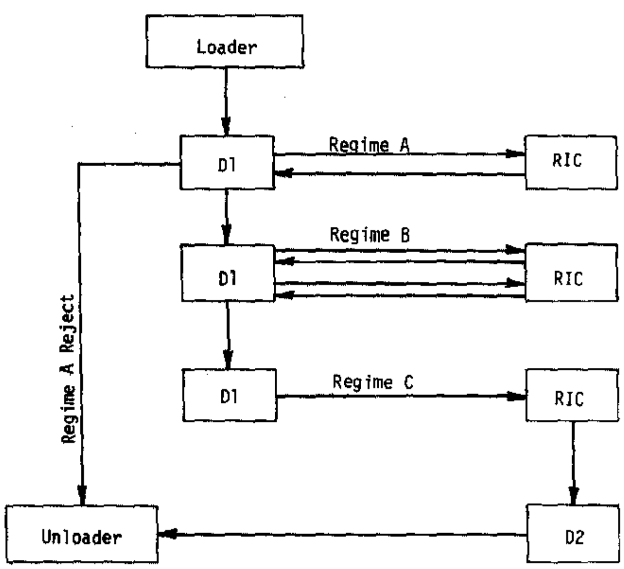
- The system could trace a rabbit through various cycles, identify its location at any time, inform the operator if a rabbit fails to reach a programmed destination, and identify the present location.

- Two analyzer systems, a PDP-9 minicomputer system and a Canberra 8100 multichannel analyzer, could be controlled by handshaking techniques.

TABLE 1

Definition of Regimes

Regime	*Description*
A	One short irradiation and one short gross activity measurement. When gross activity exceeds limits, the sample is prevented from receiving further analysis.
B	Several cycles of short irradiation and short counts.
C	One long irradiation and one intermediate-length count.
D	No irradiation, but one intermediate-length count for each rabbit not rejected in Regime A. Counting is done in off hours separately from analyses of Regimes A, B, and C.



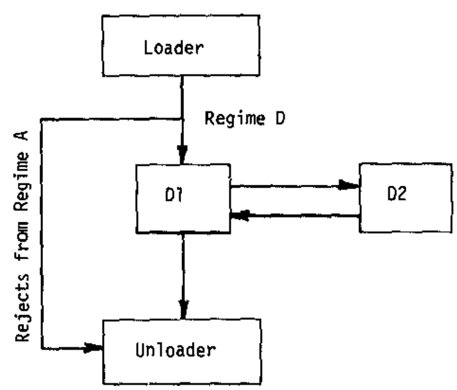


FIGURE 1. NURE Regimes

A digital system incorporating state-of-the-art technology was designed for the electronic control system, called the NURE Rabbit Controller. The base for the programmable electronic controller is a commercially available modular microcomputer system.[2] These modules include a second-generation microprocessor, the Intel 8080,[3] as its central processor. This central processor is a large-scale-integration integrated-circuit component that contains the central processing circuitry found in a small, 8-bit parallel computer. A digital interface connects the microcomputer to various input and output devices associated with the NURE pneumatic and analysis equipment. Operating programs for the NURE Rabbit Controller are stored in erasable programmable read-only memories (EPROMs) that constitute the system firmware.

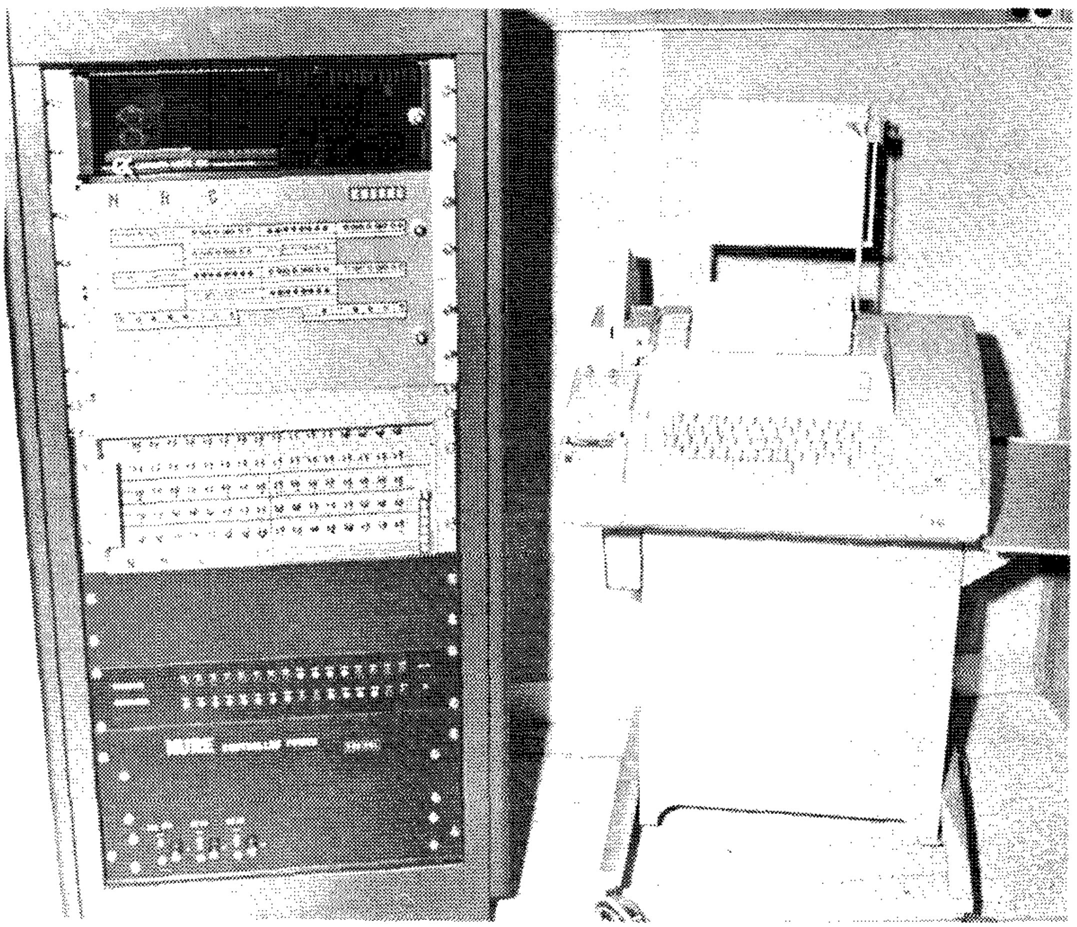


FIGURE 2. NURE Rabbit Controller

SYSTEM DESCRIPTION

Hardware

A block diagram of the major hardware components for the NURE Rabbit Controller is shown in Figure 3. M-Series logic modules from Control Logic, Inc. (plug-in, printed circuit cards) were used in designing the microcomputer (Table 2). The basic commercial system was modified to provide additional signals at the input/output (I/O) connector. The I/O terminal is an ASR-33 *Teletype* (Registered trademark of Teletype Corp.) used for input commands and output messages to the operator. A 256 x 8-bit random access memory (RAM) provides temporary storage for the systems programs. A 3.5K x 8-bit EPROM contains the firmware for the NURE Rabbit Controller.

A digital interface was designed to connect the microcomputer to process peripherals of the NURE pneumatic rabbit system. Signals from the I/O connector (Table 3) were connected to binary hexidecimal-to-decimal decoder modules to produce 16 system input signals, IN 2Ø-IN37, and 32 system output signals, OUT 4Ø-OUT 57 and OUT 1ØØ-OUT 117 (Figure 4). These I/O signals are used for the various operations required by the pneumatic rabbit controller, the PDP-9 computer, and the Canberra 8100 analyzer (Table 4).

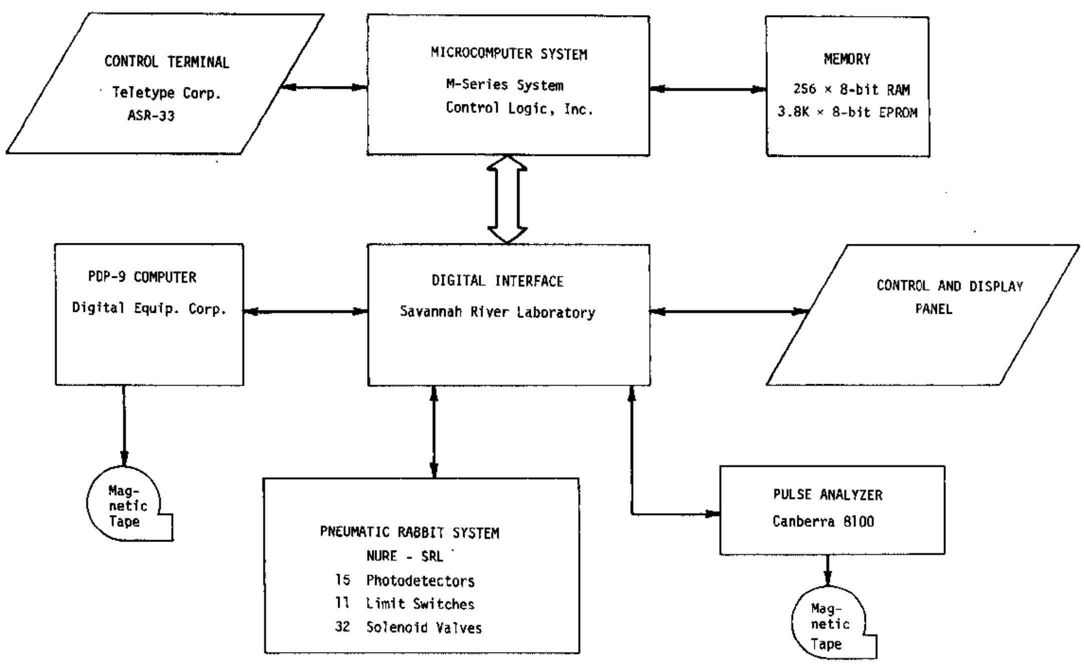


FIGURE 3. Block Diagram of Major Hardware for the NURE Rabbit Controller

TABLE 2

M-Series Logic Modules in Hardware for the NURE Rabbit Controller

Quantity	*Model*	*Description*
1	MCP-893	Central processing unit
1	MIM-894	Memory and input/output control
1	MDM-895	Data bus - multiplexer
1	MPI-810	Priority interrupt control
1	MCC-814	Console control
2	LDD-503	Device decoder
1	LTI-513	Teletypewriter interface
1	LRC-531	Real time clock
1	LRM-597	256-byte RAM
8	LRM-596	512-byte EPROM
5[a]	LRM-598	1K-byte RAM
1	CGI-540	System instrument cage (powered)

a. Used only during system development. Not permanently installed.

TABLE 3

Microcomputer Signals

Signal Name	*Description*
AØØ - A15	Address bus, 15 bits, 64K address
DIØ - DI7	Input data bus, 8 bits
$\overline{\text{IOØ}}$ - $\overline{\text{IO17}}$	I/O select lines, 16 bits, each line to select a group of 16 I/O pulses
$\overline{\text{OUTS}}$	Low pulse when output instruction is being executed
$\overline{\text{INS}}$	Low pulse when input instruction is being executed
DØ - D7	Output data bus, 8 bits

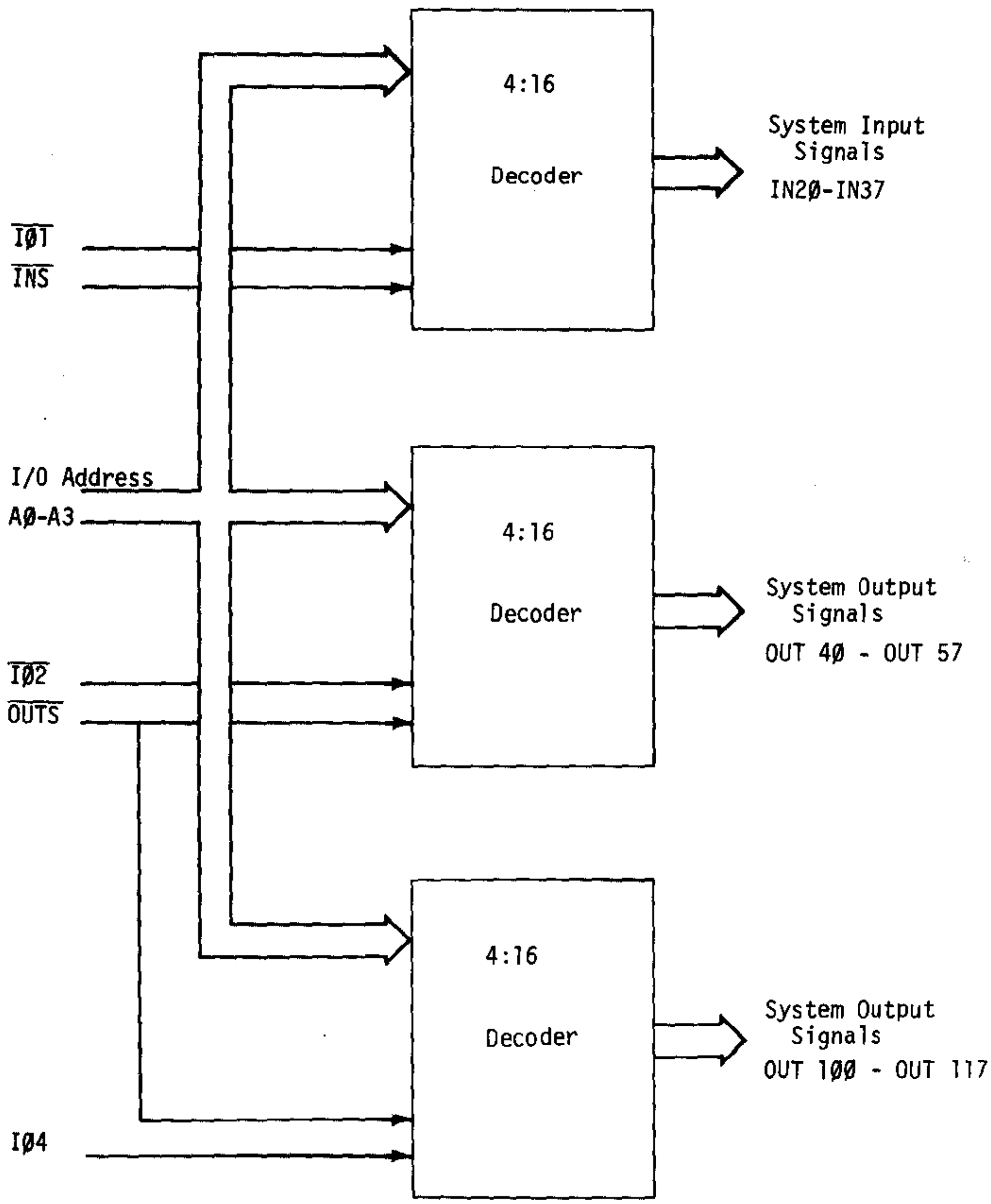


FIGURE 4. Input/Output Decoders

TABLE 4

Input/Output Commands

Signal Name	*Program Instruction Mnemonic*	*Description*
IN 2Ø	IN 2Ø	Inputs 8-bit word PD1 (photodetector status)
IN 21	IN 21	Inputs 8-bit word PD2 (photodetector status)
IN 22	IN 22	Inputs 8-bit status word, LS3 (status of limit switches for diverter valves)
IN 23	IN 23	Inputs 8-bit status word, LS4 (status of limit switches for loader and unloader)
IN 24	IN 24	Inputs 8-bit word STW5 (PDP-9 Canberra status)
IN 25	IN 25	Inputs 8-bit word PDT1 from PLA (photodetector test)
IN 26	IN 26	Inputs 8-bit word PDT2 from PLA (photodetector test)
IN 27	IN 27	Inputs 8-bit word TBL (abort status)
IN 3Ø - IN 37	-	Spare input pulses
OUT 4Ø	OUT 4Ø	Outputs pulse CLPD1 to clear PD1 status word
OUT 41	OUT 41	Outputs pulse CLPD2 to clear PD2 status word
OUT 42	OUT 42	Outputs pulse CLTBL to clear TBL status word
OUT 43	OUT 43	Outputs starting address to PLA register
OUT 44	OUT 44	Outputs pulses to solenoid driver latches
OUT 45 - OUT 46	-	Spare output pulses
OUT 47	OUT 47	Outputs PI (program interrupt) at D1 to PDP-9; PID1 pulse
OUT 5Ø	OUT 5Ø	Outputs PI at irradiation chamber to PDP-9; PIRIC pulse
OUT 51	OUT 51	Outputs PI to PDP-9 at the beginning of Regime C; PIC pulse
OUT 52	OUT 52	Outputs PI to PDP-9. Chamber full - PIF pulse
OUT 53	OUT 53	Auxiliary PI to PDP-9
OUT 54	OUT 54	Outputs pulse to panel light
OUT 55 - OUT 56	-	Spare output pulses
OUT 57	OUT 57	Outputs clear pulse to PDP-9 interrupt flags
OUT 1ØØ	OUT 1ØØ	Sets real time clock frequency
OUT 1Ø1	OUT 1Ø1	Outputs pulse SD2C to start D2 counter to collect
OUT 1Ø2	OUT 1Ø2	Outputs clear pulse CLD2 to D2 memory
OUT 1Ø3	OUT 1Ø3	Outputs pulse to panel wait indicator lamp
OUT 1Ø4	OUT 1Ø4	Outputs pulse SD2IO to start D2 I/O mode
OUT 1Ø5	OUT 1Ø5	Outputs SD2DS to start D2 display mode

Transporting rabbits to various locations in the system required the activation of 32 pneumatic valves controlled by electrical solenoids. The firing order of the valves had to be easily programmable in the prototype system. Six 256 x 8-bit EPROMs were connected in a programmable logic array (PLA). The address input to the PLA is latched into an 8-bit register when the output instruction OUT 43 is executed by the microcomputer program (Figure 5). Output data from four EPROMs in the PLA provide central signals to 32 flip-flops that drive the solenoids. The solenoids are activated by an OUT 44 instruction in the program (Figure 6). The remaining two EPROMs of the PLA provide two 8-bit status words, PDT1 and PDT2, that are input to the microcomputer during the IN 25 and IN 26 instructions (Figure 7). These status words constitute a testing sequence to trace the rabbits through the system with photodetectors.

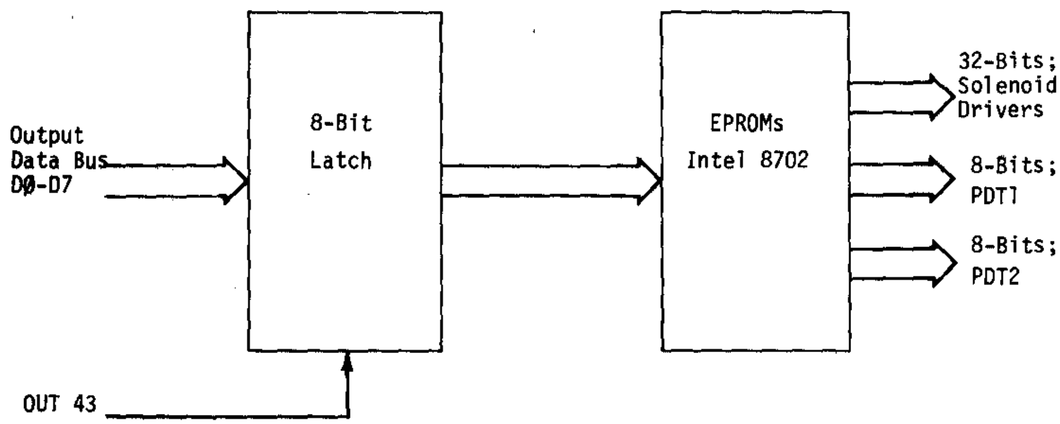


FIGURE 5. Programmable Logic Array

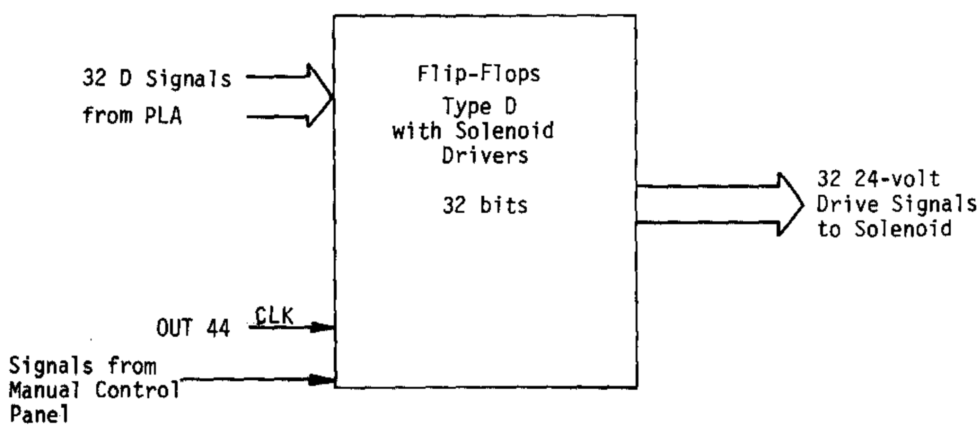


FIGURE 6. Output from Solenoid Drivers

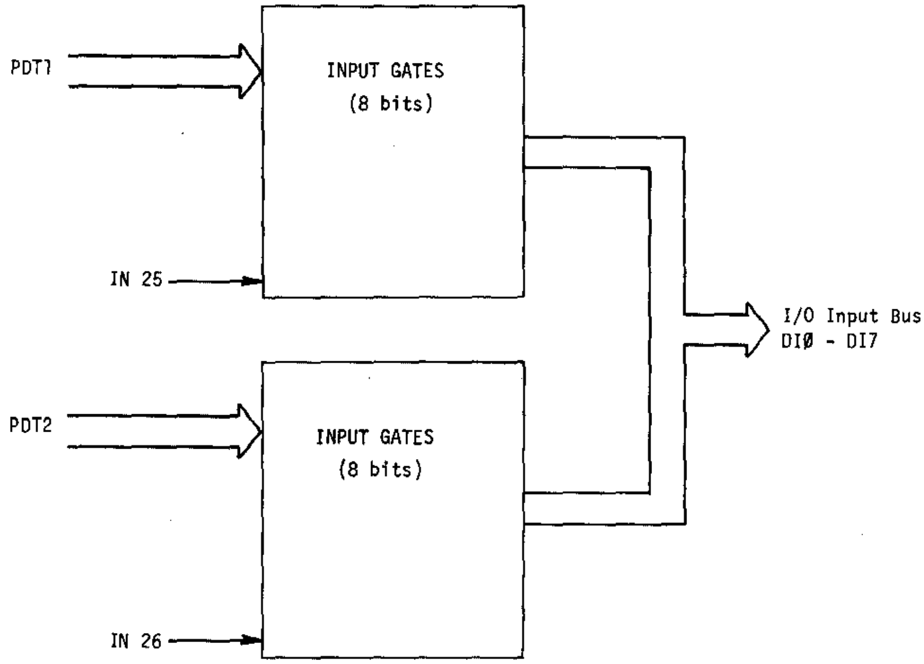


FIGURE 7. Input for the Photodetector Test

Two additional 8-bit input status words LS3 and LS4 are read by the microcomputer during instructions IN 22 and IN 23; they indicate the positions of pneumatic switches in two diverter boxes (Figure 8). As the rabbit is transported through the tubes, photodetectors transmit pulses that are latched in two 8-bit flip-flop registers (Figure 9). The photodetector status words PD1 and PD2 are read by IN 20 and IN 21 instructions; the registers may be cleared by OUT 40 and OUT 41 instructions.

Several conditions in the process — low air pressure, loss of power, high temperature, etc. — call for an abort operation. An 8-bit status word TBL is read by the program with IN 27 instructions. The TBL latches may be cleared with OUT 42 instructions (Figure 10).

The NURE Rabbit Controller was interfaced to the PDP-9 computer that functions primarily as an analyzer at detector position D1 in the pneumatic process. Also, control signals were connected to a Canberra 8100 analyzer at detector position D2. An 8-bit status work STW5 is read by IN 24 and cleared by OUT 57 (Figure 11). The microcomputer sends four program interrupt requests to the PDP-9; these must be acknowledged by the PDP-9 before the controller can continue its logical sequence (Figure 12). Four output signals command the modes of the Canberra analyzer (Figure 13); its status is tested by the microcomputer in STW5.

A manual control panel overrides the automatic functions in the NURE Rabbit Controller (Figure 14). Status indicator lamps aid in troubleshooting faults in the system.

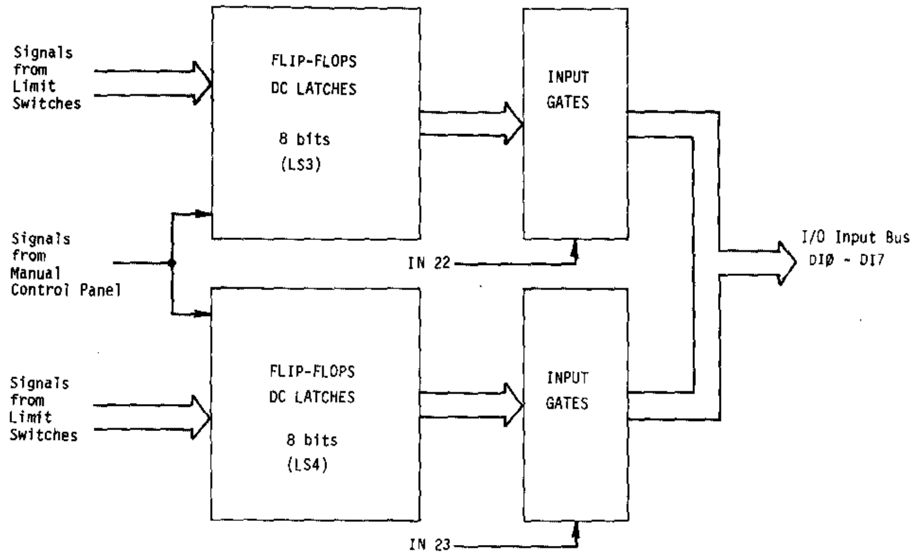


FIGURE 8. Input for Limit Switches

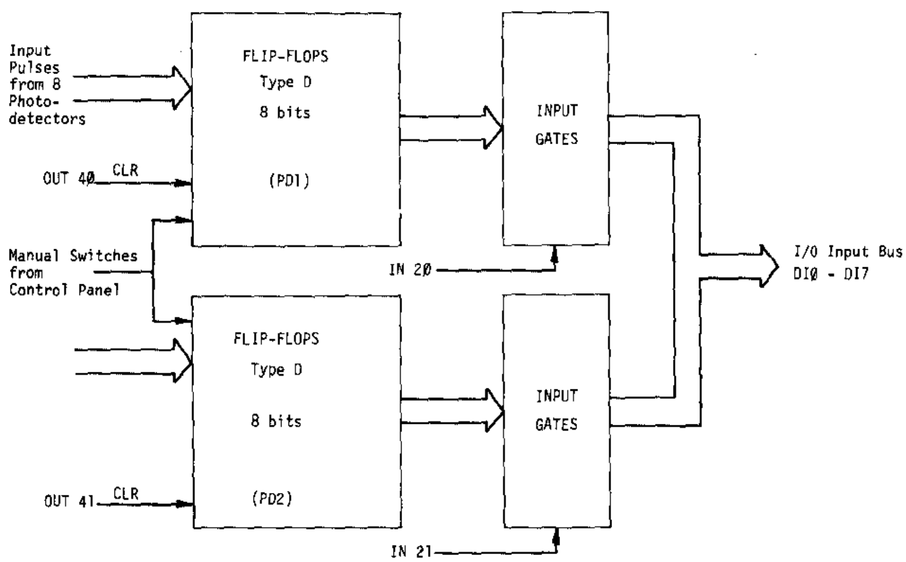


FIGURE 9. Input for Photodetectors

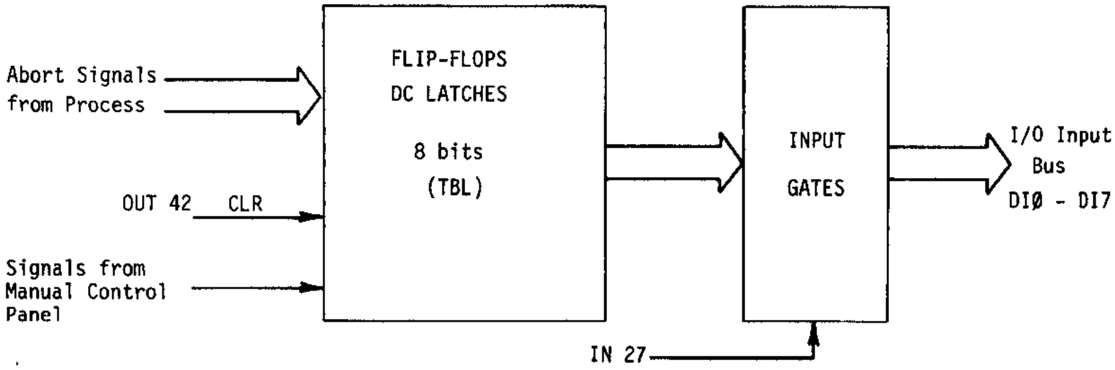


FIGURE 10. Input for Abort Status

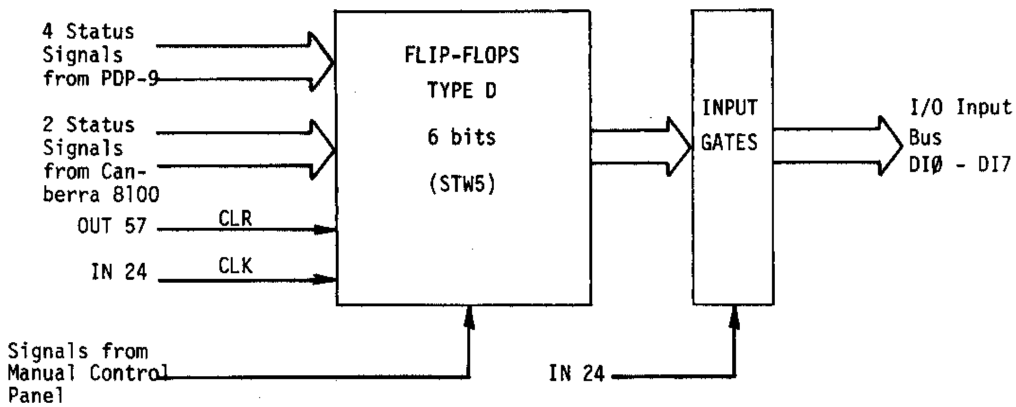


FIGURE 11. Status Input from PDP-9 Computer and Canberra 8100 Analyzer

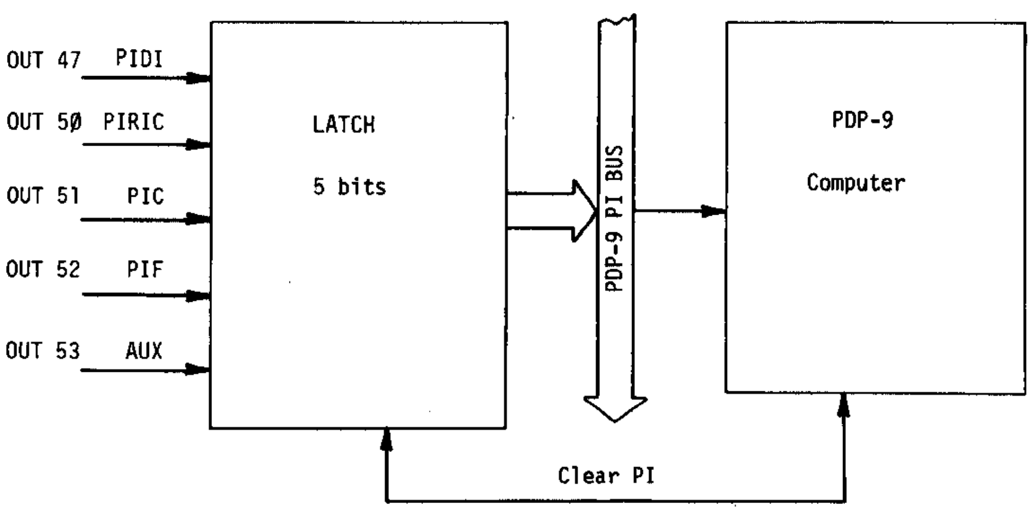


FIGURE 12. Program Interrupt Connections to PDP-9 Computer

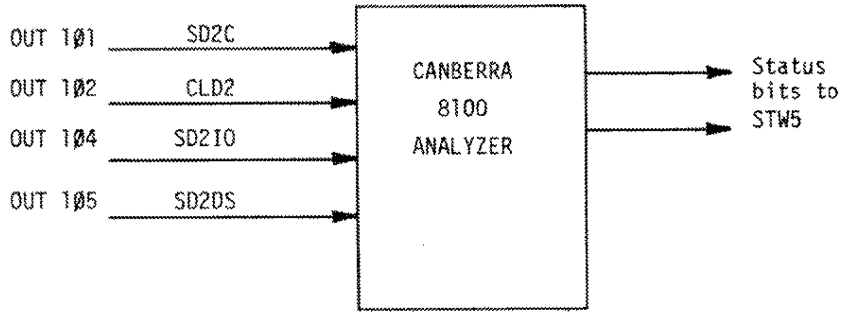


FIGURE 13. Connections to Canberra 8100 Analyzer

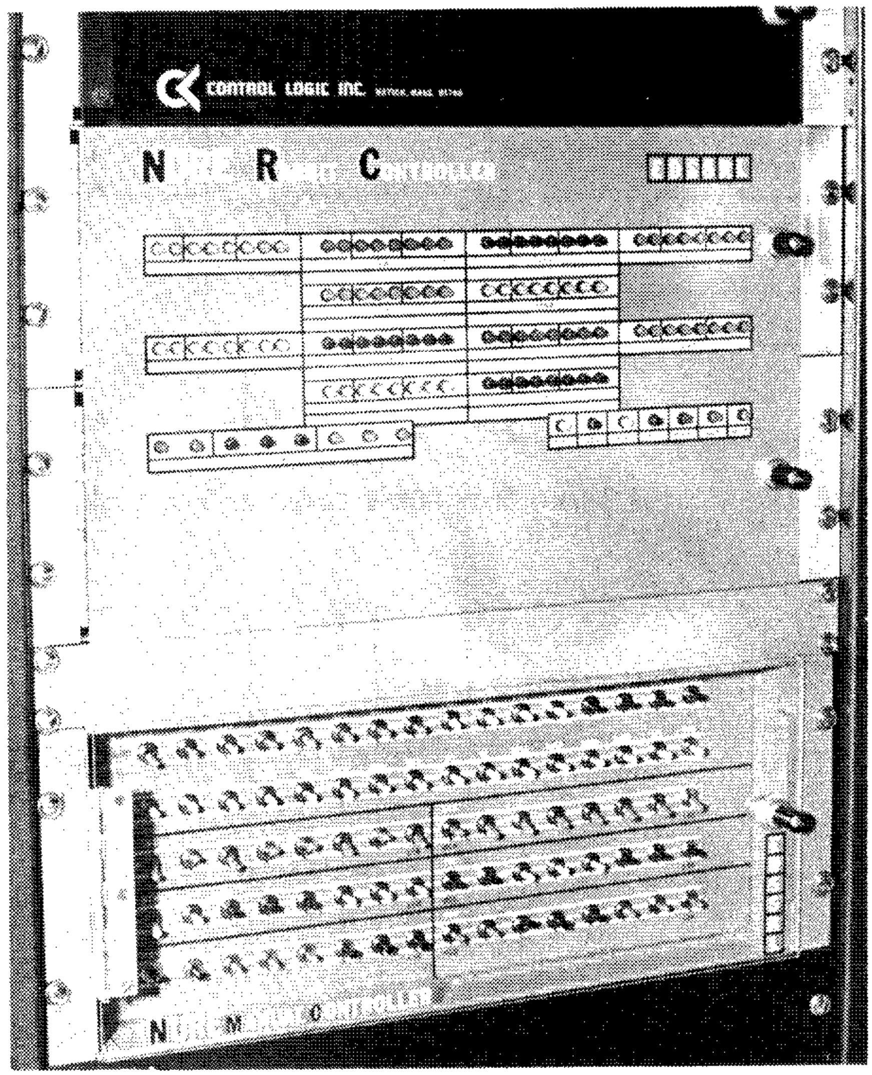


FIGURE 14. Control and Indicator Panels on NURE Rabbit Controller

Firmware

The M-series microprocessor that forms the hardware of the NURE Rabbit Controller operates from programmed instructions in the form of either software or firmware. For full operation, the controller must operate from firmware to prevent power failure or unintentional operator commands from inadvertently altering instructions.

In the controller firmware program (Appendices A and B), subroutines perform basic operations such as checking photodetectors for sample rabbit passage or accelerating or decelerating a rabbit. These basic operations are called by more specific subroutines (such as moving a rabbit from one location to another). These subroutines are ultimately called by the main program, which provides for a particular type of analysis.

Because the mechanical and pneumatic aspects of the system require much more operating time than do the electronics of the controller, program tests of limit switches and photodetectors acknowledge that mechanical motions have been completed. However, if some operation should fail to complete within a certain time, the action is assumed to be incomplete. Timing sequences in the program provide for malfunction messages, status registers, and pointers if the system should fail.

The time base in the system is changed under program control to be compatible with the use, whether the program is timing a mechanical motion or waiting for irradiation times to elapse.

The NURE Rabbit Controller, when started, identifies itself and enters a Wait routine which identifies itself as shown below:

NURE RABBIT CONTROLLER

WAITING

004 012

The numbers on the third line show the location within the program from which the Wait subroutine was called. With a program listing, the operator can determine the location of the next instruction to be executed if the Wait subroutine should execute a normal return instruction. In this case, the instruction would be page 4_8 location 12_8. These numbers are obtained by a stack dump subroutine (SPD) which extracts the information from the processor pointer stack. Because the pointer SPD is also a subroutine, it must go back two subroutine pointers in the stack to obtain useful information. It uses global *Teletype* handlers to output the information.

The message routine which types the word messages on the *Teletype* is a general-purpose routine which requires only the location in memory where the message is stored. As the routine types the message, it searches for an end character to terminate the operation.

The Wait routine is a general-purpose routine which forms the operating system of the NURE Rabbit Controller. With it, parameters for system operation are set, working registers are zeroed, and the various operating modes of the controller are executed. Parameters, such as number of samples and cycles in an analysis sequence, are entered as decimal numbers after the parameter to be entered is identified with a one or two character command.

One function of the Wait routine is to specify which irradiation tubes are being used. The reactor irradiation chamber has six irradiation tubes. The control center module is designed to be connected to any four of these tubes. The NURE rabbit controller program also permits the use of any number of the four tubes to which it is connected; therefore, the system can continue operation if some of the tubes are not functioning.

The subroutine BCD (binary coded decimal) converts decimal numbers entered as parameters to binary numbers as used in the controller. BCD will convert any decimal integer up to 9999 to a 2-byte binary number (8 bits/byte). Once entered, this subroutine will attempt to load a decimal number until a valid number is loaded. That is, if an illegal character, such as a letter, or too many numbers such as 5 digits, are entered, that load is aborted. A question mark is typed, and the subroutine starts over to await the correct number.

The main subprograms of the NURE Rabbit Controller are:

Regimes A, B, and C

Regime D

Examine Tubes

Examine Counters

Single Sample Irradiation and Count

Regime A generally controls the movement of the sample, including loading a sample from the loader tube, moving it to the reactor for a short irradiation, and returning it from the reactor to determine the presence of an undesirable high radioactivity level (Figure 1). The PDP-9 MOSES system (Monitoring Online System for Elemental Separations) determines radioactive content of samples. The PDP-9 then notifies the NURE Rabbit Controller to either reject the sample as too radioactive or continue the analysis with Regime B. A radioactive sample is immediately discharged to the unloader where it is shielded from operating personnel.

Regime B consists of longer irradiation times and shorter count times repeated for a number of cycles. The PDP-9 computer determines radioactive content of samples. At the end of Regime B, the sample rabbit is returned to the reactor for a prolonged irradiation of Regime C. The irradiation time is governed by operating parameters such as number of cycles in Regime B and the number of tubes in use. This results from the rabbit being left in the reactor until all tubes have been used, a rabbit has been deposited in each, and the need to use the tube again arises. Regime C is terminated by moving the rabbit to a Canberra 8100 multichannel analyzer and leaving the rabbit there to be counted while the next new rabbit is started through its analysis. When the Canberra is again needed, the rabbit is unloaded, and the next one is placed in the Canberra analyzer.

After Regimes A, B, and C, Regime D is separately executed for long counts on the previously analyzed rabbits. The radioactive samples from Regime A are in the unloader tube with the other rabbits, and the operator does not sort the samples.

Regime D is capable of operating either or both detector stations. Before this regime can begin, information is required concerning which detectors will be used and how many samples will be analyzed. The regime then operates with the PDP-9 to transport rabbits and operate the Canberra analyzer, as programmed. The Canberra must have the appropriate count time preset before Regime D can begin. If a sample was too radioactive to complete Regimes A, B, and C, the PDP-9 notifies the NURE Rabbit Controller to immediately unload the sample rabbit.

The program to examine the tubes is designed to test all parts of the system by moving a rabbit to and from all points in the system. The NURE Rabbit Controller completely controls this operation.

During the program to examine the counters, a known source rabbit is moved from the loader to the PDP-9; it is counted and then moved to the Canberra analyzer. The Canberra analyzer determines the radioactive level in the standard source, and the rabbit is unloaded.

The single sample irradiation and count program is structured to determine irradiation capabilities of the system. Known rabbit samples are irradiated for operator-determined intervals and counted by either the PDP-9 or the Canberra analyzer. These rabbits are then unloaded.

At the end of each of the main programs, control is returned to the operating system WAIT of the NURE Rabbit Controller from which any program can be excecuted or any parameter can be changed.

The octal debugging technique program supplied by Control Logic, Inc., also resides in the firmware. Some of its general handlers are used by the NURE Rabbit Controller, and the octal debugging technique itself is used to troubleshoot any program changes and some hardware problems.

Basic Operating Principles

The following basic criteria were used in designating the NURE Rabbit Controller: all valves will, in their normal position, provide for proper cooling of the system without undue expenditures of compressed air. Dual photodetectors are used in the transport of rabbits to and from the reactor to ensure detection and to allow operation after the failure of one of the pair. The actual transport of the rabbit consists of a primary firing action to move the rabbit from its origin to the photodetectors at its destination. The photodetectors are positioned a short distance from the end of the tubes. When the rabbit passes these photodetectors, a braking action slows the rabbit to cushion its impact at the end of the tube. After a preset time, all transport valves are returned to their normal position to complete the four-step transport cycle. This cycle includes a step to position diverter paths.

Photodetector check points are used to determine rabbit position. At the reactor irradiation chamber and at the PDP-9 detector station D1, photodetectors are dual assemblies. All other points are single assemblies. The routines PDK1 (reactor irradiation chamber) and PDK2 (central control module) use the programmed logic array to determine the proper detectors to be checked. The routine then checks the photodetector register for a nonzero condition which shows whether a rabbit has passed a photodetector. If this does not occur within 5 seconds after the routine is entered, the system assumes a failure, dumps all photodetectors and limit switch registers.

If the nonzero condition does occur within 5 seconds, the routines must determine whether the proper photodetectors were triggered. Because the photodetectors are constructed in line with the transit tubes, the rabbit takes a period of time between passing the first and second one. The detector routines must allow for this time lapse before determining whether the rabbit position is correct. If the photodetectors are not all correct, the condition of the photodetector at the time of departure from the routine is stored to be dumped at the end of the rabbit transit.

Transport subroutines are used to handle the actual movement of the rabbits by the NURE Rabbit Controller. The system has two basic areas: the RIC and the CCM. Three basic paths exist for rabbit movement:

CCM → RIC	T21
RIC → CCM	T12
CCM → CCM	T22

The CCM → CCM path is handled by Subroutine T22. This subroutine is used for loading rabbits, moving rabbits to counters, or unloading rabbits. A transport sequence consists of four steps for valve actuation: position, start, cushion, and stop. The transport routine obtains sequence address locations, clears the photodetector register, and activates the first valve sequence. The first sequence positions the diverter path and verifies the diverter positions. The second sequence moves the rabbit. The routine then verifies departure of the rabbit by calling the appropriate photodetector routine. After departure is verified, the routine must allow the trailing end of the rabbit to clear the photodetector assembly before further action is taken. Then, the photodetector register is cleared to await arrival of another rabbit, the transport sequence address is incremented to set valves to be actuated for braking, and the photodetector routine is called to watch for the rabbit. When the rabbit arrives, the braking is initiated, and the rest of the sequencing is concluded. After the rabbit is halted, the transport routine checks the photodetector error registers and, if an error has occurred, dumps error information in the following form:

DP1	$PD2_1$	$PD2_2$
XXX	XXX	XXX

where XXX is the octal representation of the 8-bit photodetector register.

PD1 is the photodetector register made up of photodetectors in the RIC. PD2 is made up of photodetectors in the CCM. $PD2_1$ indicates the first time in the CCM, and $PD2_2$ indicates the second. For example, with Subroutine T22, $PD2_1$ is the departure and $PD2_2$ is the arrival.

Transport Subroutine T21 is used to transport rabbits from the CCM to the RIC. In this case, PD1 is arrival and $PD2_1$ is departure. Likewise, in Subroutine T12 (RIC → CCM), PD1 is departure and $PD2_1$ is arrival. Any register which was correct for the trip is indicated by a zero register.

The T12 and T21 subroutine in the reactor irradiation chamber automatically notify the PDP-9 of a rabbit entering or leaving the RIC. The program interrupt PIRIC is issued after the rabbit passes the RIC photodetectors.

Tables for Determining State of NURE Rabbit Controller

The following tables are useful for determining the state of NURE Rabbit Controller from the front panel.

Table 5: Operation Table. STAD, the mnemonic for the PLA address register, identifies the operation being attempted or most recently completed. STAD numbers in the table are the octal representation of the 8-bit register on the controller panel. The format of the table and PLA is such that for a given address the state of all solenoids is defined. Usually in blocks of four states each, the table can be interpreted as follows: STAD 27. Address 27 provides information to position the diverters for a path from reactor irradiation chamber tube W to GeLi detector D1. EA is the path for diverter one as specified in the vendor documentation; EC is the path for diverter two. The state of the diverter limit switches is identified by PLA word 5. STAD 30 identifies which solenoids must be activated so that the rabbit can be moved. PLA word 5 now identifies the photodetectors which should actuate. STAD 31 identifies solenoids to operate for cushioning after the photodetectors formatted in PLA 6 are activated. STAD 32 returns all solenoids to their normal positions to stop the rabbit propulsion.

Table 6: PLA Bit States. Table 6 is the actual bit specifications to achieve the proper solenoid operation. Table 6C also determines whether PLA words 5 and 6 are to be used as test words with limit switches or photodetectors. Table 6D specifies (in octal) the coding for the internal PLA EPROMs.

Table 7: Status Word Bit Descriptions. The status word bit descriptions are listed in Table 7. PD is an acronym for photodetectors, LS is for limit switches, and PS is for pressure switches.

Table 8: Status Words and Program Interrupts in External Electronics. Table 8 lists the input signals from the PDP-9 and Canberra analyzers which are input with STW5. The program interrupts to the PDP-9 are also listed.

Table 9: Canberra Communications. The microprocessor signals to and from the Canberra are listed in Table 9.

Table 10: Input/Output Commands. Input/output commands, as added to Control Logic M-Series processor, are listed in Table 10. Acronyms used in the program listing comments are identified.

Table 11: L596 Card Jumpers. Table 11 identifies firmware PROM cards as to where pages are located.

Table 12: Reactor Irradiation Chamber Cross Reference. Table 12 is a cross reference between the 6 reactor tubes and the 4 tubes that the NURE Rabbit Controller handles. Any one of the reactor tubes can be used for any one of the 4 controller tubes. This permits spare tubes to be connected to the needed positions.

Table 12 allows correlation between identification W, X, Y, and Z from the NURE Rabbit Controller to the reactor irradiation chamber and identification of RT1, RT2, RT4, RT5, and RT6 from the actual hardware tube.

Table 13: Manual Operations. Table 13 is a chart to permit manual operation of the pneumatic system. Each four-way diverter has two solenoids. In this table, the solenoid states for a desired path are shown, the function of necessary valves are defined, and the necessary valve states to move a sample rabbit along the chosen path are given. Figure 15 is a layout diagram which will aid in selecting the proper sequences.

TABLE 5

Operation Table

STAD	*Operation*	*Path*	*Path for Diverter One*	*Path for Diverter Two*
0	Normal position of all solenoids		X	X
1	Load loader		X	ED
2	Unused		X	X
3	Position diverters	L → D1	X	ED
4	Send	L → D1	X	ED
5	Cushion	L → D1	X	ED
6	Stop	L → D1	X	ED
7	Position	D1 → RICW	EA	EC
10	Send	D1 → RICW	EA	EC
11	Cushion	D1 → RICW	EA	EC
12	Stop	D1 → RICW	EA	EC
13	Position	D1 → RICX	EB	EC
14	Send	D1 → RICX	EB	EC
15	Cushion	D1 → RICX	EB	EC
16	Stop	DI → RICX	EB	EC
17	Position	D1 → RICY	EC	EC
20	Send	D1 → RICY	EC	EC

(continued)

TABLE 5, continued

STAD	*Operation*	*Path*	*Path for Diverter One*	*Path for Diverter Two*
21	Cushion	D1 → RICY	EC	EC
22	Stop	D1 → RICY	EC	EC
23	Position	D1 → RICZ	ED	EC
24	Send	D1 → RICZ	ED	EC
25	Cushion	D1 → RICZ	ED	EC
26	Stop	D1 → RICZ	ED	EC
27	Position	RICW → D1	EA	EC
30	Send	RICW → D1	EA	EC
31	Cushion	RICW → D1	EA	EC
32	Stop	RICW → D1	EA	EC
33	Position	RICX → D1	EB	EC
34	Send	RICX → D1	EB	EC
35	Cushion	RICX → D1	EB	EC
36	Stop	RICX → D1	EB	EC
37	Position	RICY → D1	EC	EC
40	Send	RICY → D1	EC	EC
41	Cushion	RICY → D1	EC	EC
42	Stop	RICY → D1	EC	EC
43	Position	RICZ → D1	ED	EC
44	Send	RICZ → D1	ED	EC
45	Cushion	RICZ → D1	ED	EC
46	Stop	RICZ → D1	ED	EC
47	Position	D1 → D2	X	EA
50	Send	D1 → D2	X	EA
51	Cushion	D1 → D2	X	EA
52	Stop	D1 → D2	X	EA
53	Position	D2 → D1	X	EA
54	Send	D2 → D1	X	EA
55	Cushion	D2 → D1	X	EA
56	Stop	D2 → D1	X	EA
57	Position	D1 → U	X	EB
60	Send	D1 → U	X	EB
61	Cushion	D1 → U	X	EB
62	Stop	D1 → U	X	EB
63	Open	UNLOADER	X	EB
64	Close	UNLOADER	X	EB

TABLE 6A

PLA Bit States

	PLA 1								PLA 2							
STAD	31	32	33	34	35	36	37	38	WA	WB	WC	WD	XA	XB	XC	XD
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
31	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
35	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0
55	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 6B

PLA Bit States

	PLA 3								PLA 4							
STAD	YA	YB	YC	YD	ZA	ZB	ZC	ZD	U	L	D1A	D1B	D2A	D2B	SPR1	SRP2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
4	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0
5	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
13	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
14	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
15	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
16	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
17	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
20	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0
21	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
22	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
23	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
24	0	0	0	0	0	1	0	0	0	0	1	1	0	1	0	0
25	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
26	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
33	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
34	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
35	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
36	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
37	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
40	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
41	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
42	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
43	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
44	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0
45	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
46	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
61	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
63	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

TABLE 6C

PLA Bit States

	PLA 5 Test Word One								Compared With P = Photodetector L = Limit Switch X = Not Used		PLA 6 Test Word Two							
STAD	7	6	5	4	3	2	1	0			7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	0	← X	L →	0	0	0	0	0	1	0	0
1	0	0	0	0	0	0	0	0	X	L	0	0	0	0	0	0	1	0
2	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
3	0	1	0	1	1	0	1	0	L	X	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	X	P	0	0	0	1	0	0	0	0
5	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
6	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
7	0	1	1	0	1	0	1	0	L	X	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
11	0	0	0	0	0	0	1	1	P	X	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
13	0	1	1	0	1	0	0	1	L	X	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
15	0	0	0	0	1	1	0	0	P	X	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
17	0	1	1	0	0	1	1	0	L	X	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
21	0	0	1	1	0	0	0	0	P	X	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
23	0	1	1	0	0	1	0	1	L	X	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
25	1	1	0	0	0	0	0	0	P	X	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
27	0	1	1	0	1	0	1	0	L	X	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	1	1	P	X	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
32	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
33	0	1	1	0	1	0	0	1	L	X	0	0	0	0	0	0	0	0
34	0	0	0	0	1	1	0	0	P	X	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
36	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
37	0	1	1	0	0	1	1	0	L	X	0	0	0	0	0	0	0	0
40	0	0	1	1	0	0	0	0	P	X	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
42	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
43	0	1	1	0	0	1	0	1	L	X	0	0	0	0	0	0	0	0
44	1	1	0	0	0	0	0	0	P	X	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
46	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
47	1	0	1	0	1	0	1	0	L	X	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
51	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	1	0	0
52	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
53	1	0	1	0	1	0	1	0	L	X	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	1	0	0
55	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
56	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
57	1	0	0	1	1	0	1	0	L	X	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	X	P	0	0	0	0	0	0	1	1
61	0	0	0	0	0	0	0	0	X	P	0	0	0	0	1	0	0	0
62	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	X	L	0	0	0	0	0	1	0	0
64	0	0	0	0	0	0	0	0	X	P	0	1	0	0	0	0	0	0

TABLE 6D

Prom Coding

STAD	*PLA* 1	2	3	4	5	6
0	0	0	0	0	0	4
1	0	0	0	114	0	2
2	0	0	0	0	0	0
3	0	0	0	114	132	0
4	41	0	0	116	0	20
5	40	0	0	114	0	3
6	0	0	0	14	0	0
7	0	0	0	4	152	0
10	200	100	0	4	0	3
11	200	0	0	4	3	0
12	0	0	0	4	0	0
13	0	0	0	44	151	0
14	200	4	0	44	0	3
15	200	0	0	44	14	0
16	0	0	0	44	0	0
17	0	0	0	24	146	0
20	200	0	100	24	0	3
21	200	0	0	24	60	0
22	0	0	0	24	0	0
23	0	0	0	64	145	0
24	200	0	4	64	0	3
25	200	0	0	64	300	0
26	0	0	0	64	0	0
27	0	0	0	4	152	0
30	40	200	0	4	3	0
31	40	0	0	4	0	3
32	0	0	0	4	0	0
33	0	0	0	44	151	0
34	40	10	0	44	14	0
35	40	0	0	44	0	3
36	0	0	0	44	0	0
37	0	0	0	24	146	0
40	40	0	200	24	60	0
41	40	0	0	24	0	3
42	0	0	0	24	0	0
43	0	0	0	64	145	0
44	40	0	10	64	300	0
45	40	0	0	64	0	3
46	0	0	0	64	0	0
47	0	0	0	0	252	0
50	202	0	0	0	0	3
51	0	0	0	0	0	4
52	0	0	0	0	0	0
53	0	0	0	0	252	0
54	54	0	0	0	0	4
55	40	0	0	0	0	3
56	0	0	0	0	0	0
57	0	0	0	10	232	0
60	202	0	0	10	0	3
61	0	0	0	10	0	10
62	0	0	0	10	0	0
63	0	0	0	210	0	4
64	0	0	0	10	0	100
370					1	1
371					3	3
372					7	7
373					17	17
374					37	37
375					77	77
376					177	177
377					377	377

TABLE 7

Status Word Bit Descriptions

Status Word	*Test Word*		*Word Bit Number*	*Description*
PD1	1	PDW1	0	Reactor irradiation chamber photodetector tube W
		PDW2	1	Reactor irradiation chamber photodetector tube W
		PDX1	2	Reactor irradiation chamber photodetector tube X
		PDX2	3	Reactor irradiation chamber photodetector tube X
		DPY1	4	Reactor irradiation chamber photodetector tube Y
		PDY2	5	Reactor irradiation chamber photodetector tube Y
		PDZ1	6	Reactor irradiation chamber photodetector tube Z
		PDZ2	7	Reactor irradiation chamber photodetector tube Z
PD2	2	PD13	0	GeLi D1 photodetector
		PD14	1	GeLi D1 photodetector
		PD15	2	GeLi D2 photodetector
		PD16	3	Unloader entrance photodetector
		PD17	4	Loader exit photodetector
		PD18	5	Loader entrance photodetector
		PD19	6	Unloader exit photodetector
			7	Unused
LS3	1	LS1	0	CCM Diverter 1 limit switch DLS1
		LS2	1	CCM Diverter 1 limit switch DLS2
		LS3	2	CCM Diverter 1 limit switch DLS3
		LS4	3	CCM Diverter 1 limit switch DLS4
		LS5	4	Reactor Diverter 2 limit switch DLS1
		LS6	5	Reactor Diverter 2 limit switch DLS2
		LS7	6	Reactor Diverter 2 limit switch DLS3
		LS8	7	Reactor Diverter 2 limit switch DLS4
LS4	2	LS9	0	Loader limit switch L1
		LS10	1	Loader limit switch L2
		PS11	2	Unloader pressure switch U1
			3	Unused
			4	Unused
			5	Unused
			6	Unused
			7	Unused

TABLE 8

Status Words and Program Interrupts in External Electronics

Status Word	*Bit Acronyms*	*Word Bit Number*	*Description*
STW5	ST1	0	Start Regime B
	ST2	1	Reject sample. Start new Regime A.
	ST3	2	Continue Regime B subcycles
	ST4	3	Magtape OK
	CSA	4	Canberra Mode, Sense A
	CSB	5	Canberra Mode, Sense B
		6	Unused
		7	Unused
	Acronyms	*Hardware Pulse*	
PI	PIDI	OUT 47	PI to PDP-9. Rabbit at GeLi.
	PIRIC	OUT 5Ø	PI to PDP-9. Rabbit passing RIC photodetectors.
	PIC	OUT 51	PI to PDP-9. Regime B ending, Regime C starting.
	PIF	OUT 52	PI to PDP-9. All tubes have Regime C rabbits in.

TABLE 9

Canberra Communications

Canberra Signal		*Microprocessor Signal*
Start Collect J103	Pin 1	SD2C OUT 101
Start Input/Output J103	Pin 2	SD2IO OUT 104
Start Display J103	Pin 3	SD2DS OUT 105
Clear Memory J103	Pin 4	CLD2 OUT 102
Sense A J103	Pin 7	STW5 Bit 4 IN 24
Sense B J103	Pin 8	STW5 Bit 5 IN 24
Ground J103	Pin 5, 6	

TABLE 10

Input/Output Commands

I/O Number	*Acronym*	*Description*	*I/O Function*
20	PD1	Photodetector status word one	IN
21	PD2	Photodetector status word two	IN
22	LS3	Diverter limit switch status	
23	LS4	Loader limit switch, unloader pressure switch	IN
24	STW5	PDP-9 status word 5	IN
25	PDT1	Photodetector test word one	IN
26	PDT2	Photodetector test word two	
27	TBL	Trouble abort status	IN
40	CLPD1	Clear photodetectors one	OUT
41	CLPD2	Clear photodetectors two	OUT
42	CLTBL	Clear trouble word	OUT
43	STAD	PLA starting address	OUT
44	ACTV	Activate values	OUT
47	PID1	Program interrupt at D1 to PDP-9	OUT
50	PIRIC	Program interrupt reactor irradiation chamber to PDP-9	OUT
51	PIC	Program interrupt begin Regime C to PDP-9	OUT
52	PIF	Program interrupt full to PDP-9	OUT
53	AUX		OUT
54	SD2	NRC front panel light for detector D2	OUT
57	CLIF	Clear interrupt flags to PDP-9	OUT
100	FRQSL	Frequency select real time clock	OUT
101	SD2C	Start D2 counter collect	OUT
102	CLD2	Clear D2 memory	OUT
103		Wait light	OUT
104	SD2IO	Start D2 I/O	OUT
105	SD2DS	Start D2 display	OUT

TABLE 11

L596 Card Jumpers

L596 Cards	*Jumpers*	*Page Number*
#1	A-C	
	D-F	
	G-0	0
	H-4	4
#2	A-C	
	D-F	
	G-5	5
	H-6	6
#3	A-C	
	D-F	
	G-7	7
	H-10	10
#4	A-C	
	D-F	
	G-11	11
	H-12	12
#5	A-C	
	D-F	
	G-13	13
	H-14	14
#6	A-C	
	D-F	
	G-15	15
	H-16	16
#7	A-B	
	D-E	
	G-10	70
	H-14	74

TABLE 12

Reactor Irradiation Chamber Cross Reference

Controller Tube Components[a]	*Reactor Tubes* *RT1*	*RT2*	*RT3*	*RT4*	*RT5*	*RT6*
__A	V1	V2	V3	V4	V5	V6
__B	V13	V14	V15	V16	V17	V18
__C	V7	V8	V9	V10	V11	V12
__D	V19	V20	V21	V22	V23	V24
DP__1	PD1	PD3	PD5	PD7	PD9	PD11
DP__2	PD2	PD4	PD6	PD8	PD10	PD12

a. Where __ = either W, X, Y, or Z, and any letter W, X, Y, or Z may represent any number RT1, RT2, RT3, RT4, RT5, or RT6.

RTx	Physical reactor tube number
Vx	Valve number
PDx	Photodetector number
xA	Controller fire valve
xB	Controller exhaust valve
xC	Controller cushion valve
xD	Controller bleed valve

TABLE 13

Manual Operations

Four-way No. 1 Solenoid State

Path	*SD1A*	*SD1B*
W	0	0
X	1	0
Y	0	1
Z	1	1

Four-way No. 2

	SD2A	*SD2B*
D-2	0	0
4-Way I	0	1
Unloader	1	0
Loader	1	1

V-35	D-2 Fire Valve
V-36	D-2 Exhaust
V-37	Unloader Exhaust
V-38	Loader Fire Valve
A	Fire Valve
B	Exhaust
C	Cushion
D	Bleed

Control Center Module: Valve States

	V-31 *Fire*	*V-32* *Cushion*	*V-33* *Exhaust*	*V-34* *Bleed*
SEND	0>1	1	0	1
STANDBY	0	0	0	0
RECEIVE	0	0	1	1

Reactor Irradiation Chamber Valve States

	A *Fire*	*B* *Exhaust*	*C* *Custion*	*D* *Bleed*
SEND	0>1	0	1	1
STANDBY	0	0	0	0
RECEIVE	0	1	0	1

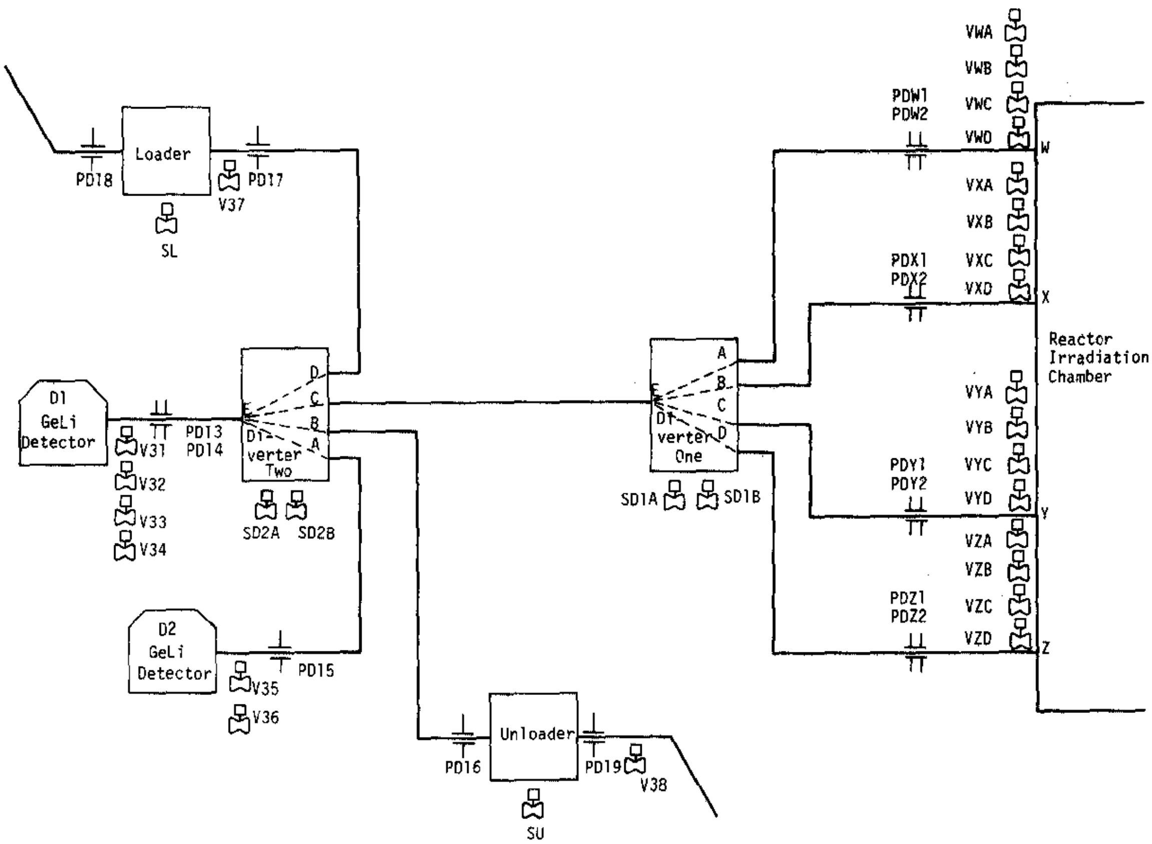


FIGURE 15. Layout Diagram of Rabbit System

NURE Commands

The commands used for the NURE Rabbit Controller are entered during the waiting portion of the program. However, the I command is used to signal the program, while it is running, that the operator wishes to gain control. The I, when typed, is not echoed.

All other commands are entered after the *Teletype* types WAITING and an address. Commands are either operation commands or number-entering commands.

Operation Commands

The operation command may be either one, two, or three characters; it requires no terminating character. Operating commands include:

A	Abort. Remove any rabbits in reactor to D1.
C	Continue at address from which the program exited.
D1Ø	Detector D1 out of use for Regime D.
D11	Detector D1 in use for Regime D.
D2Ø	Detector D2 out of use for Regime D.
D21	Detector D2 in use for Regime D.
G	Begin Regimes A, B, and C.
O	Jump to octal debugging techniques.
Ø	Zero all random access variables.
ET	Examine tubes. Run rabbit through all paths.
EC	Examine counters. Place standard in each counter.
ER1	Examine irradiation with D1. Irradiate standard and count.
ER2	Examine irradiation with D2. Irradiate standard and count.
R	Run Regime D.
W1	Set tube W in use.
WØ	Set tube W out of use.
X1	Set tube X in use.
XØ	Set tube X out of use.
Y1	Set tube Y in use.
YØ	Set tube Y out of use.

Z1	Set tube Z in use.
Z∅	Set tube Z out of use.

*Number Entry Commands**

The number-entering command can be either one or two characters followed by up to 4 decimal digits (9999_{10}) and by a terminating carriage return (CR). Number entry commands include:

Bnnnn(CR)	Number of cycles in Regime B
Snnnn(CR)	Number of samples to be run
TAnnnn(CR)	Number of seconds multiplied by 10 for Regime A irradiation**
TBnnnn(CR)	Number of seconds multiplied by 5 for Regime B irradiation**
TCnnnn(CR)	Number of seconds divided by 10 for Regime C final irradiation**
TDnnnn(CR)	Number of seconds multiplied by 1 for count time in D2
TSnnnn(CR)	Number of seconds multiplied by 1 for ER1 and ER2 irradiation

Information Required by Programs

- Single Sample Irradiation and Count

Number of seconds to be irradiated	(TS)
To execute program count in D1	ER1
To execute program count in D2	ER2

- Regime D

Number of samples to be analyzed	(S)
Detectors in use	(D1) (D2)
To execute program	R

- Examine Counters

None	
To execute program	EC

* Where n = Decimal Digit.

** Where nnnn - 255_{10} max.

- Examine Tubes

Tubes in use	(W-Z)
To execute program	ET

- Regimes A, B, and C

Number of samples to be analyzed	(S)
Number of seconds to be irradiated in Regime A	(TA)
Number of seconds to be irradiated in Regime B	(TB)
Number of seconds to be irradiated for Regime C final time	(TC)
Number of cycles in Regime B	(B)
Tubes in use	(W-Z)
To execute program	G

*Number Messages from the NURE Rabbit Controller**

Page	*Location*				*Meaning of Message*
XXX	XXX				Address to which program will return if continued
PD1	$PD2_1$	$PD2_2$			
XXX	XXX	XXX			Photodetector errors. Displays actual response which did not match desired response.
PD1	*PD2*	*LS3*	*LS4*	*STAD*	
XXX	XXX	XXX	XXX	XXX	Photodetector, limit switch, and PLA address status at time of failure to complete operation within specified time

* Where XXX is the octal value for the implied register.

System Pointers

Program Status[a]	*Program Pointer* Page	*Program Pointer* Location	*Pointer Meaning*
	4	12	System has been started from processor console card.
	4	112	Processor has received invalid status flag from PDP-9.
	4	265	Regimes A, B, and C have been completed.
C	7	154	Photodetectors in the reactor have not actuated within the allotted time.
C	7	210	An operation has exceeded the time limit set for it.
C	7	237	A diverter has not actuated within the allotted time.
C	10	20	The loader has not actuated within the allotted time.
C	10	130	Photodetectors in the CCM have not actuated within the allotted time.
C	10	160	The loader is empty for Regime A.
	11	0	Processor has received an invalid status flag from PDP-9.
C	13	50	Operator has requested control.
C	13	230	Loader is empty for Regime D.
C	13	336	Processor has received an invalid status flag from PDP-9.
C	14	202	Loader is empty for examining counters.
	14	303	Counters have been examined.
C	15	13	Loader is empty for examining tubes.
C	15	270	Pressure in line to unloader has not dropped to safe level for opening within the allotted time.
C	15	325	Rabbit has not exited unloader within the allotted time.
	16	210	Irradiation and count for a single sample have been completed.
C	16	277	Program requiring reactor tubes was started with no tubes specified.

a. The letter "C" indicates that the program can be continued after the problem is corrected.

Software

Four programs are supplied by Control Logic, Inc., for program development on the M-Series logic system: editor, 3-pass assembler, EPROM programmer, and octal debugging techniques. The octal debugging techniques are supplied on three EPROMs and contain utility routines to read binary paper tape from the *Teletype*, punch paper tapes on *Teletype*, input/output *Teletype* characters, and modify memory locations. Many of these routines are called and executed from system firmware. The other three control logic programs may be executed by replacing system firmware modules with random access memory modules and operating the M-Series system via *Teletype*.

The only Control Logic software used for the development of system firmware was the EPROM programmer. Final object tapes for firmware programs were automatically transferred to EPROMs using the M-Series system.

The firmware programs were developed offline on a PDP-8E minicomputer with disk from an OS/8 operating system.[4] A Control Logic L-Series cross-assembler for PDP-8, modified for OS/8 operation, was obtained from the University of South Carolina. It was modified at SRL to use the M-Series machine language codes.

ASCII (American Standard Code for Information Interchange) source disk files were generated by the OS/8 editor program. The source files were assembled as object (binary) disk files. Paper tapes of the object files were punched on a high-speed punch; these tapes were used to operate the M-Series logic microcomputer system.

ADVANTAGES OF THE SYSTEM

This system demonstrates the flexibility that can be attained in a complex digital system with a microcomputer. An effective hardware-software tradeoff reduces design effort and overall system cost. However, the flexibility of the programmed system could not be duplicated with a hardware-only system at any reasonable cost. Interfaces for peripherals can be designed and tested individually without a complicated hardware timing circuit. The microcomputer is programmed to handle the timing. To make minor changes in the system operation or to configure the system for an entirely different test, the firmware is altered with no major changes in the hardware. During this development, several major system changes were implemented by minimal firmware changes.

The firmware contains simple machine-language programs. That type of programming is generally done best by the design engineer who thoroughly understands the hardware. He must write simple input/output subroutines to test the hardware. Those subroutines can be called from a main program to generate the final software. After all, the programs essentially implement logical commands that the designer would normally realize with hardware. Very simple *Teletype* commands and responses were designed into the operating programs to reduce programming effort and memory requirements.

Microcomputers can be programmed to analyze results as well as collect data. This programming would involve a larger effort that normally would not be done by the design engineer. Higher-order programming languages and cross-assemblers for larger computers are available for some microcomputers. However, the system described in this report uses the microcomputer in its most cost-effective mode; that is, digital system timing and data-byte manipulations. With the microcomputer and with a mass storage output peripheral, such as the magnetic tape, the data can be analyzed efficiently offline with software on a large computer. In this system, magnetic tape outputs were generated by the Canberra analyzer and PDP-9 computer. The speed of low-cost microcomputers also limits their ability to perform all but simple real-time computations.

The hardware interface was built from standard transistor-transistor logic, integrated circuit modules plugged into a wire-wrapped sock array. We have proven that wire wrapping (Figure 16) provides the lowest cost in terms of components, fabrication, modification, and maintenance.

The system described has operated trouble-free for over six months. The microcomputer techniques described in this report apply to many other instruments for chemical controls and analysis.[5]

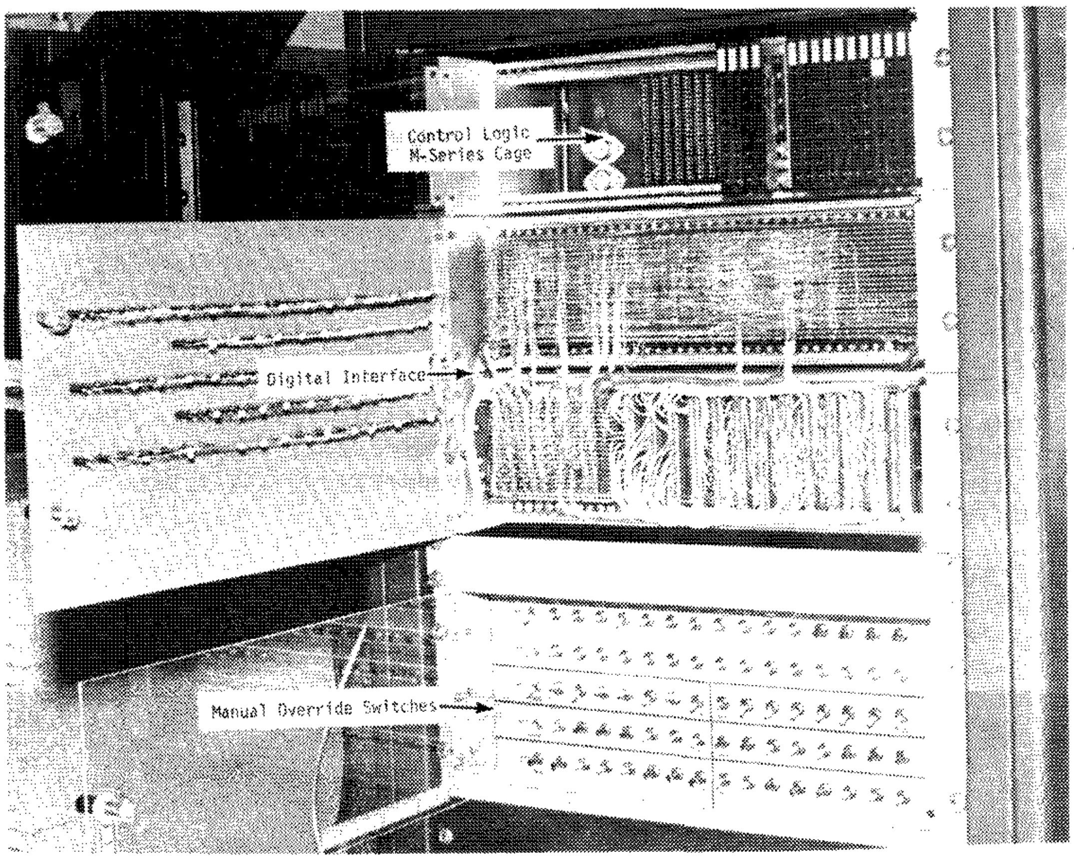


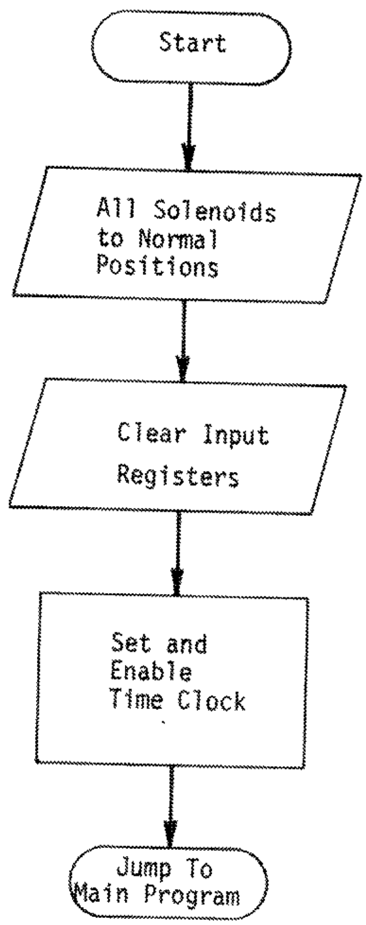
FIGURE 16. Wire Wrapping in Hardware for NURE Rabbit Controller

APPENDIX A
LOGIC OF THE PROGRAM FIRMWARE FOR THE NURE RABBIT CONTROLLER

The following flowcharts show the logic of the program firmware for the NURE Rabbit Controller. The flowcharts are arranged in the order that the routines appear in the program listing (Appendix B).

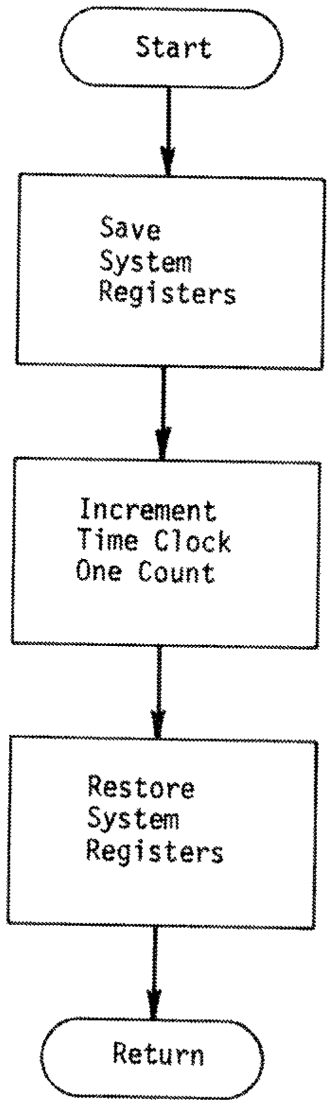
ROUTINE SYSTEM STARTUP

INITIALIZE SYSTEM



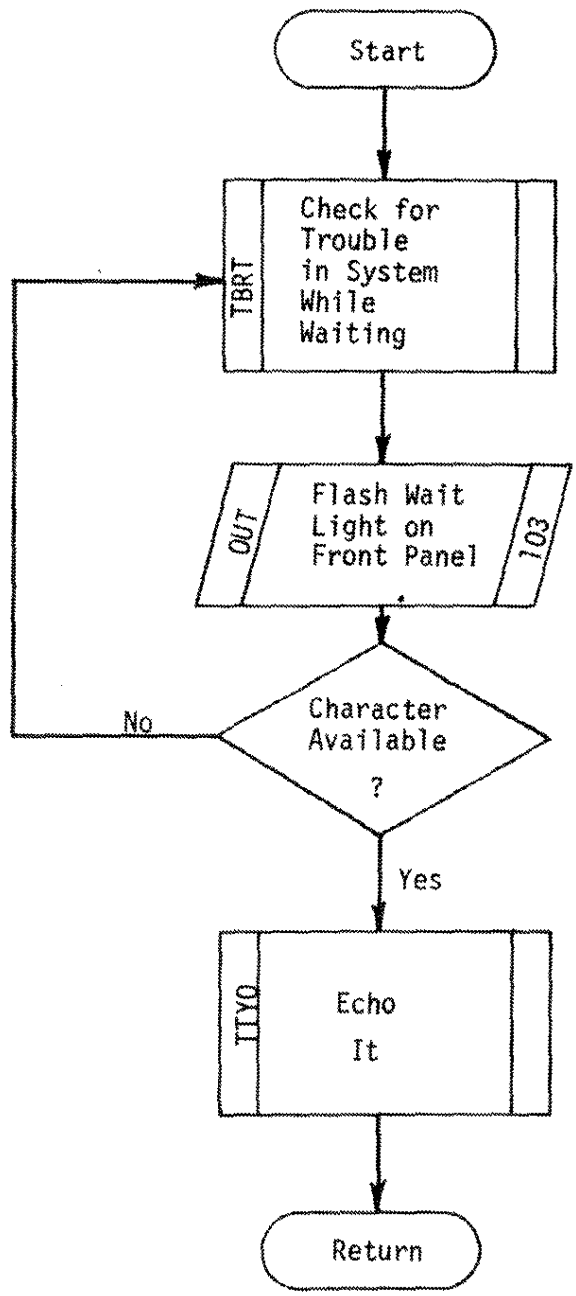
ROUTINE TIMER INTERRUPT

UPDATES TIME CLOCK REGISTERS



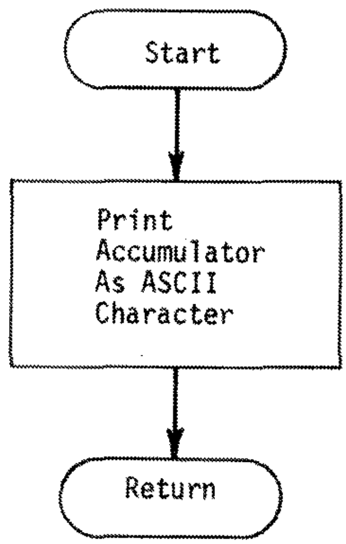
SUBROUTINE TTYI

INPUTS CHARACTER FROM TELETYPE



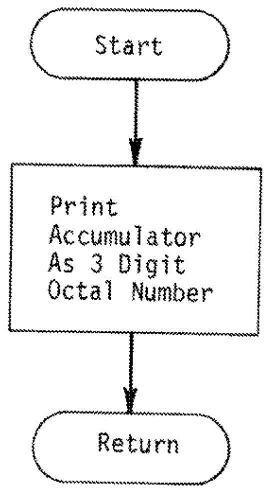
SUBROUTINE TTYO

PRINT ACCUMULATOR AS ASCII CHARACTER
(Resident in ODT)



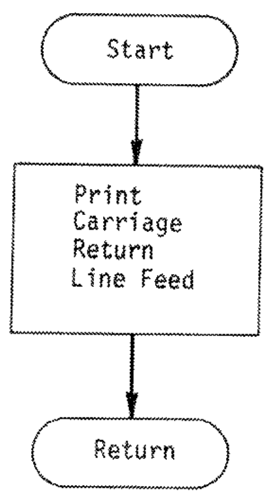
SUBROUTINE OCTO

PRINT ACCUMULATOR AS 3 DIGIT OCTAL NUMBER
(Resident in ODT)



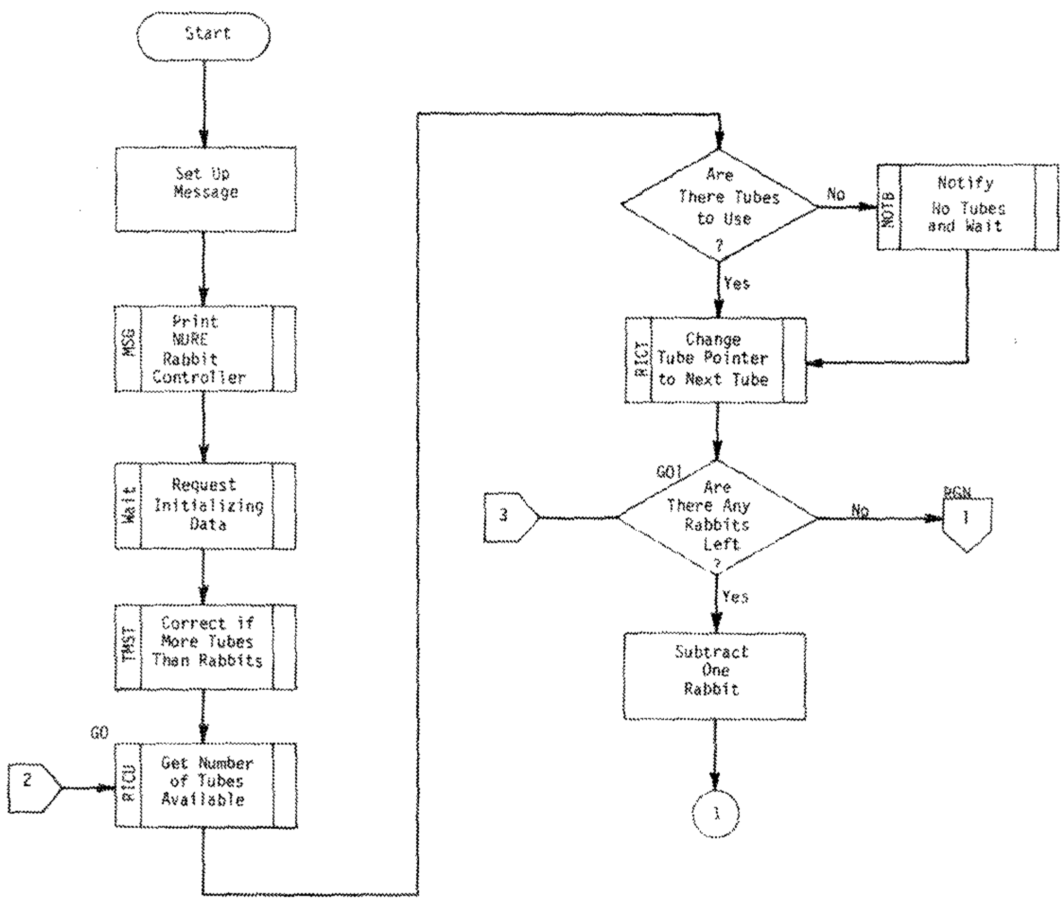
SUBROUTINE CRLF

PRINT CARRIAGE RETURN LINE FEED
(Resident in ODT)

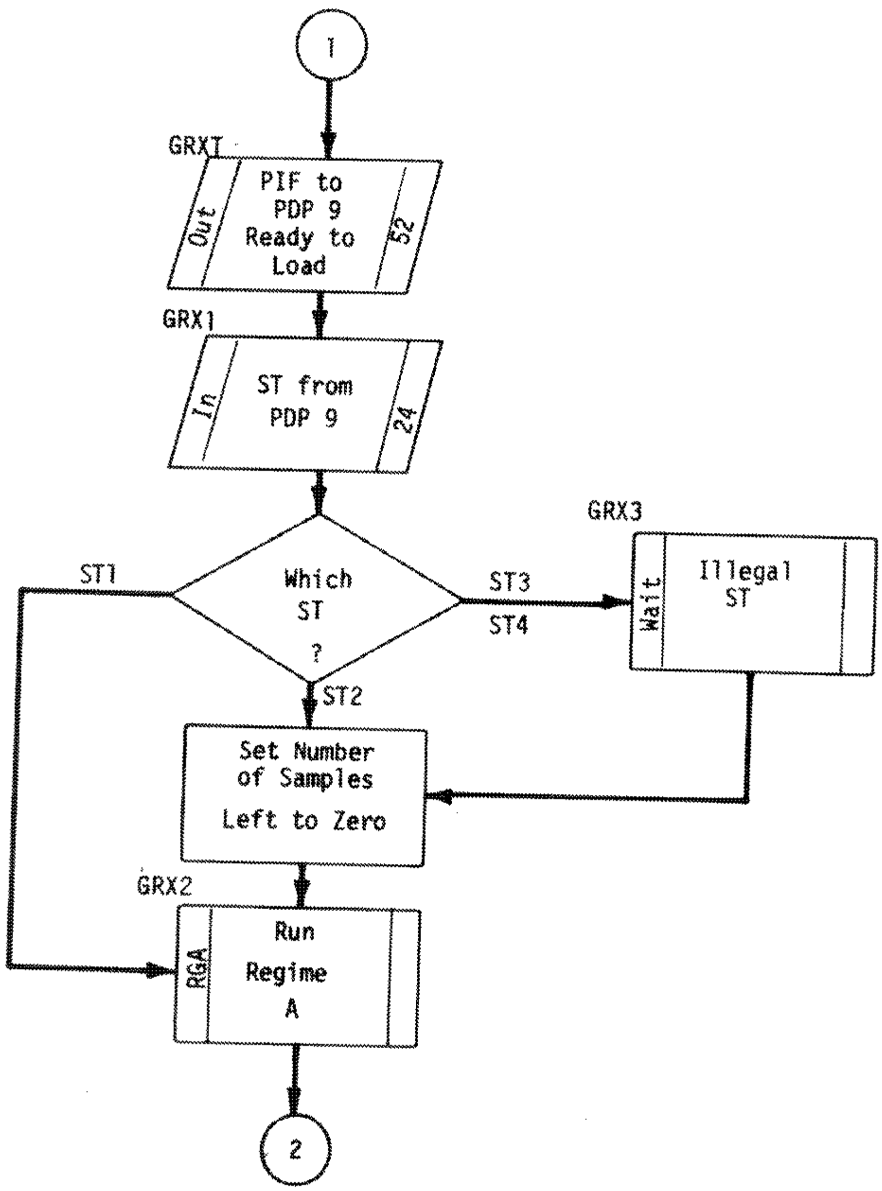


MAIN PROGRAM

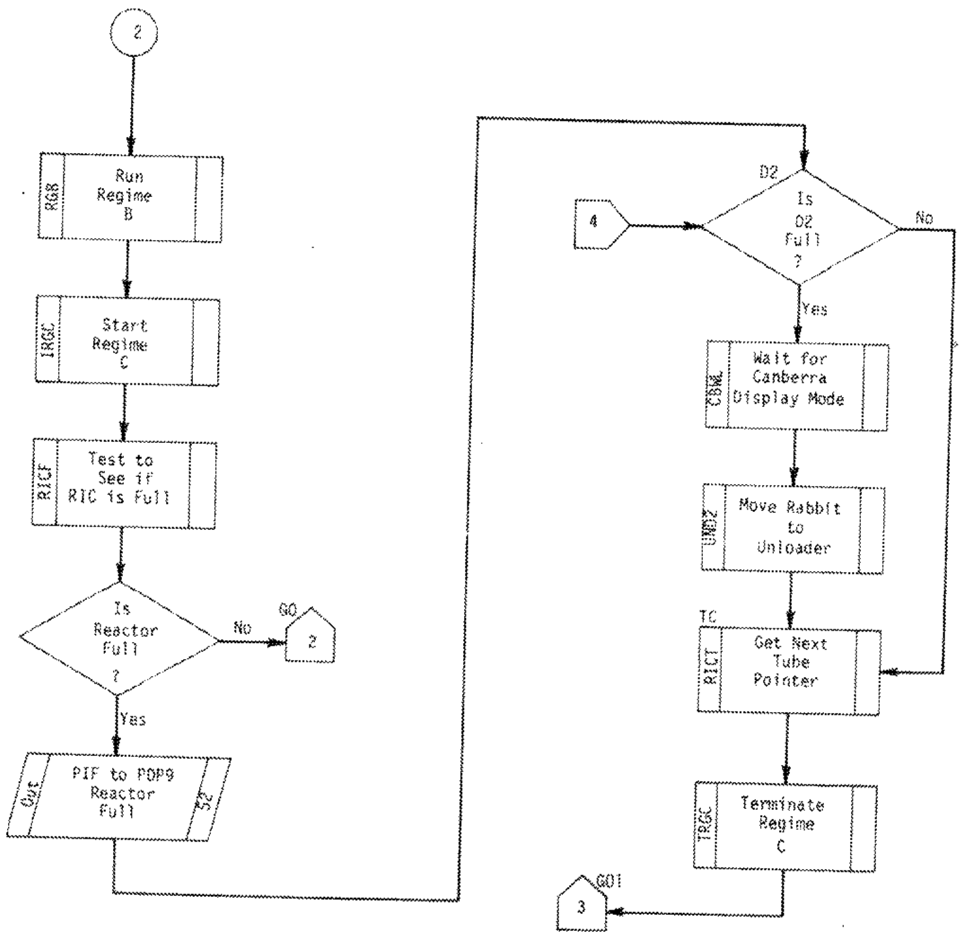
Runs Combination of Regime A B C to Analyze Rabbits



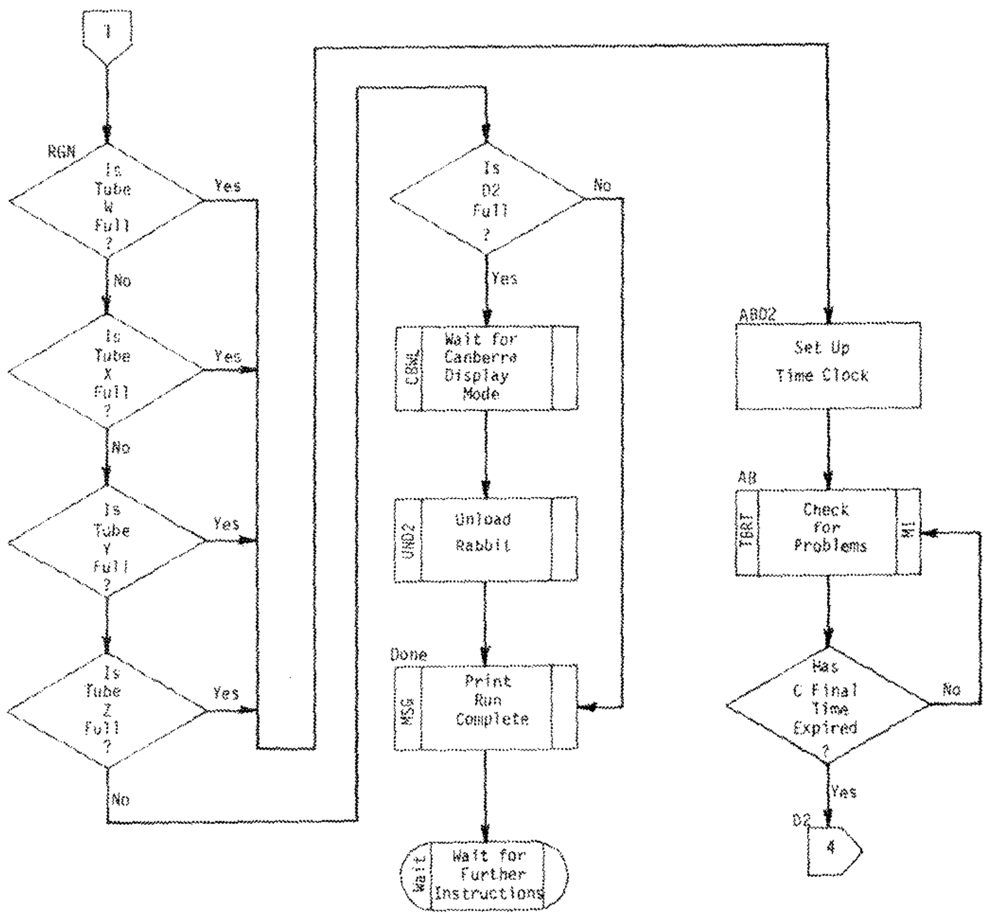
Main Program (Continuation)



Main Program (Continuation)

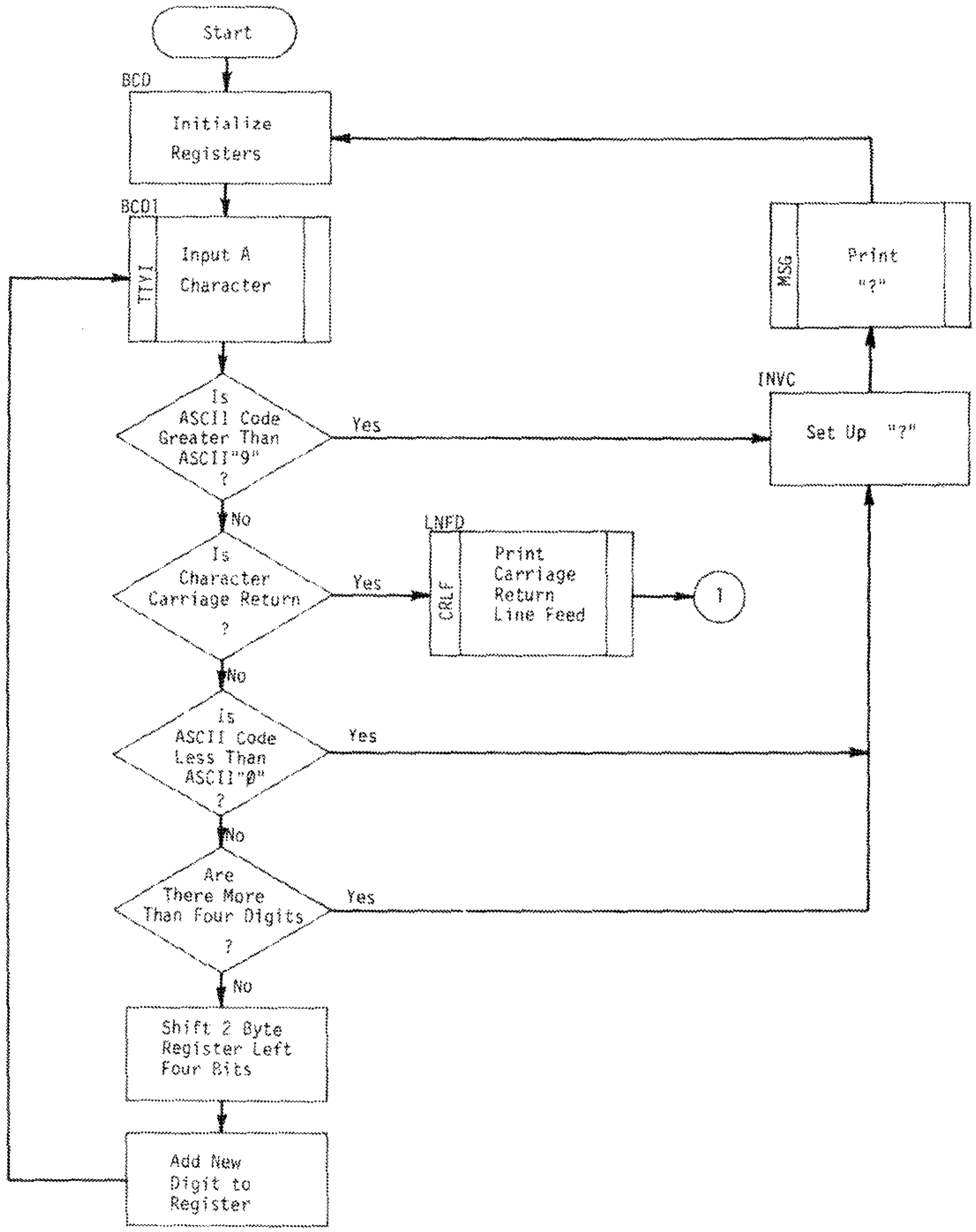


Main Program (Continuation)

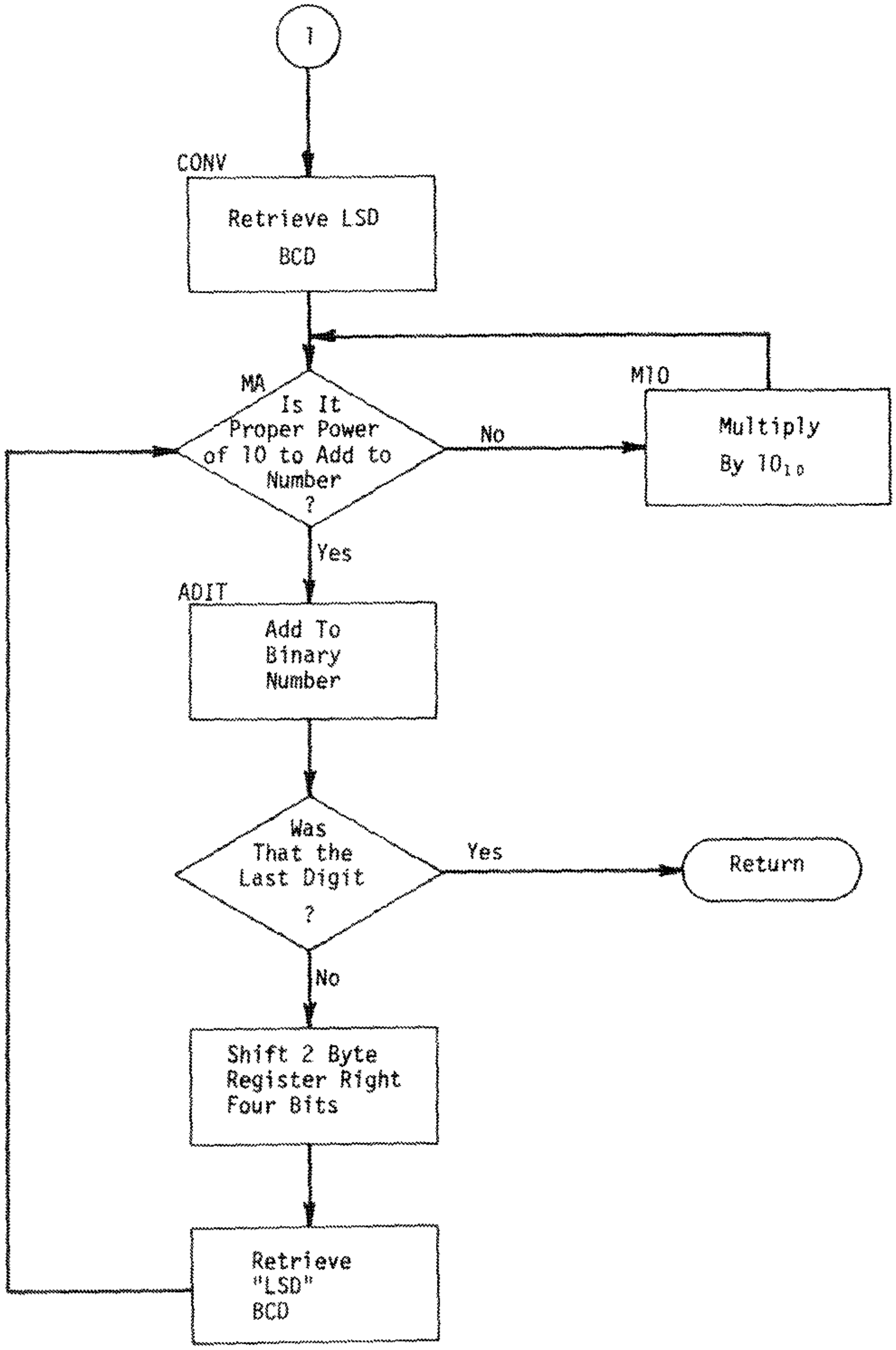


SUBROUTINE BCD

Input Up to Four Digit Decimal Number and Convert to Binary from BCD

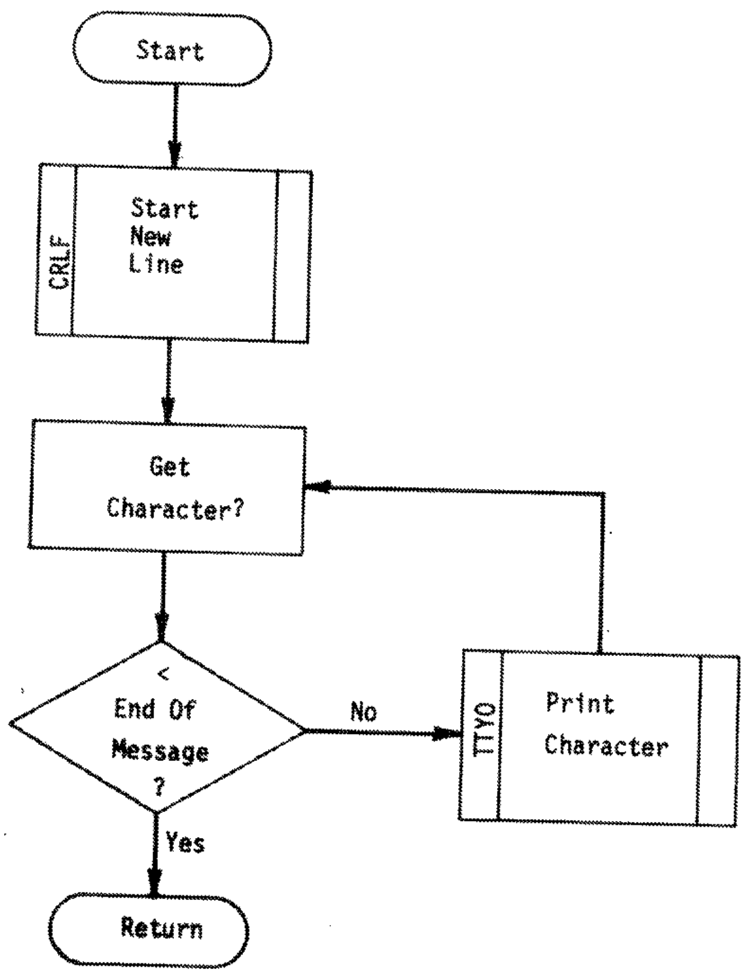


Subroutine BCD (Continuation)



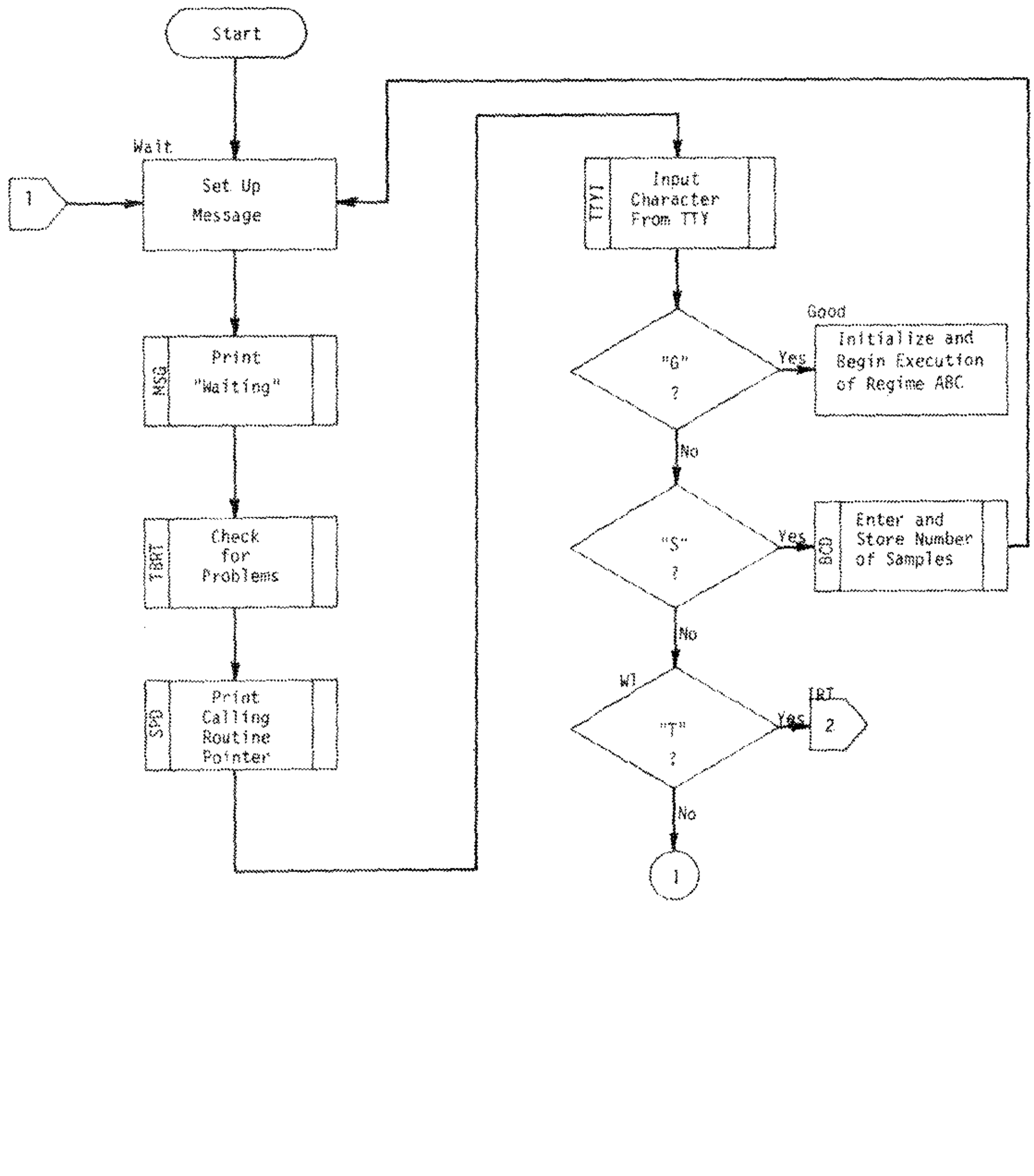
SUBROUTINE MSG

Print Message Beginning at Location Specified by HL and Ending When "<" is Reached

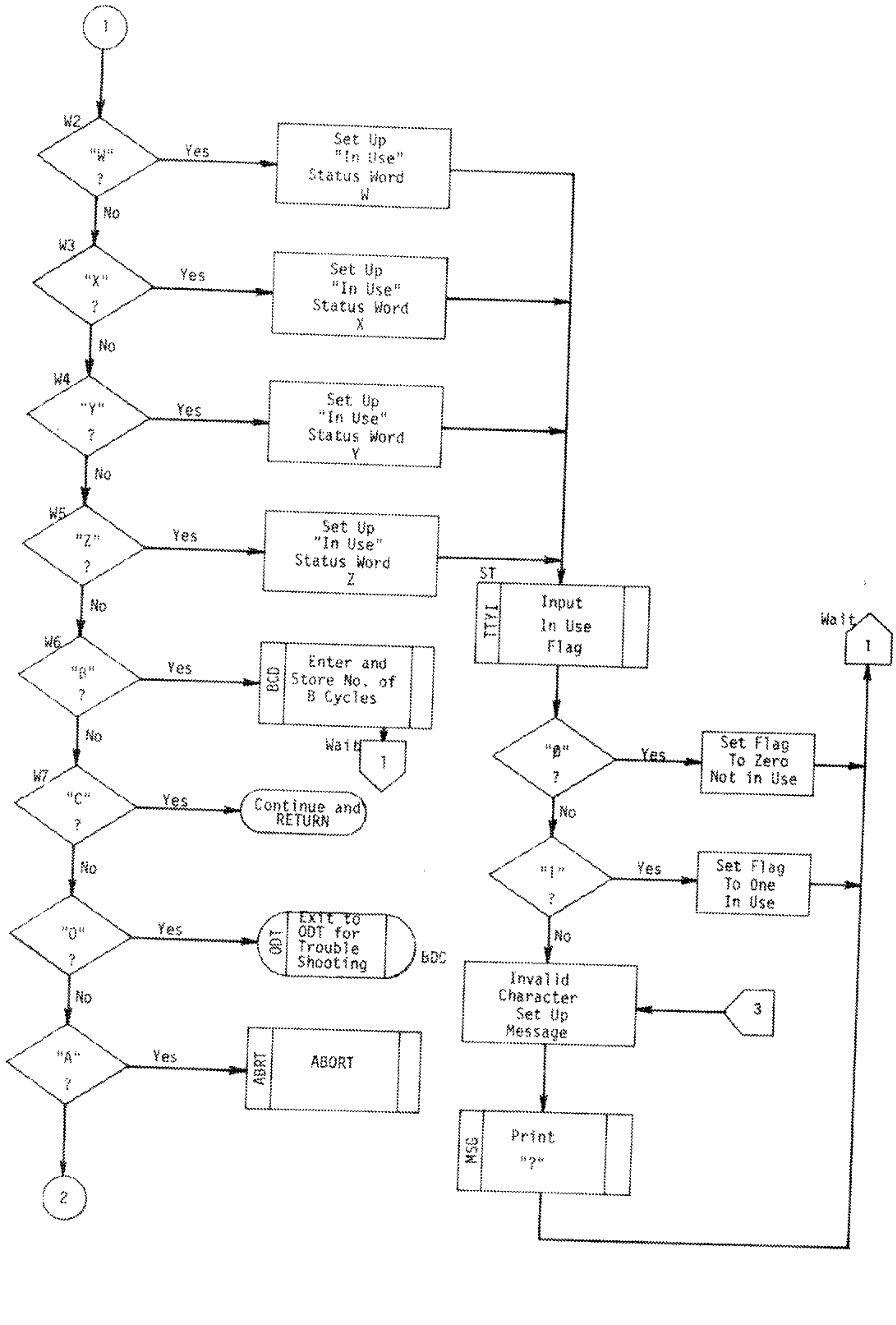


SUBROUTINE WAIT

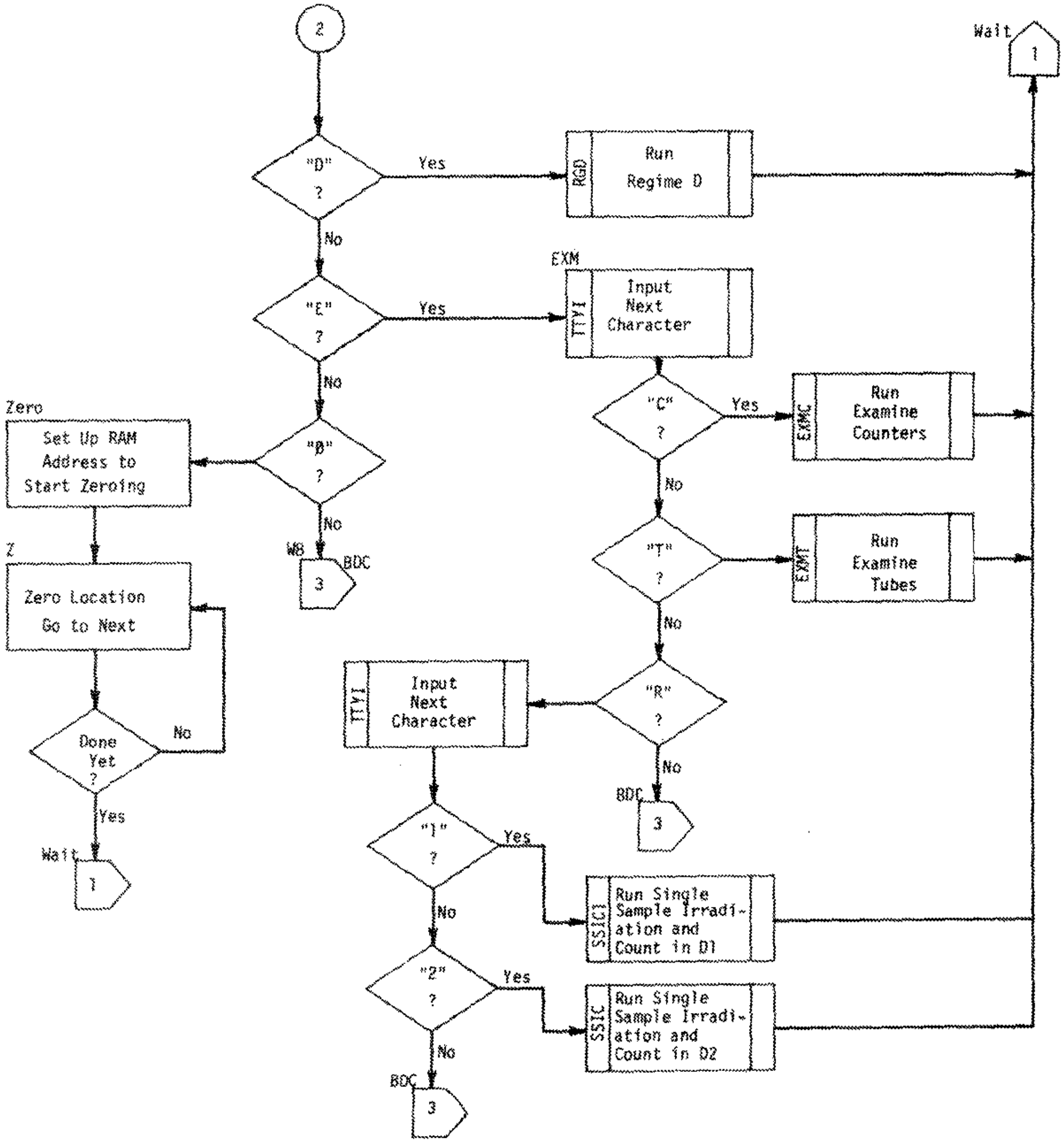
Act as Operating System of NRC. Enter or Clear Variable Parameters and Determine Operations to be Executed.

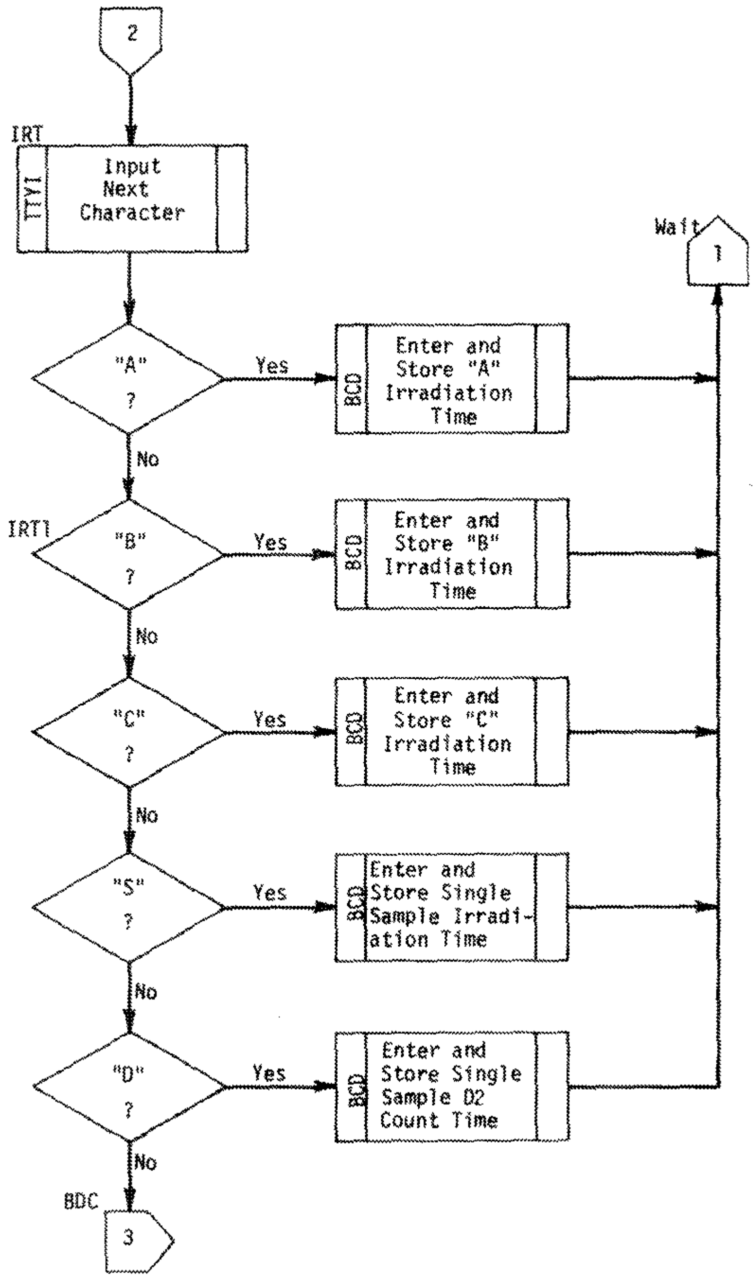


Subroutine Wait (Continuation)



Subroutine Wait (Continuation)

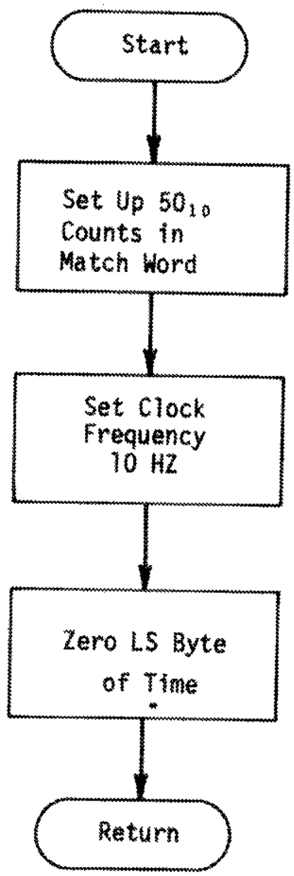




2
IRT
TTY1
Input Next Character
Wait
1
"A" ?
Yes
No
BCD
Enter and Store "A" Irradiation Time
IRT1
"B" ?
Yes
No
BCD
Enter and Store "B" Irradiation Time
"C" ?
Yes
No
BCD
Enter and Store "C" Irradiation Time
"S" ?
Yes
No
BCD
Enter and Store Single Sample Irradi-ation Time
"D" ?
Yes
No
BCD
Enter and Store Single Sample D2 Count Time
BDC
3

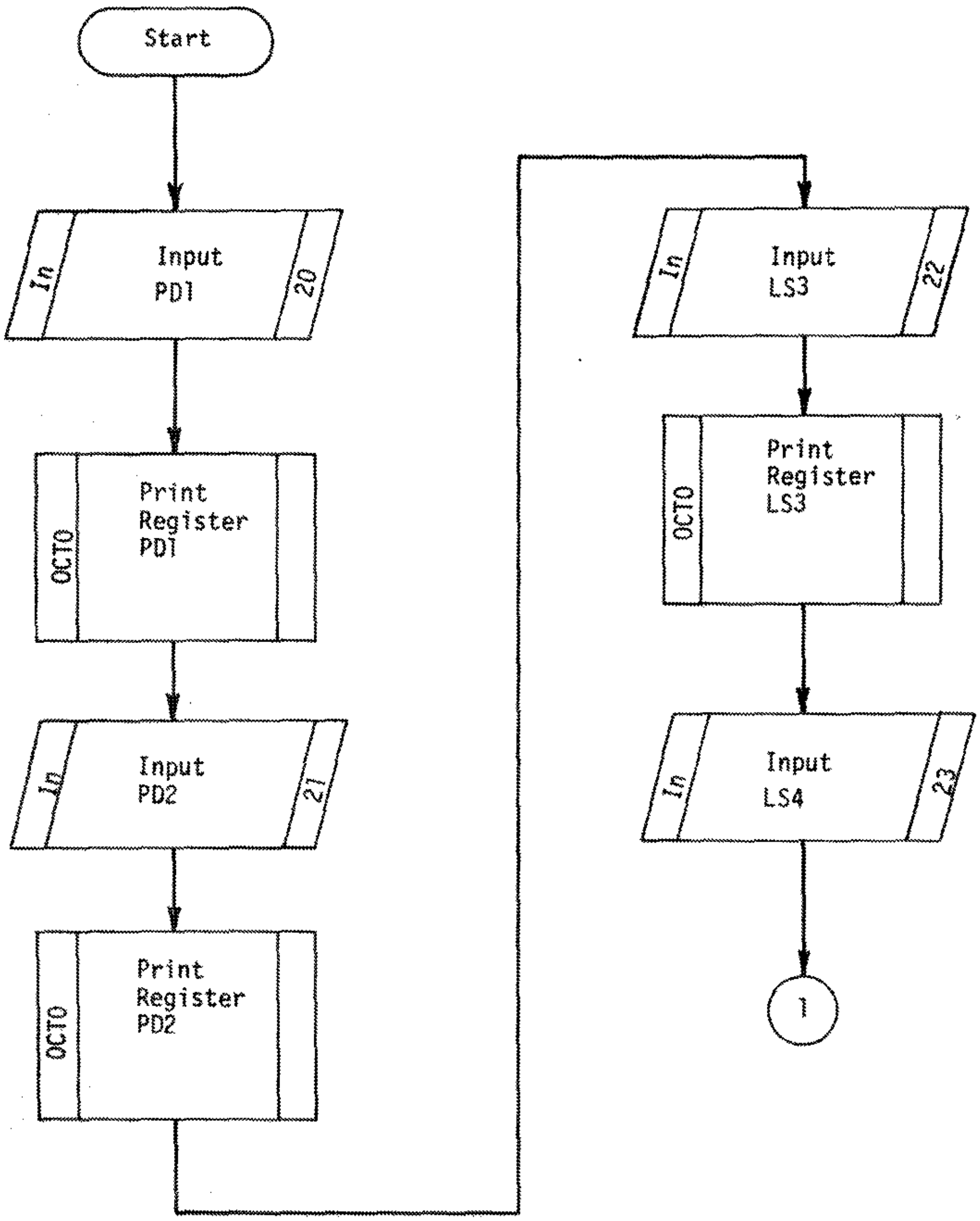
SUBROUTINE TM5

Start Time Clock and Set Up Time Check for Five Seconds

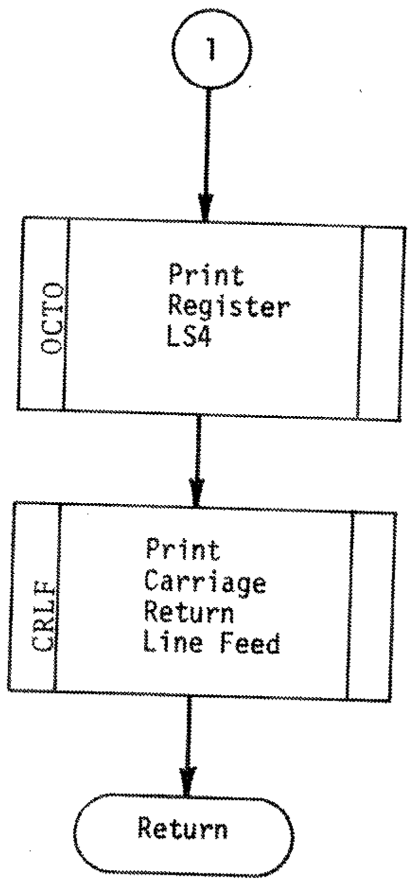


SUBROUTINE STDM

Dump Photodetector and Limit Switch Status Words

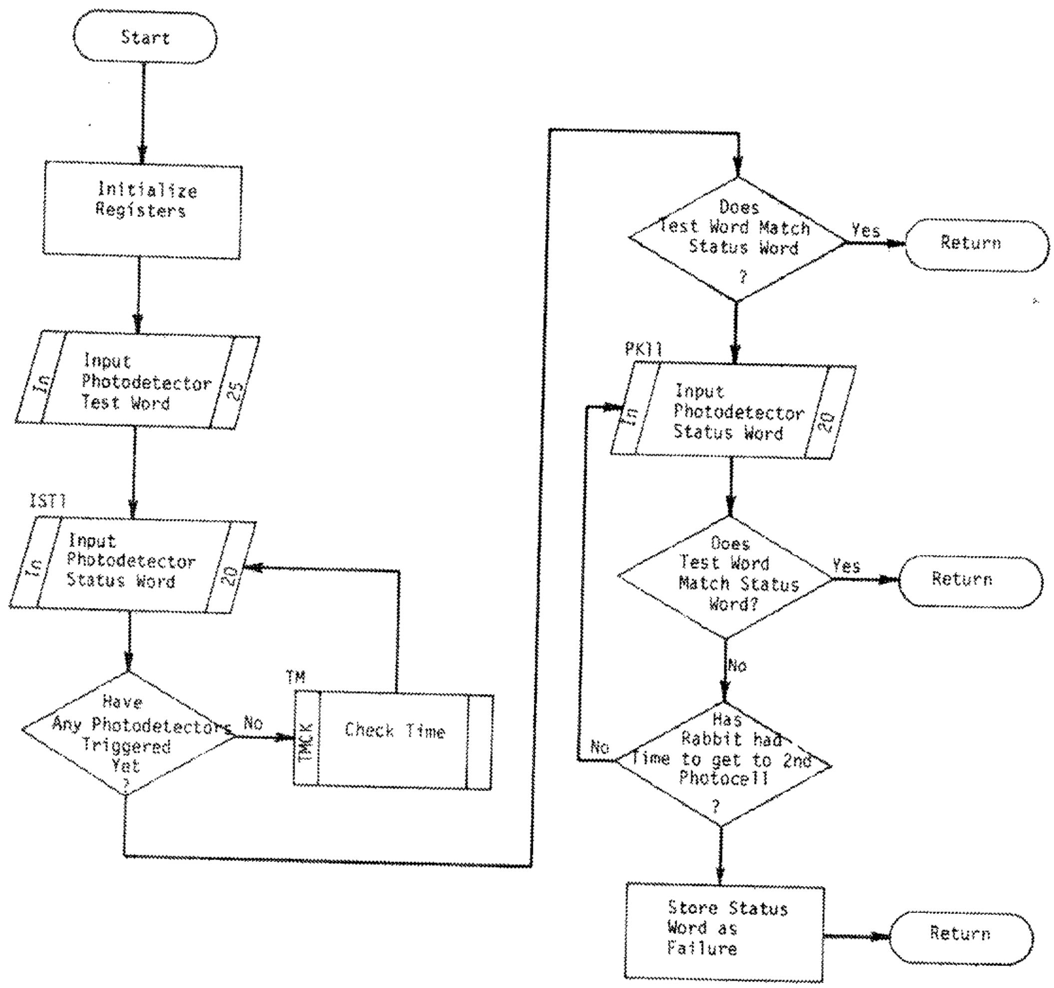


Subroutine STDM (Continuation)



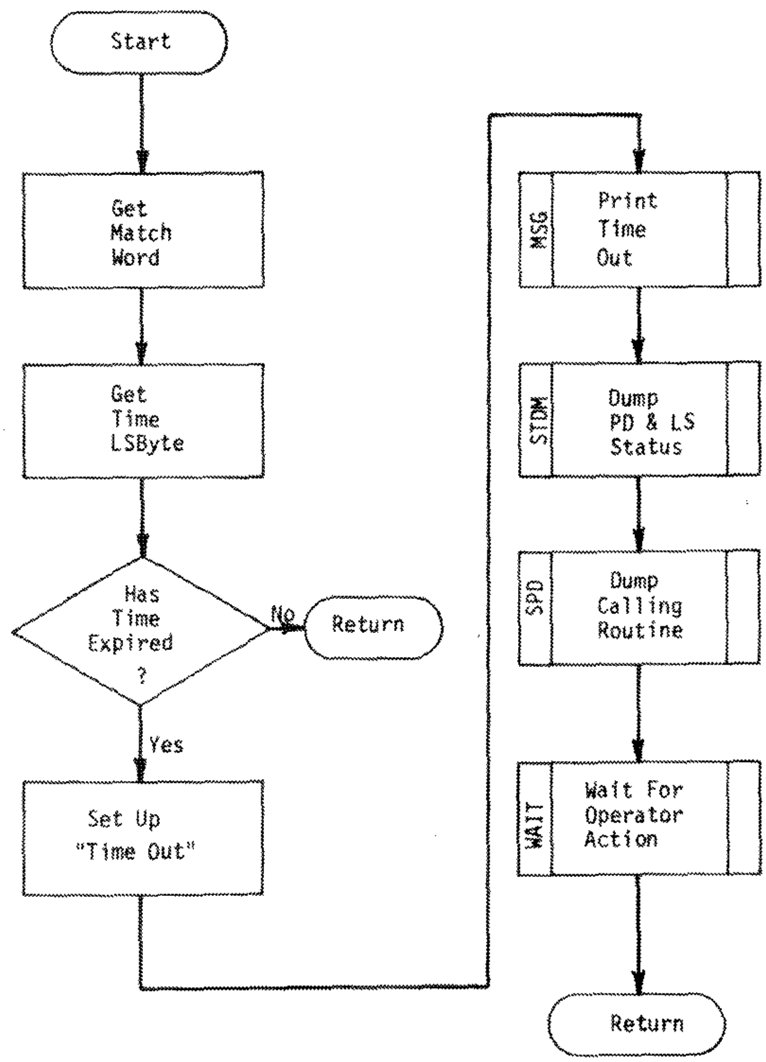
SUBROUTINE PDK1

Check Photodetectors at Reactor For Correct Actuation



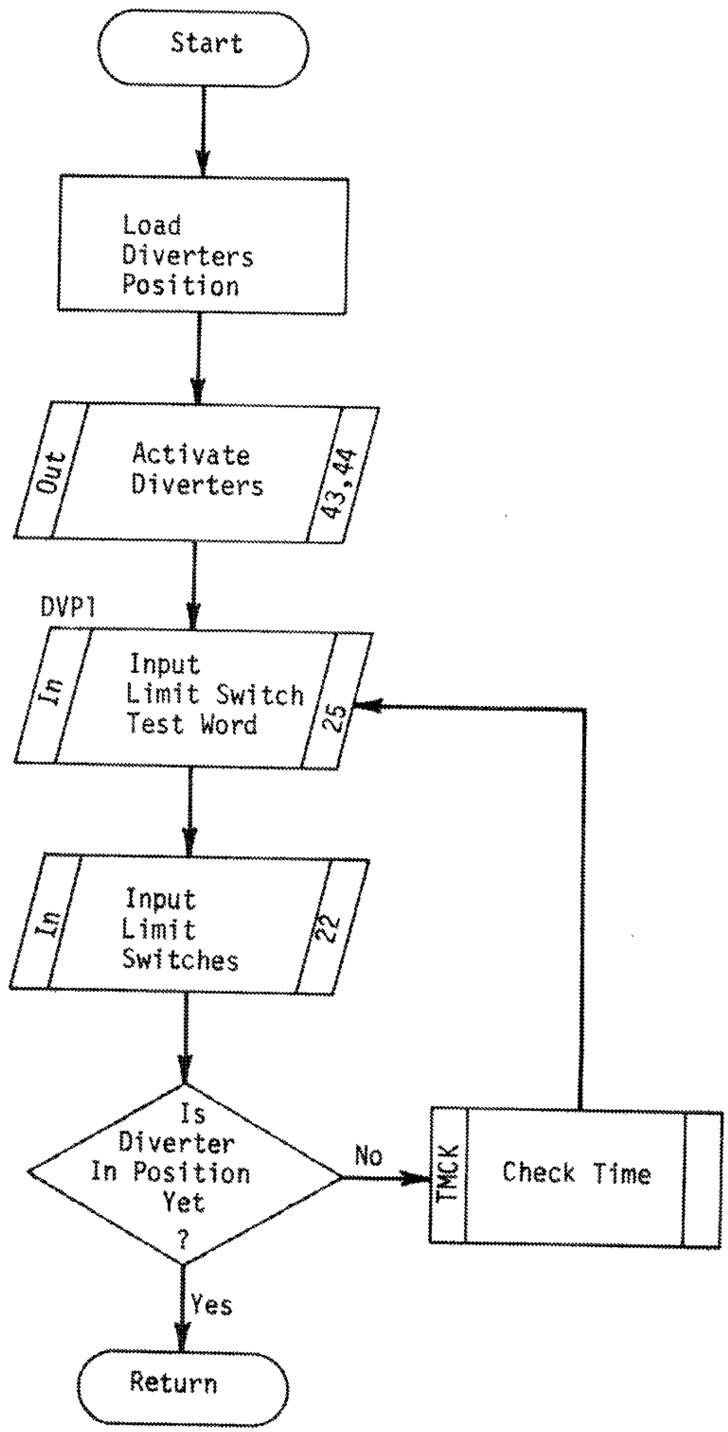
SUBROUTINE TMCK

Compares Time Clock to a Match Word. If Time Has Not Expired, Routine Returns to Calling Routine. If Time Has Expired, Dumps Registers and Calls Wait. When Timed Out Operation Has Been Corrected the Program May Be Continued.



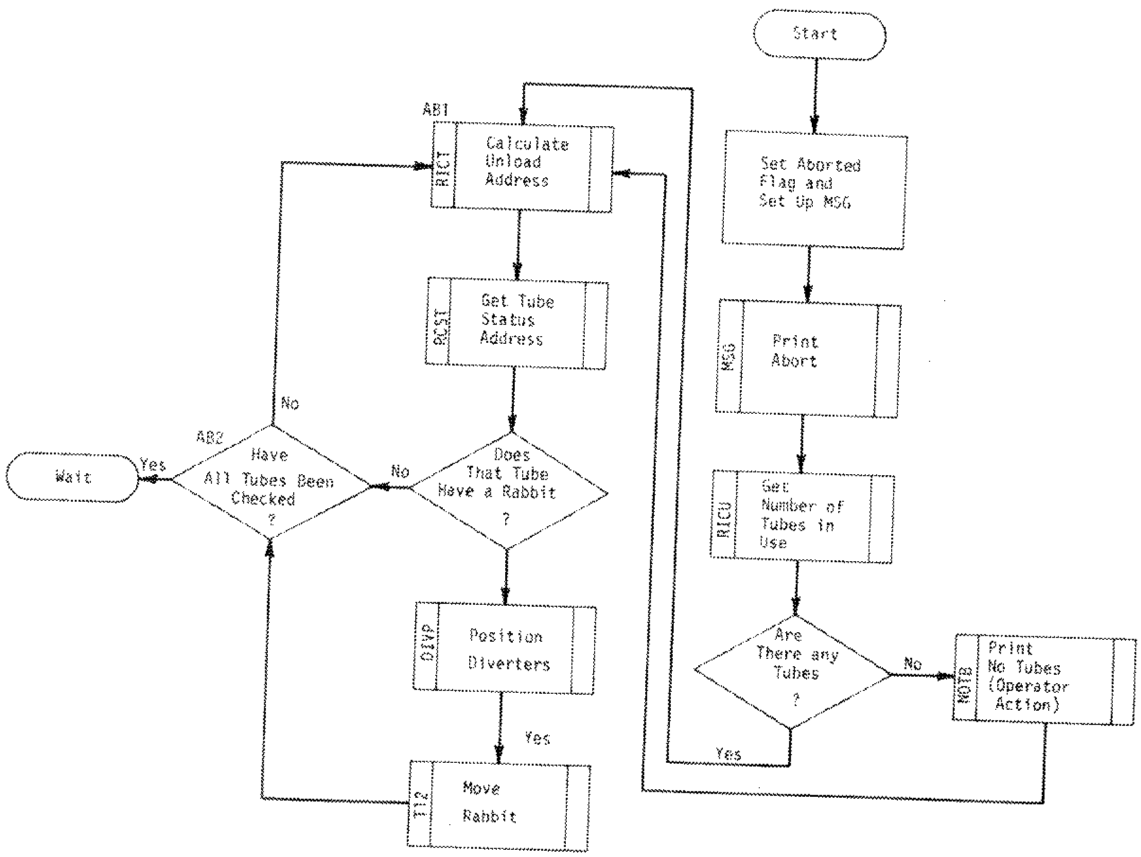
SUBROUTINE DIVP

Position Diverters



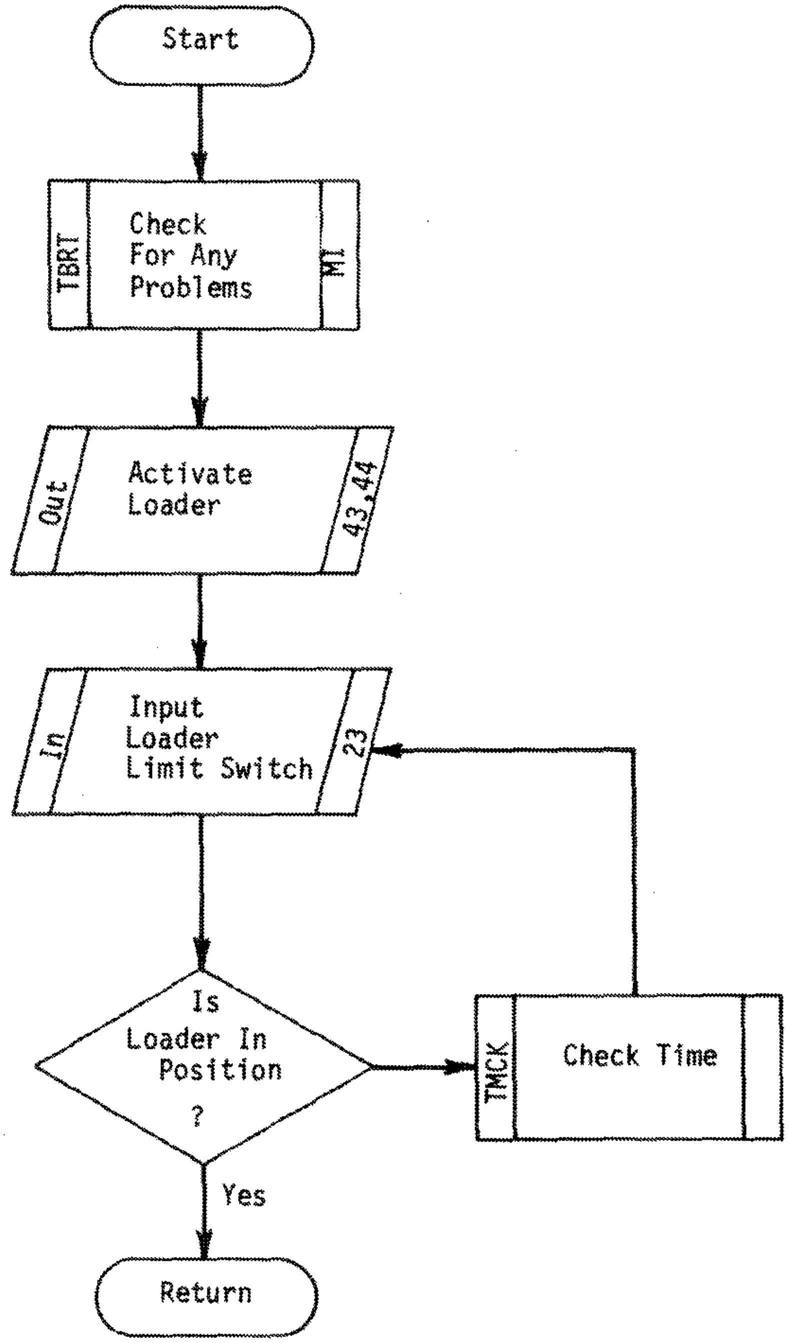
ROUTINE ABRT

Move All Rabbits in Reactor to DI



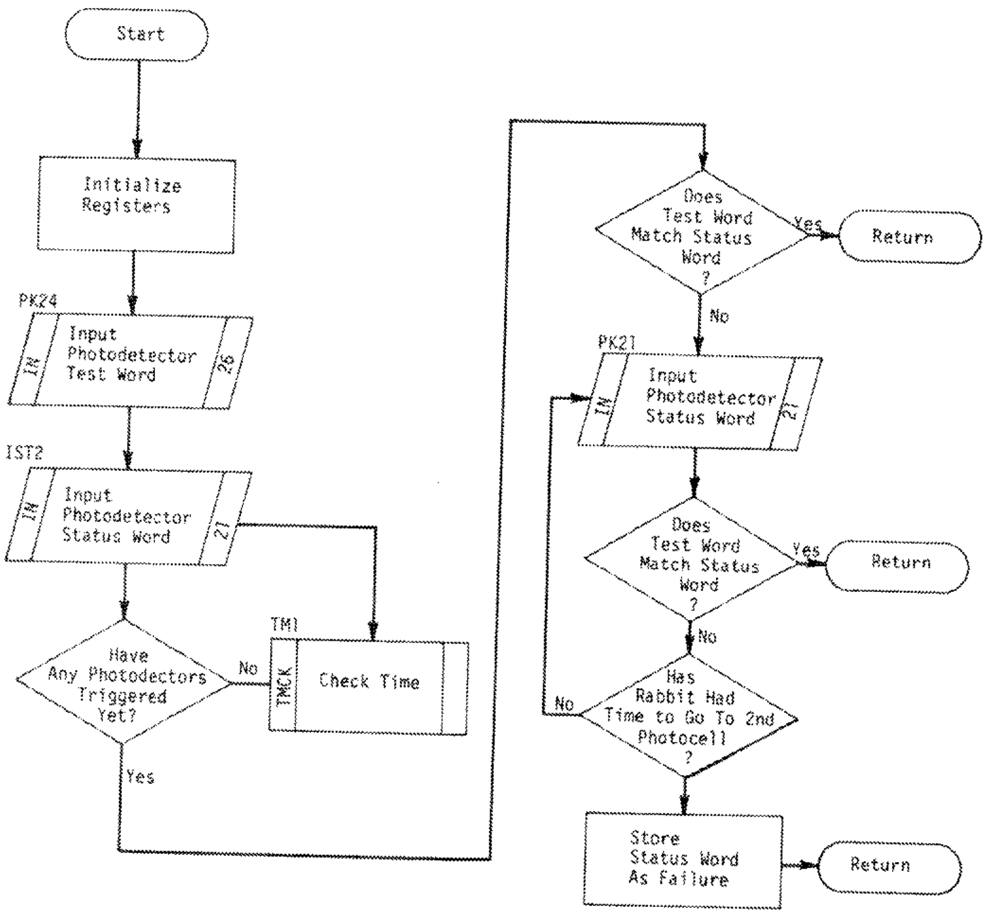
SUBROUTINE LDR

Set Up Loader to Put Rabbit in System



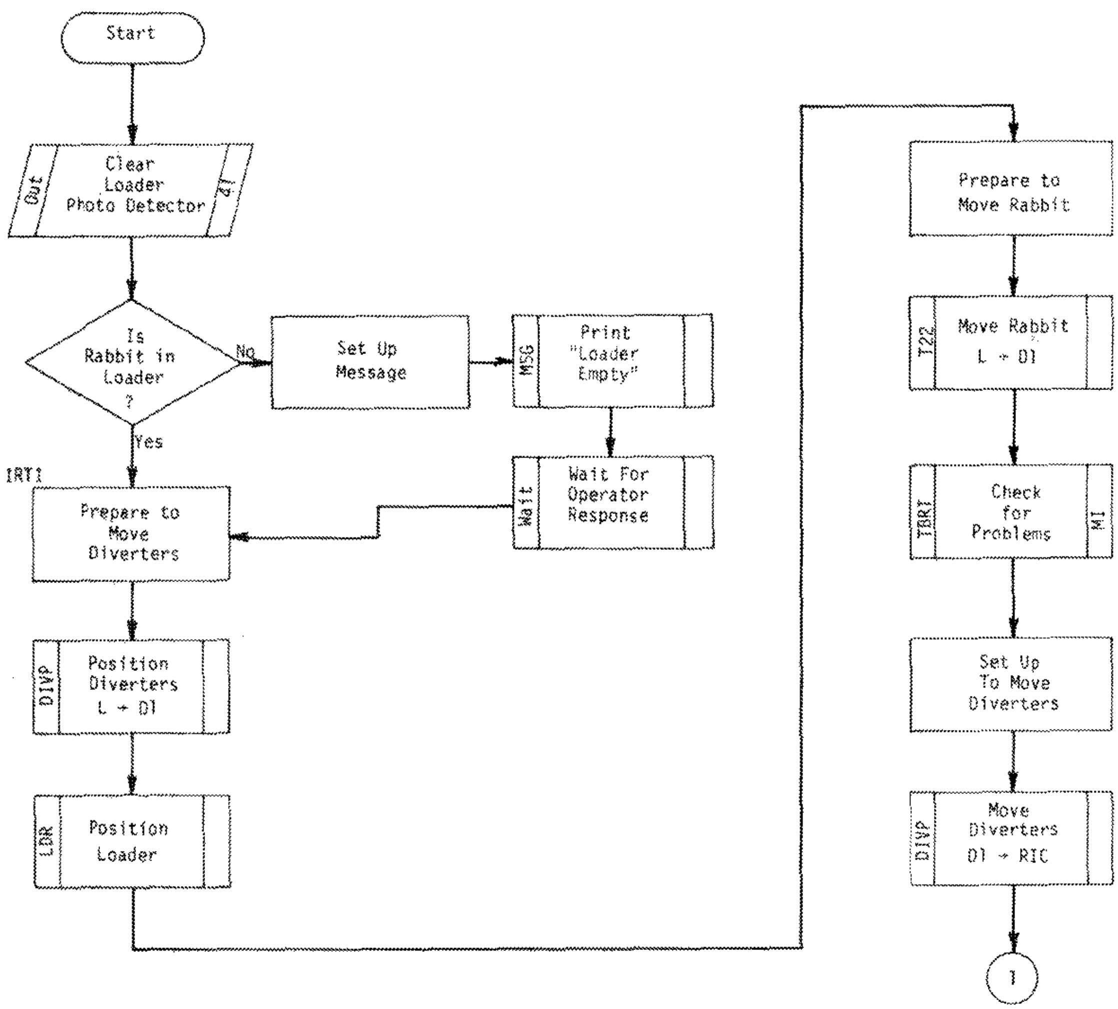
SUBROUTINE PDK2

Check Photodetectors in CCM for Correct Actuation

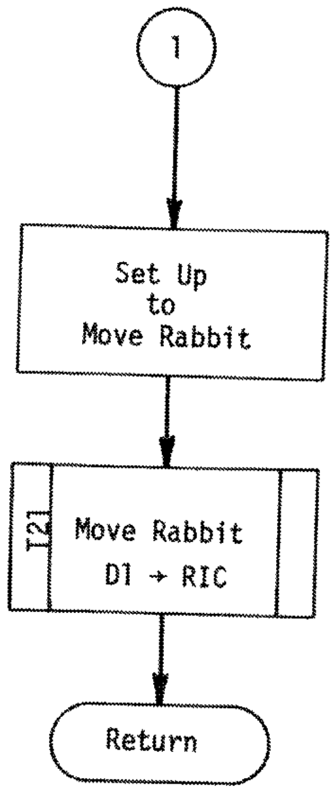


SUBROUTINE IRRD

Move Rabbit from Loader into Reactor

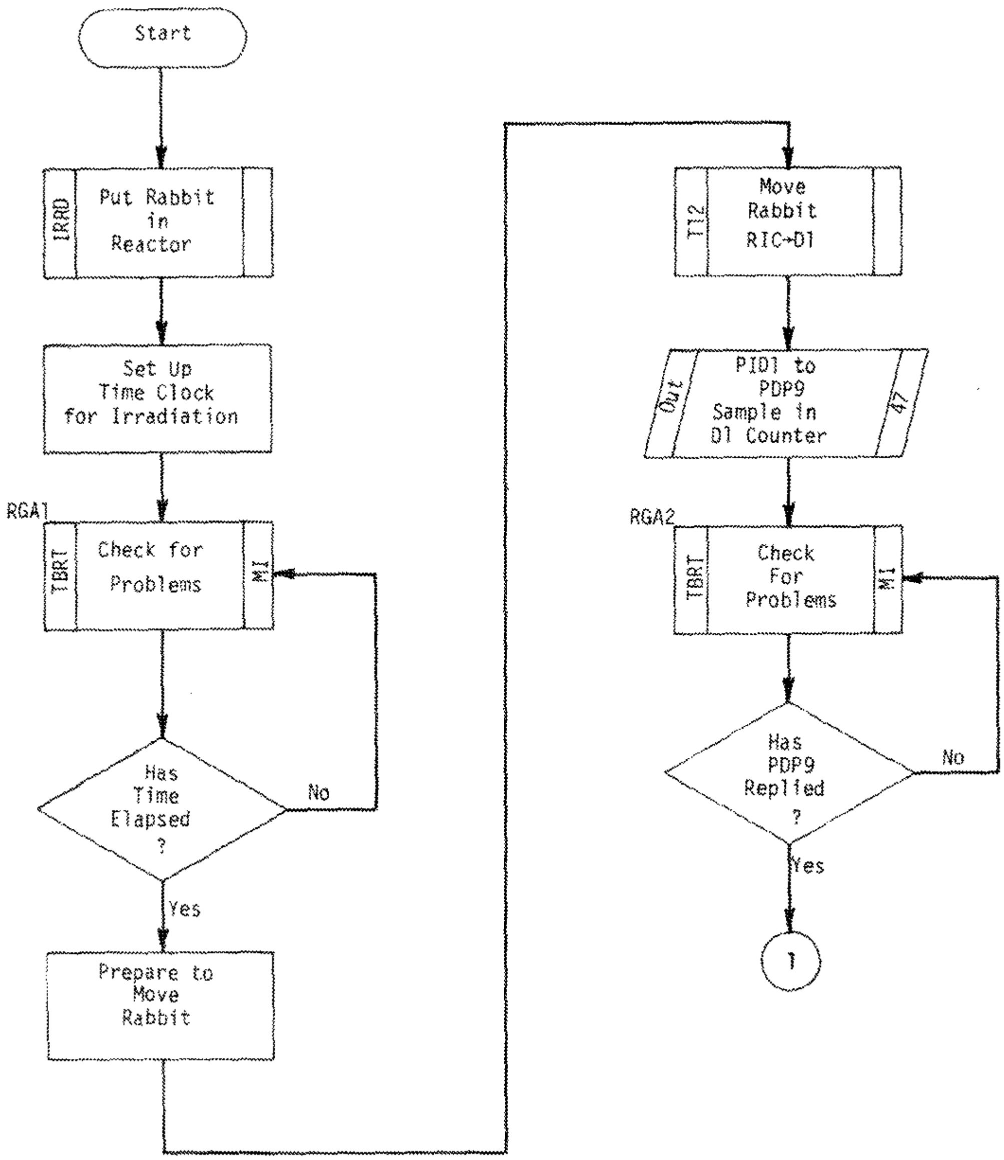


Subroutine IRRD (Continuation)

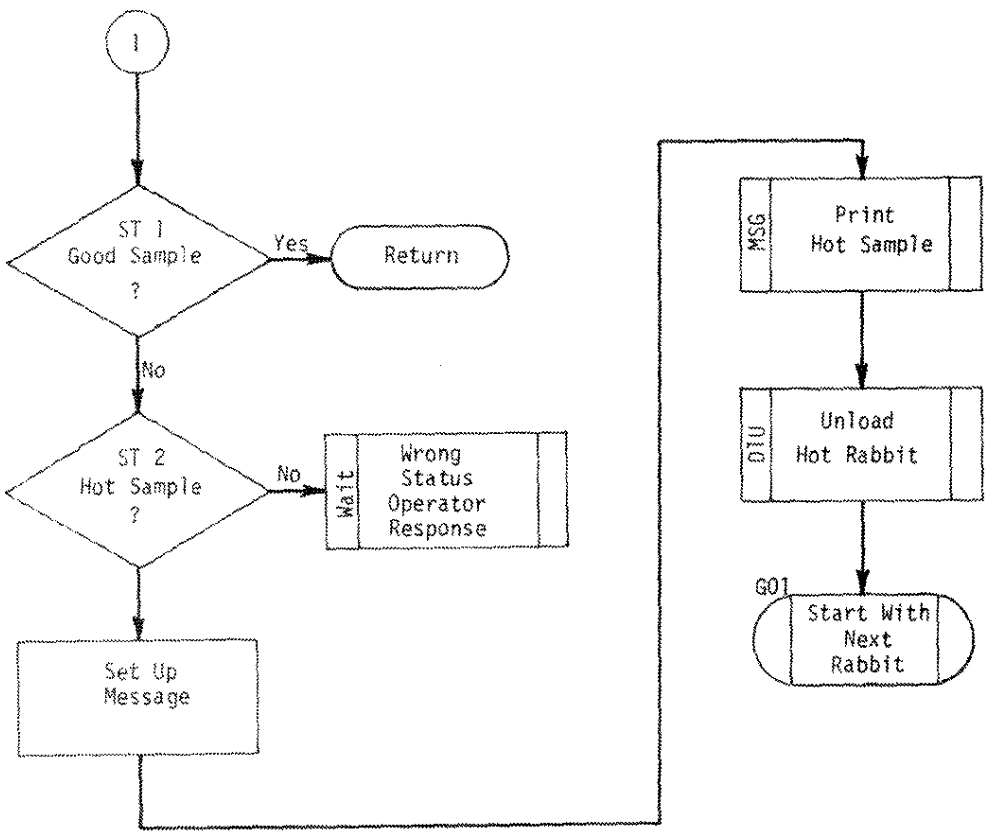


SUBROUTINE RGA

Regime A for Production Run. Give Sample Short Irradiation. Allow PDP9 to Count. If Activity too High, Reject Sample. Otherwise Continue With Analysis.

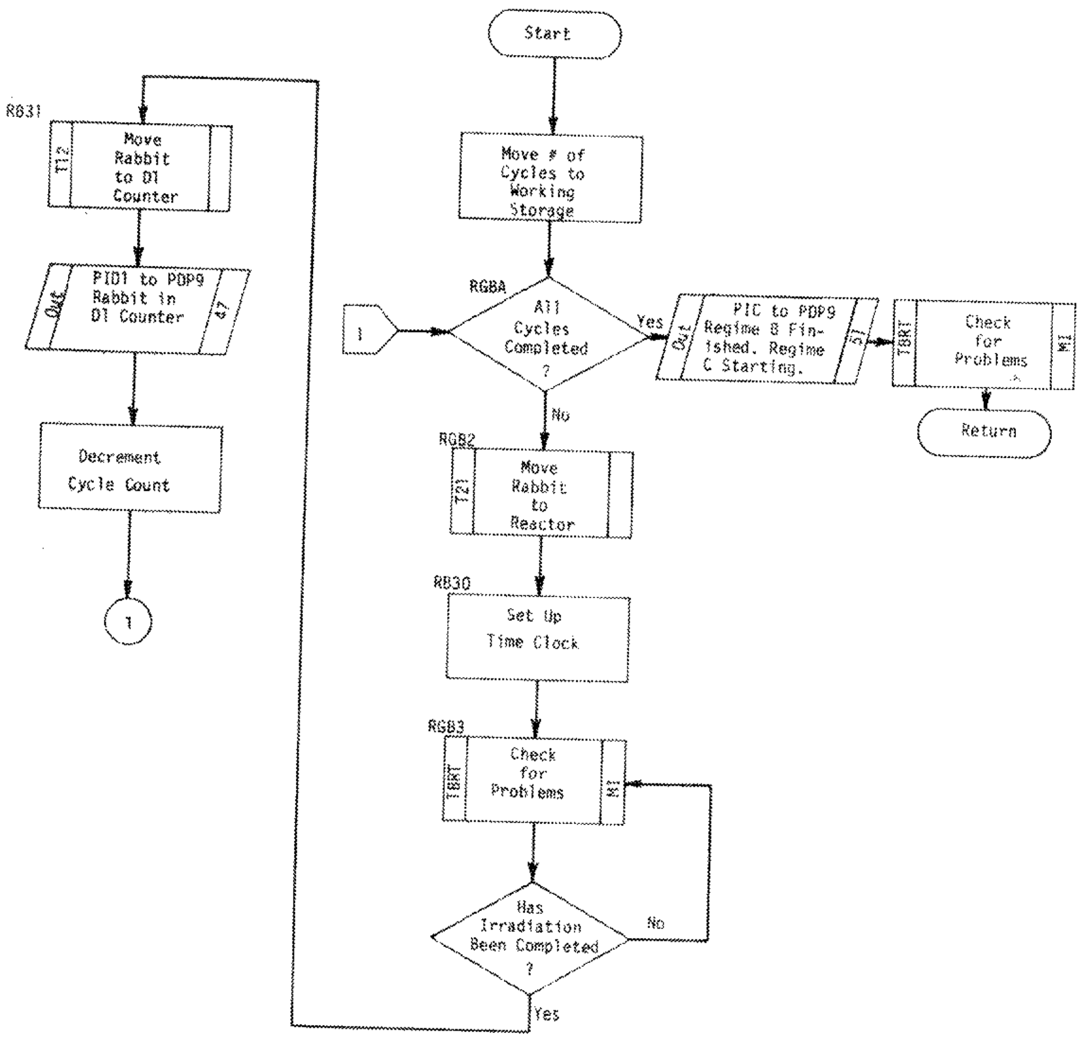


Subroutine RGA (Continuation)

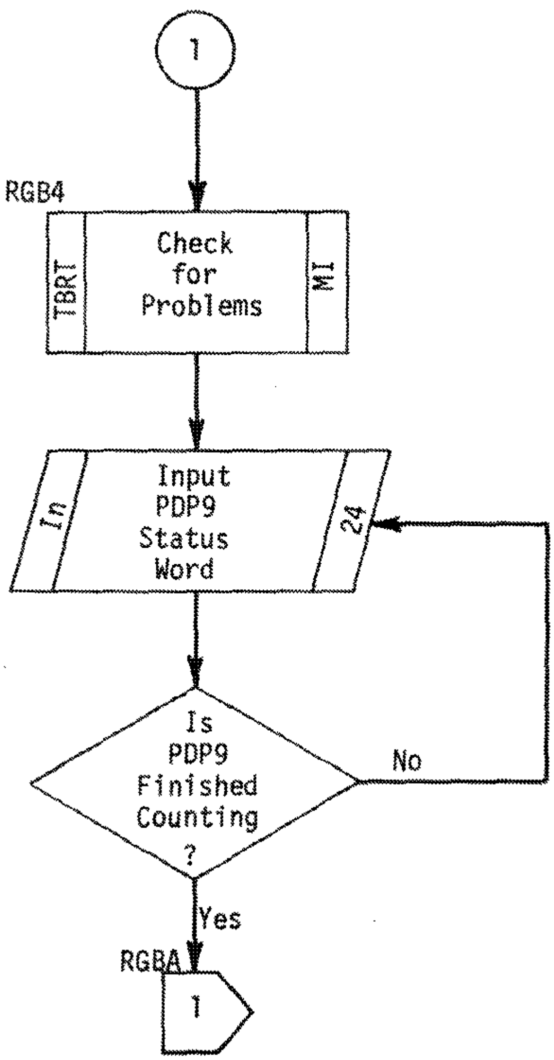


SUBROUTINE RGB

Regime B for Production Run. Cycle Sample Rabbit Through Specified Number of Irradiations and Counts.

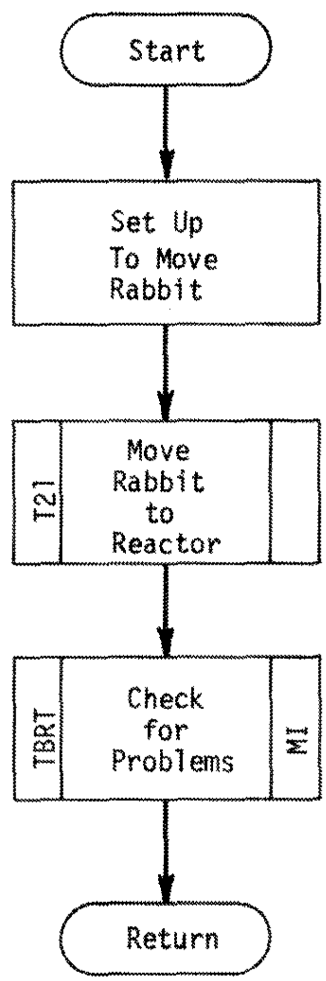


Subroutine RGB (Continuation)



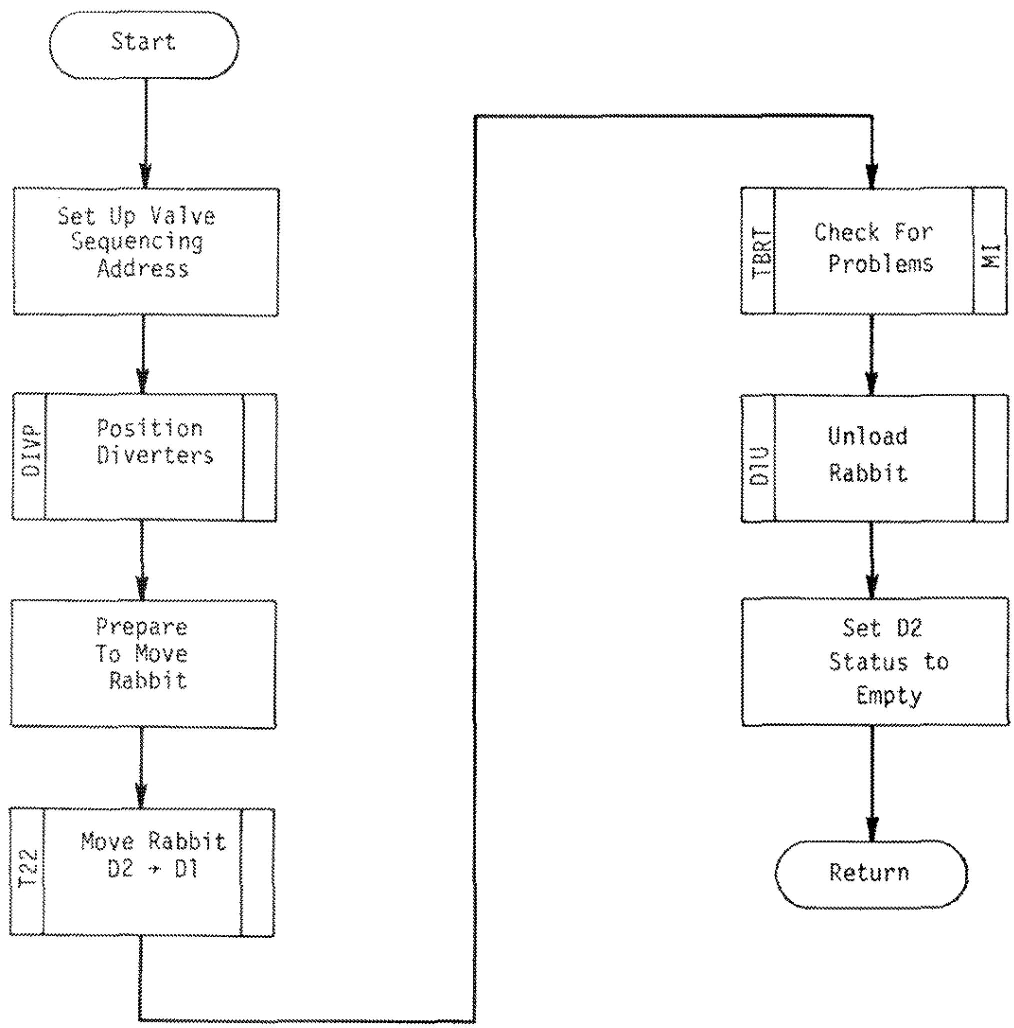
SUBROUTINE IRGC

Initiate Regime C for Production Run.
Leave Rabbit in Reactor Before Starting New Sample.



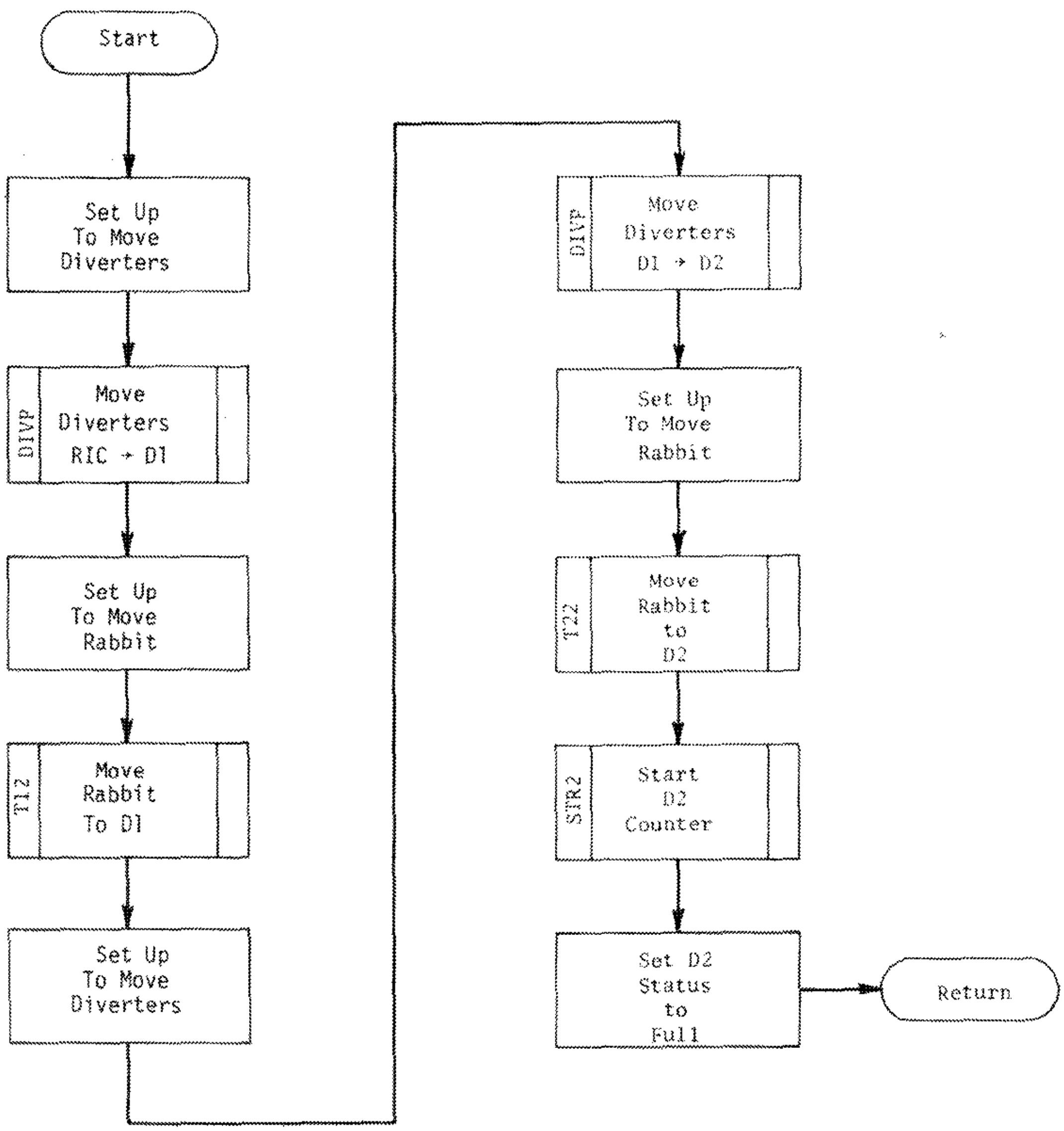
SUBROUTINE UND2

Unload GELI D2



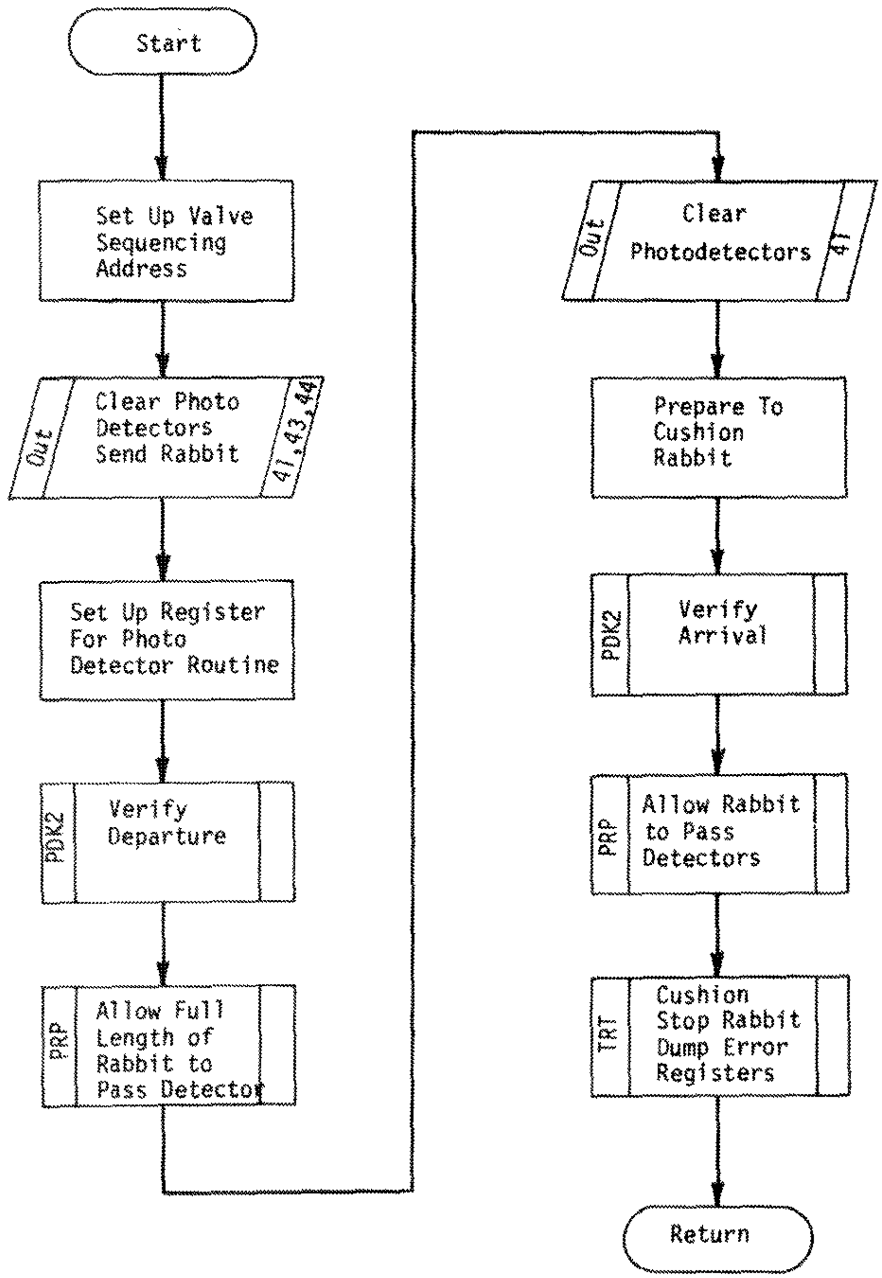
SUBROUTINE TRGC

Remove Rabbit from Reactor After Long Irradiation and Move to D2 Counter for Long Count on Canberra.



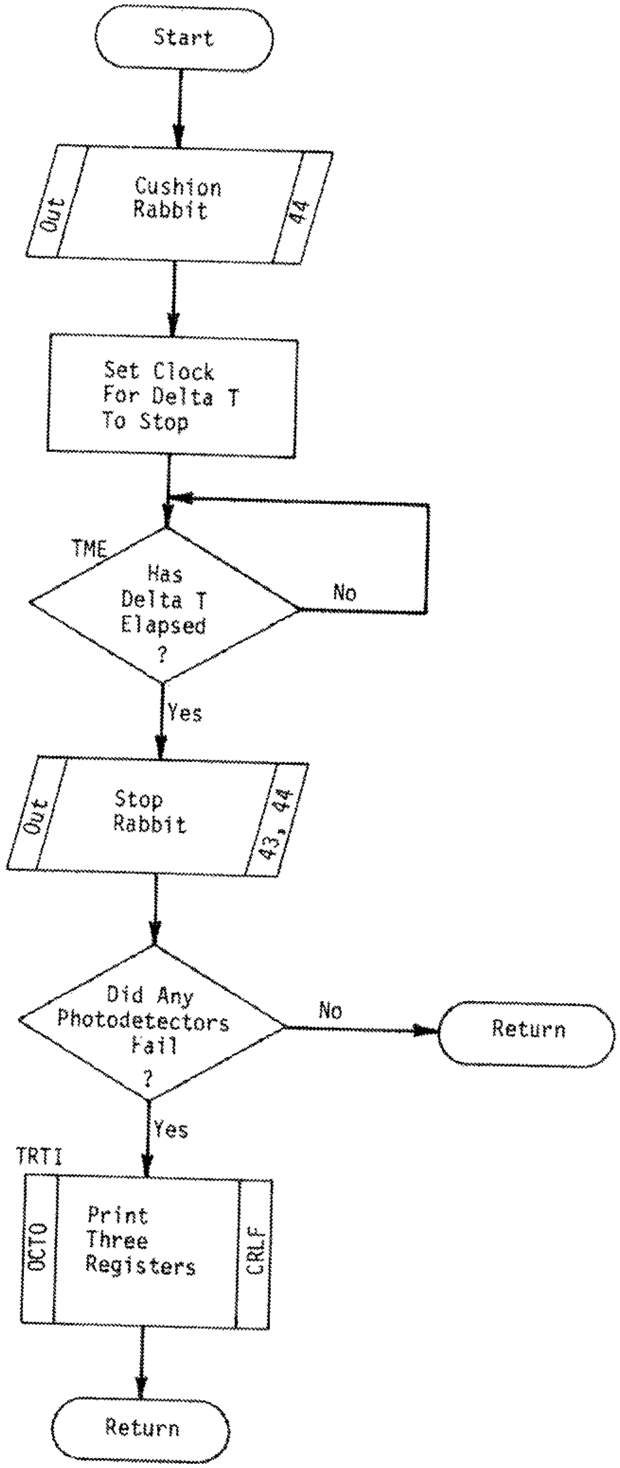
SUBROUTINE T22

Transport Rabbit Between Points Within the CCM



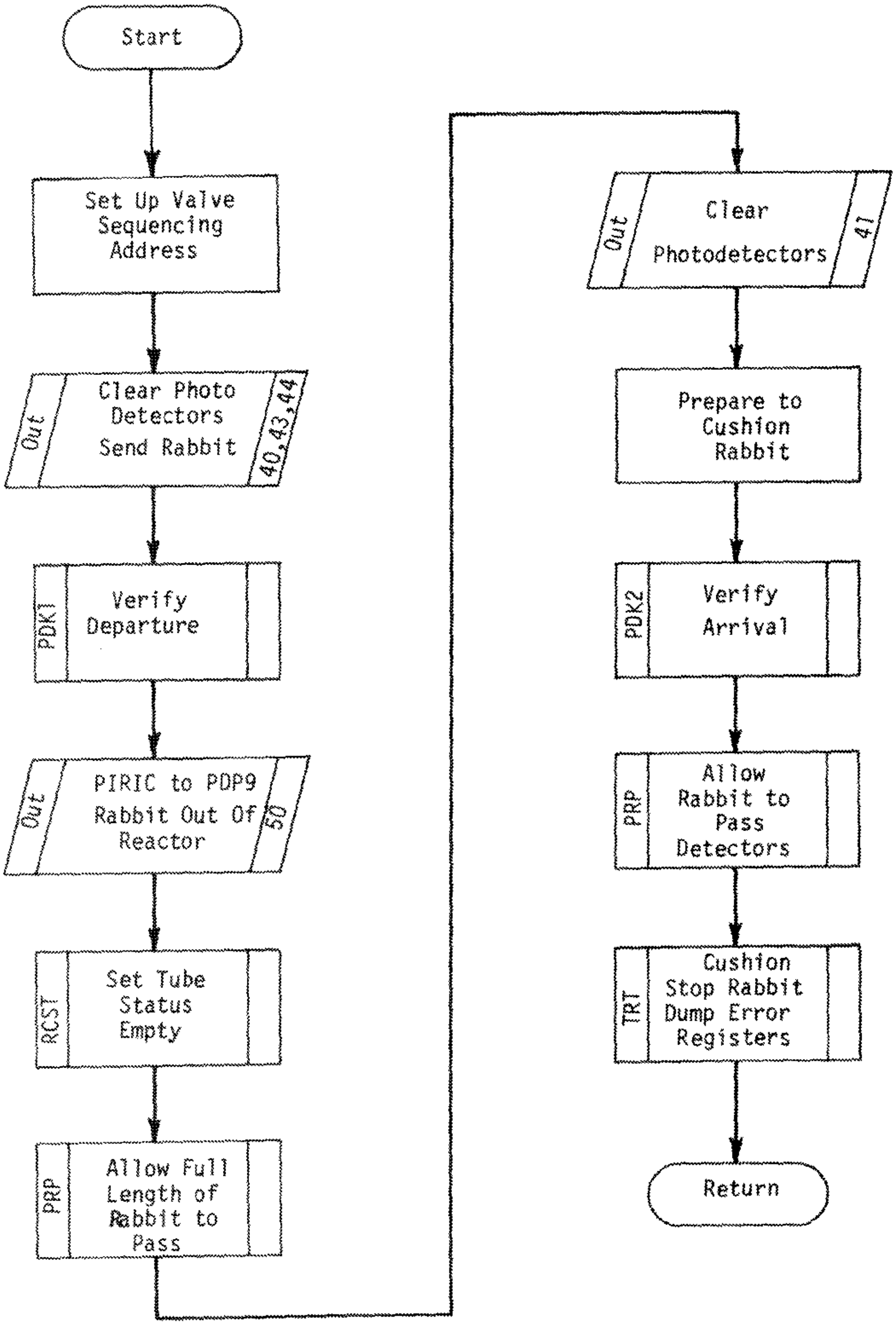
SUBROUTINE TRT

Terminate Transport Routines. Cushion and Stop Rabbit. Dump Error Registers if Photodetector Fails.



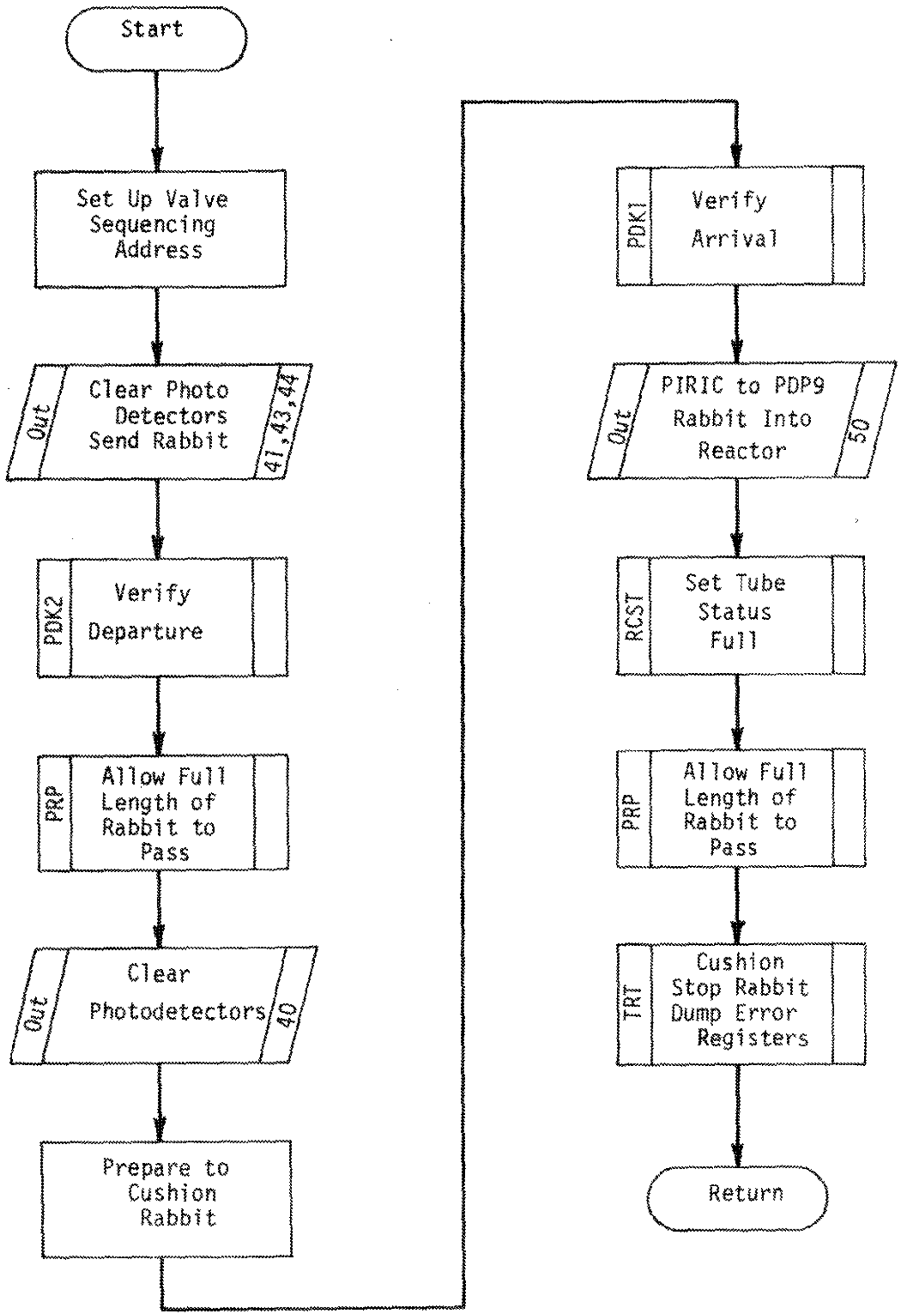
SUBROUTINE T12

Transport Rabbit From Reactor to CCM



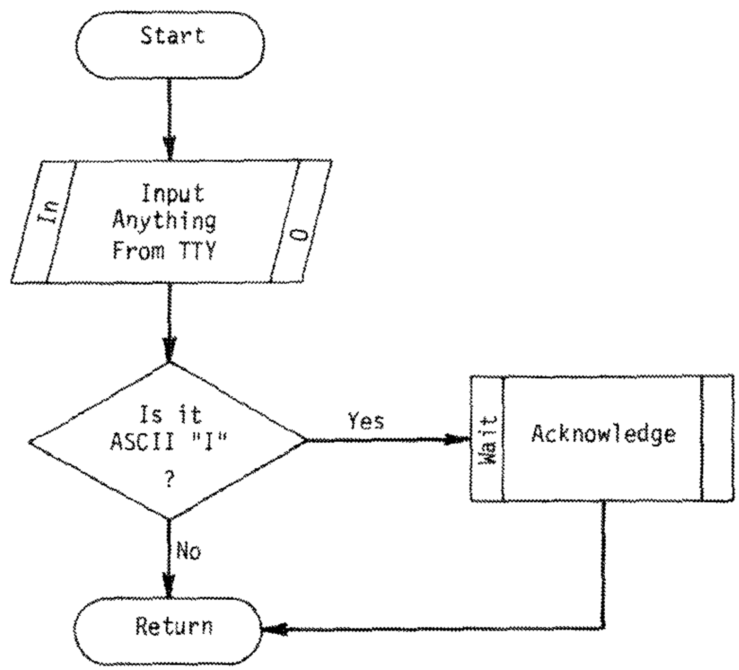
SUBROUTINE T21

Transport Rabbit to Reactor From CCM



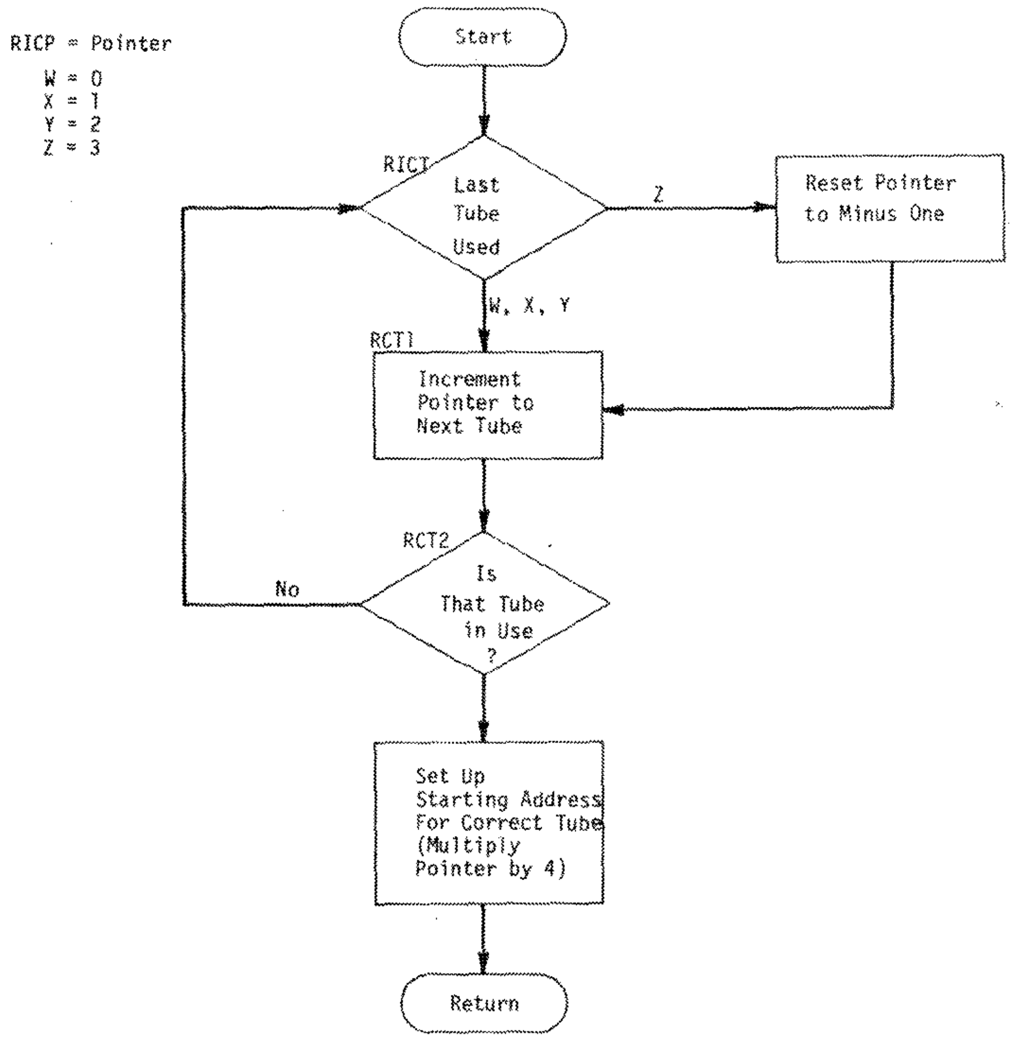
SUBROUTINE MI

Monitor Teletype for Signal That Operator Wishes to Gain Control



SUBROUTINE RICT

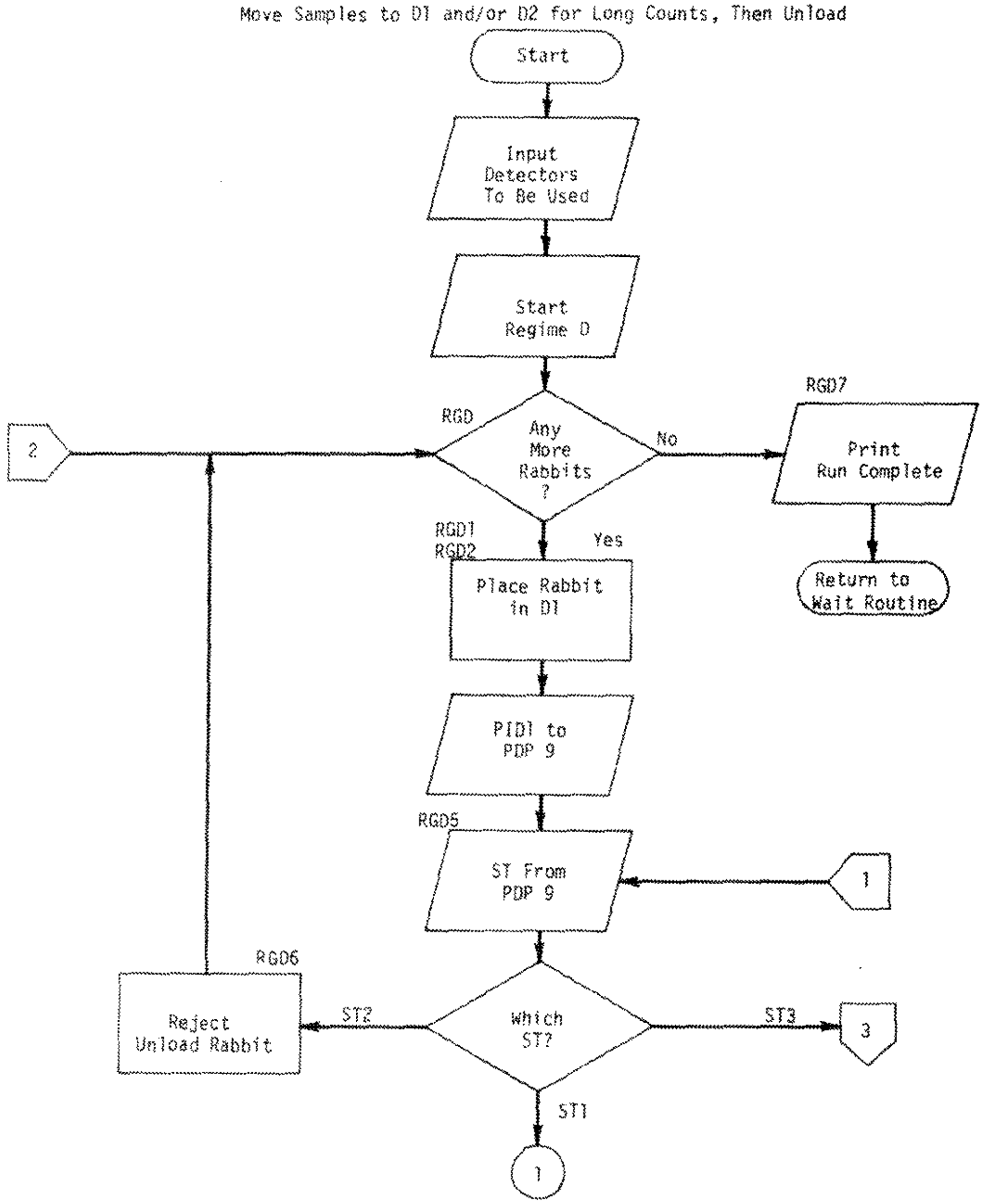
DETERMINES WHICH TUBE TO USE NEXT



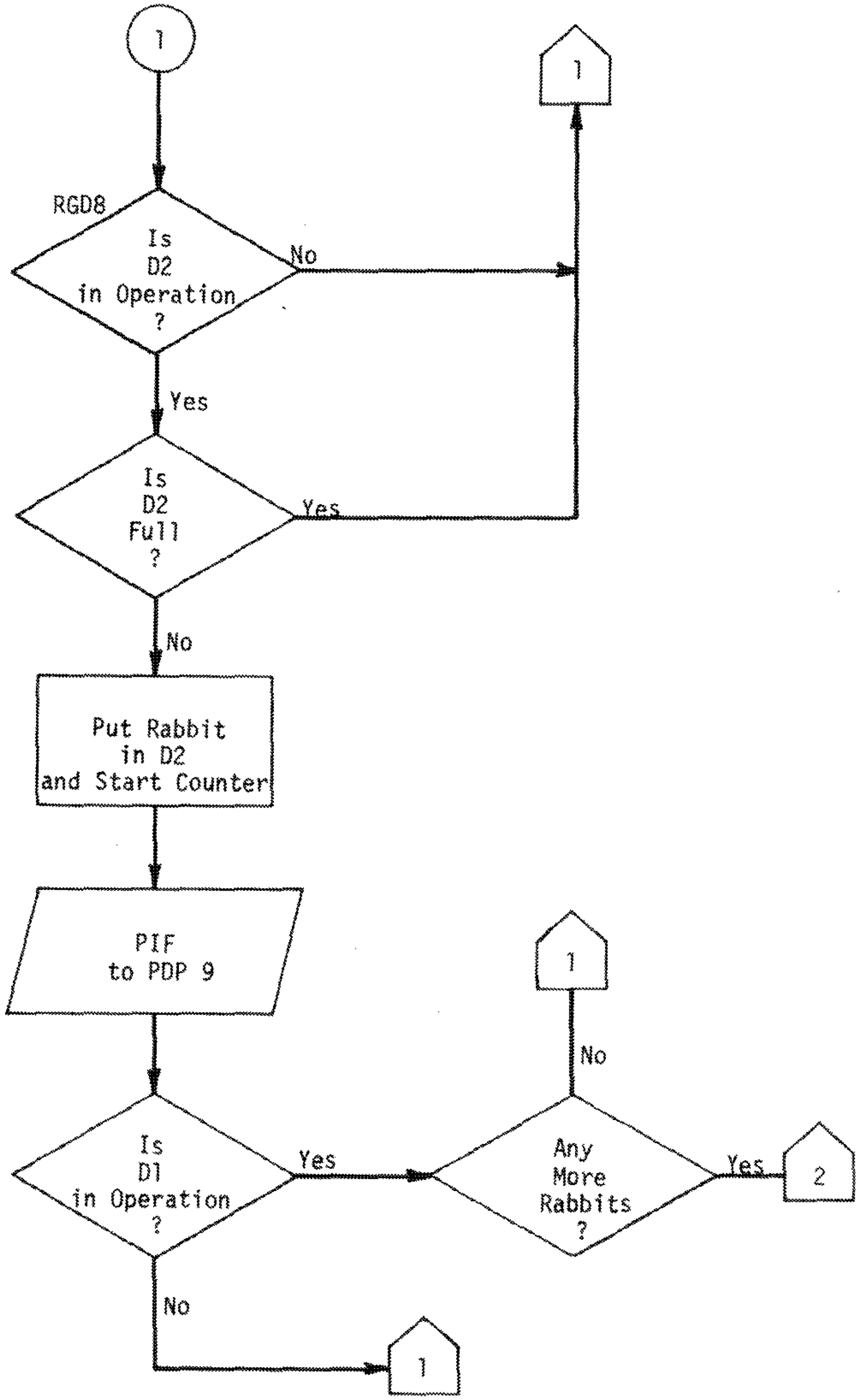
ROUTINE RGD

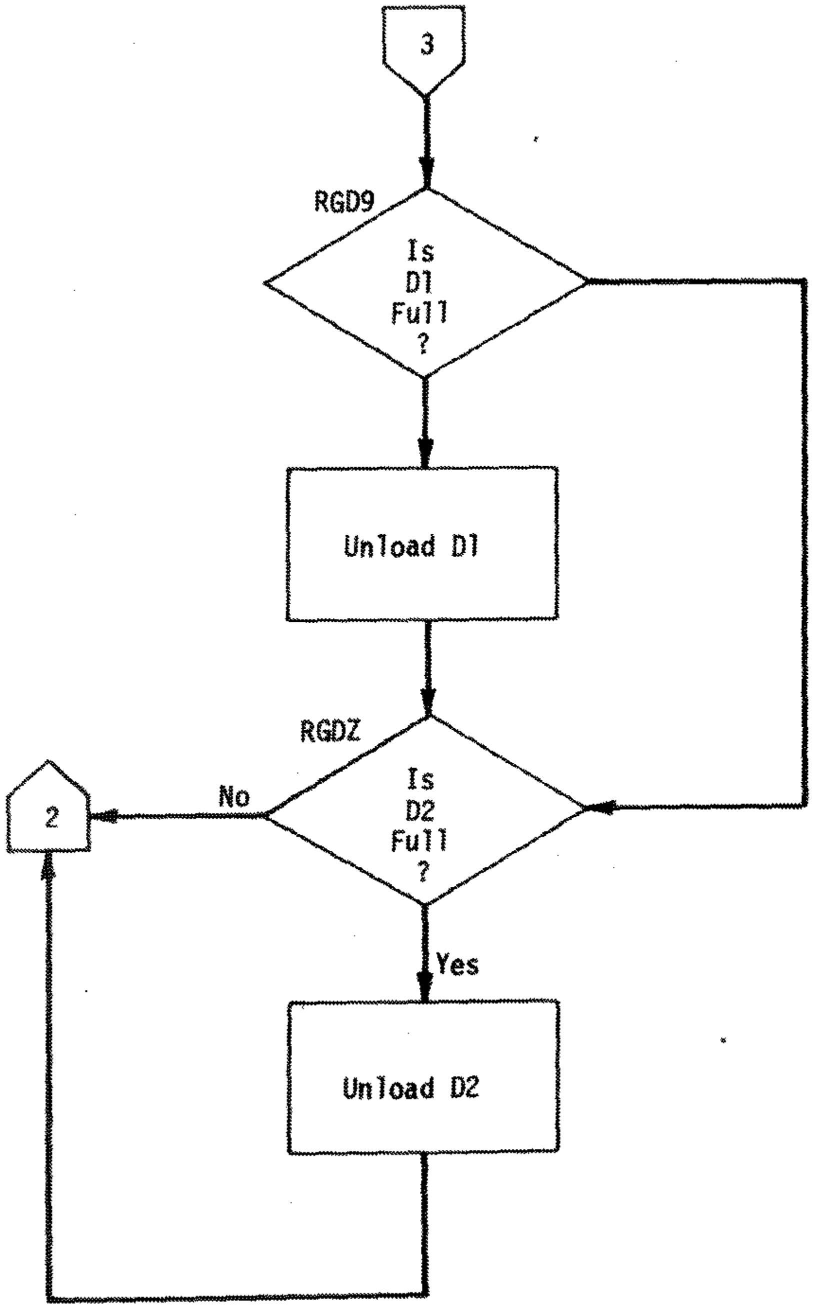
Regime D of Production Run

Move Samples to D1 and/or D2 for Long Counts, Then Unload



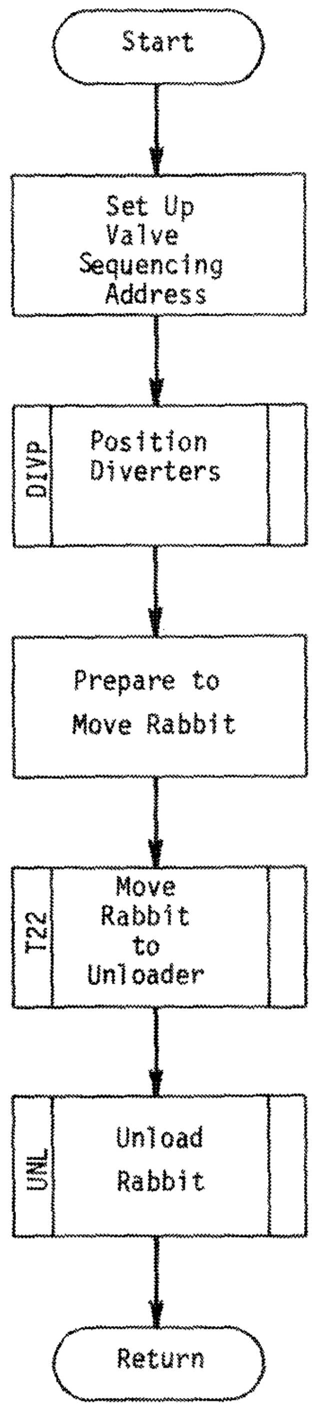
Routine RGD (Continuation)




3
RGD9
Is D1 Full ?
Unload D1
RGDZ
Is D2 Full ?
No
2
Yes
Unload D2

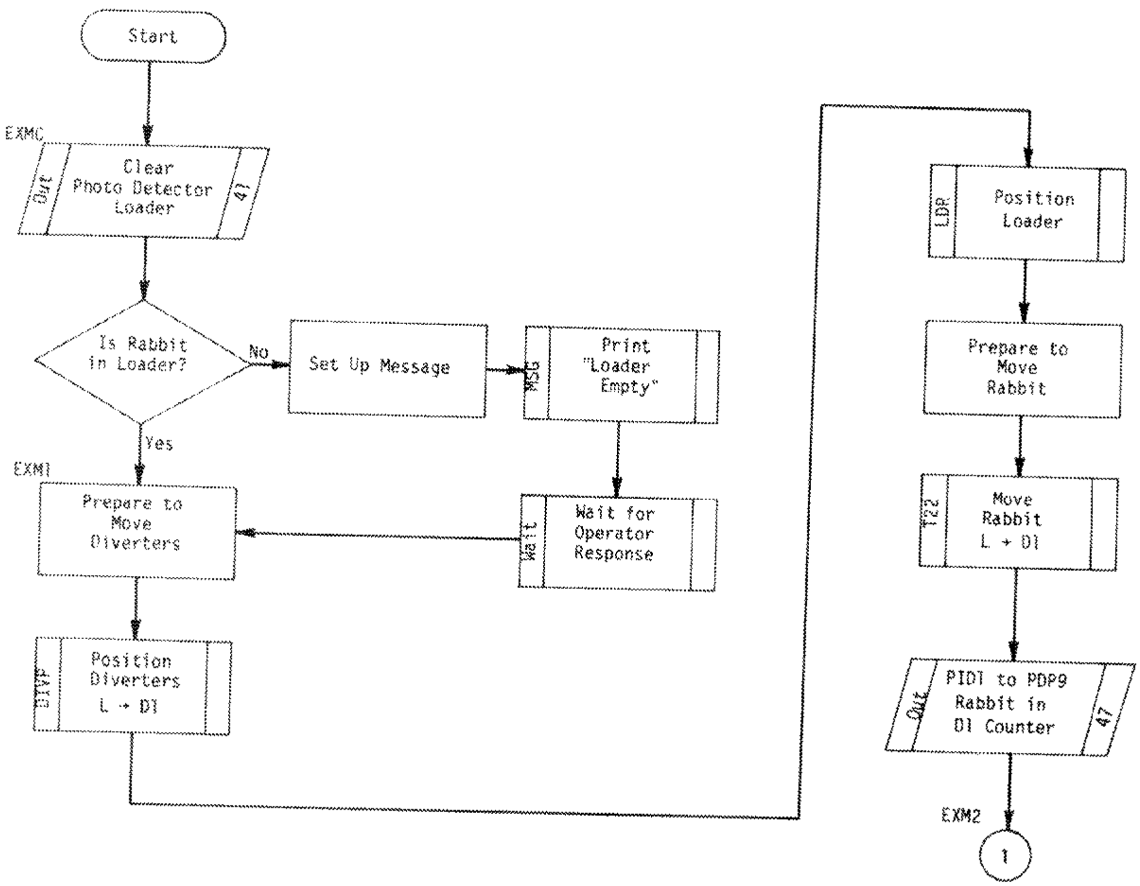
SUBROUTINE D1U

Unload Rabbit From D1

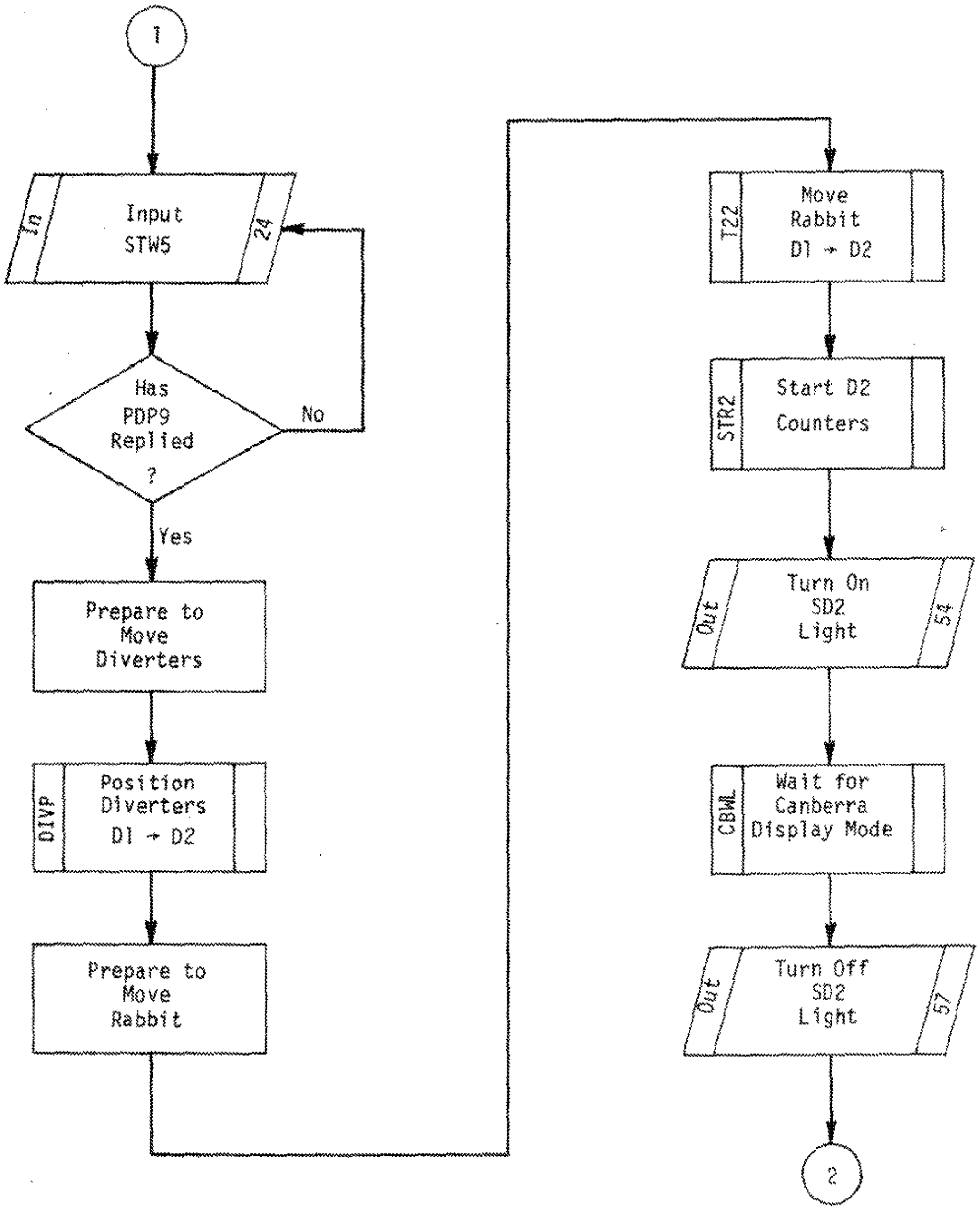


ROUTINE EXMC

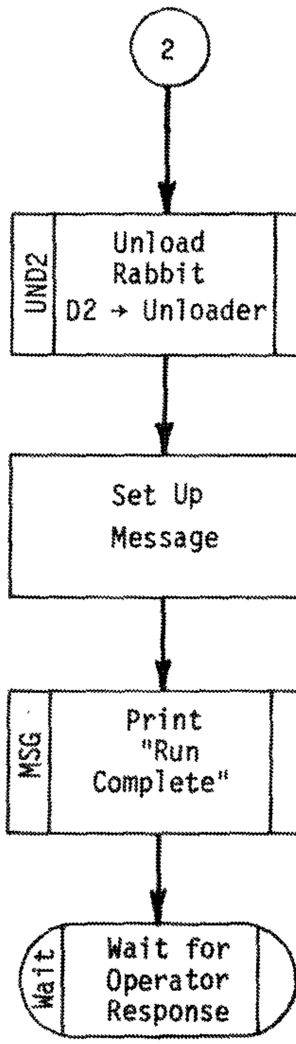
Move Rabbit from Loader to D1. Wait for PDP9 to Finish Counting. Move Rabbit to D2. Wait for Canberra to Finish Counting. Unload Rabbit.



Routine EXMC (Continuation)

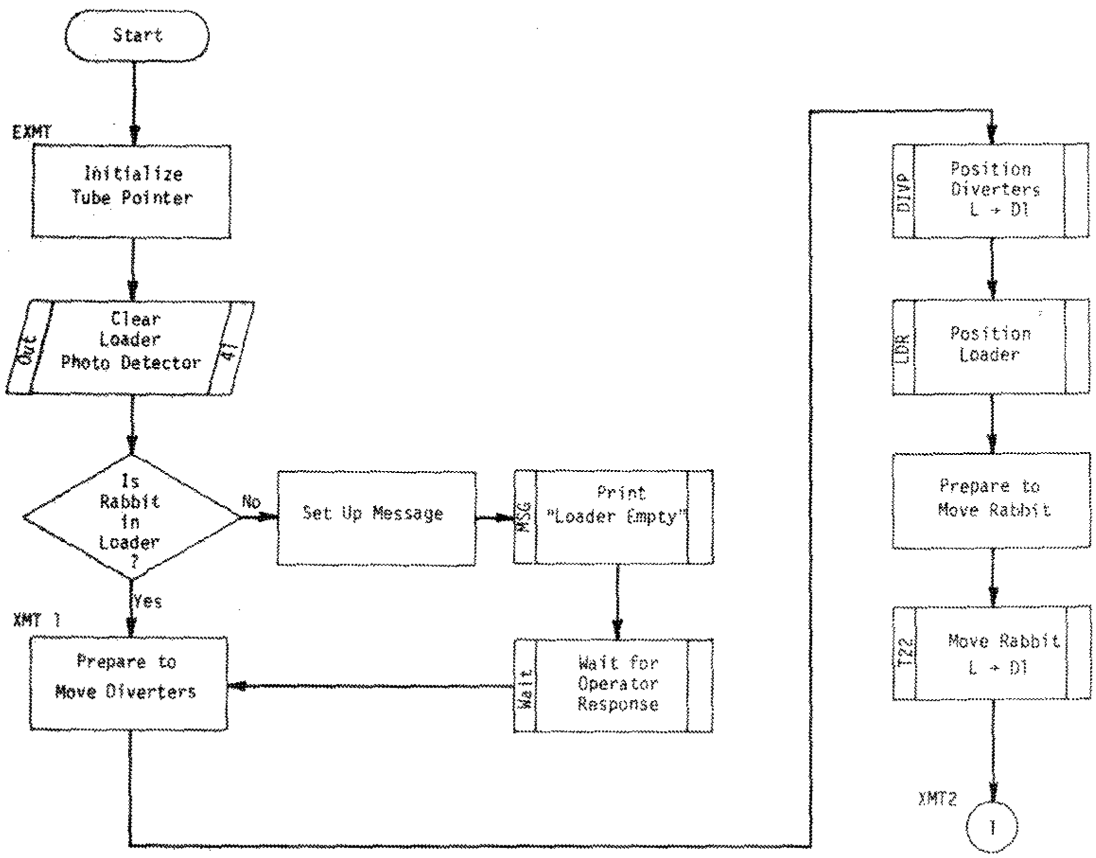


Routine EXMC (Continuation)

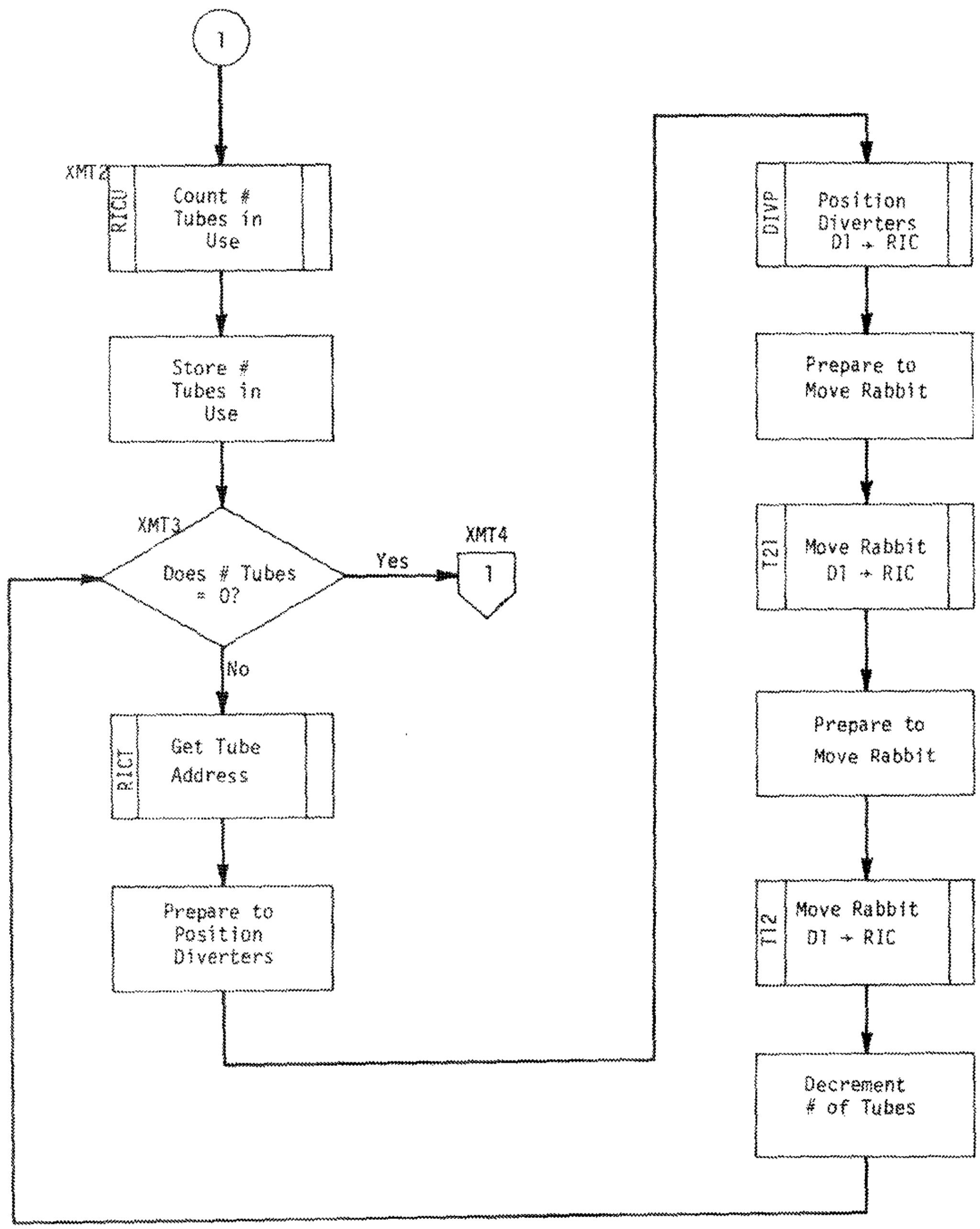


ROUTINE EXMT

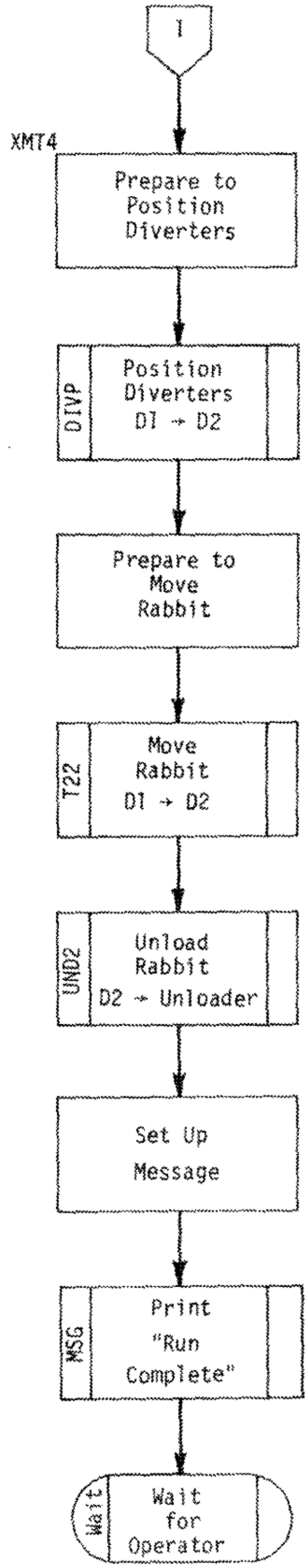
Move Rabbit Through all Possible Paths and Unload



Routine EXMT (Continuation)

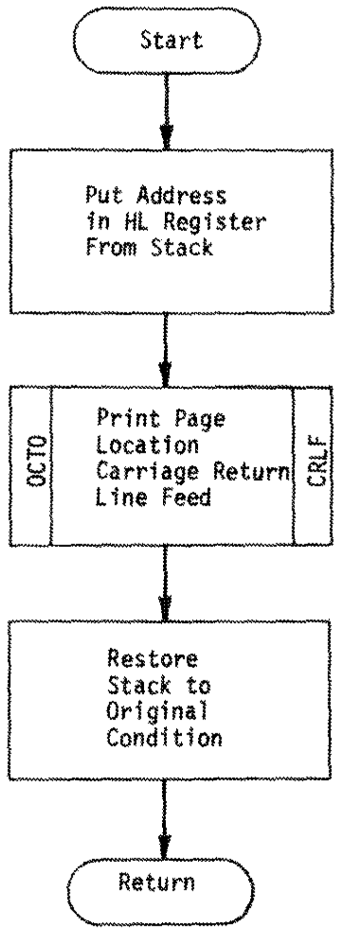


Routine EXMT (Continuation)



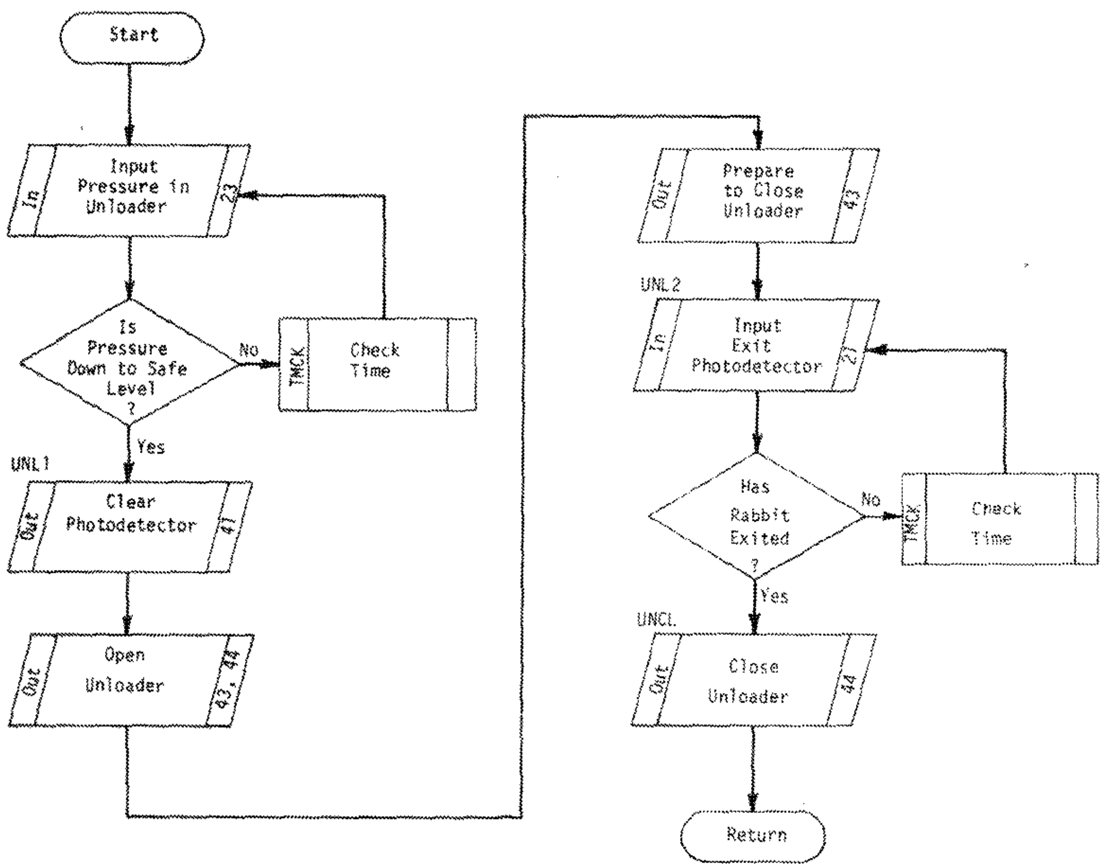
SUBROUTINE SPD

PRINTS ADDRESS TO WHICH ROUTINE CALLING SPD WILL RETURN



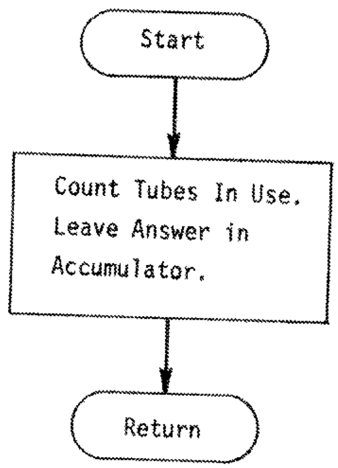
SUBROUTINE UNL

Operate Unloader to Unload Rabbit



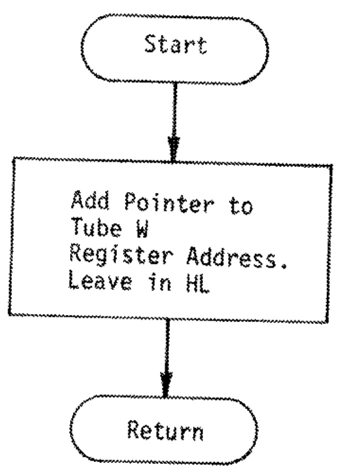
SUBROUTINE RICU

COUNTS TOTAL NUMBER OF TUBES IN USE



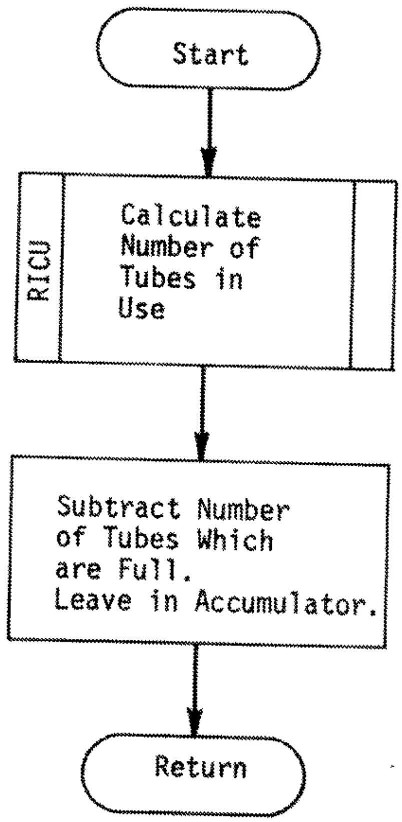
SUBROUTINE RCST

CALCULATES ADDRESS OF TUBE CONTENTS REGISTER



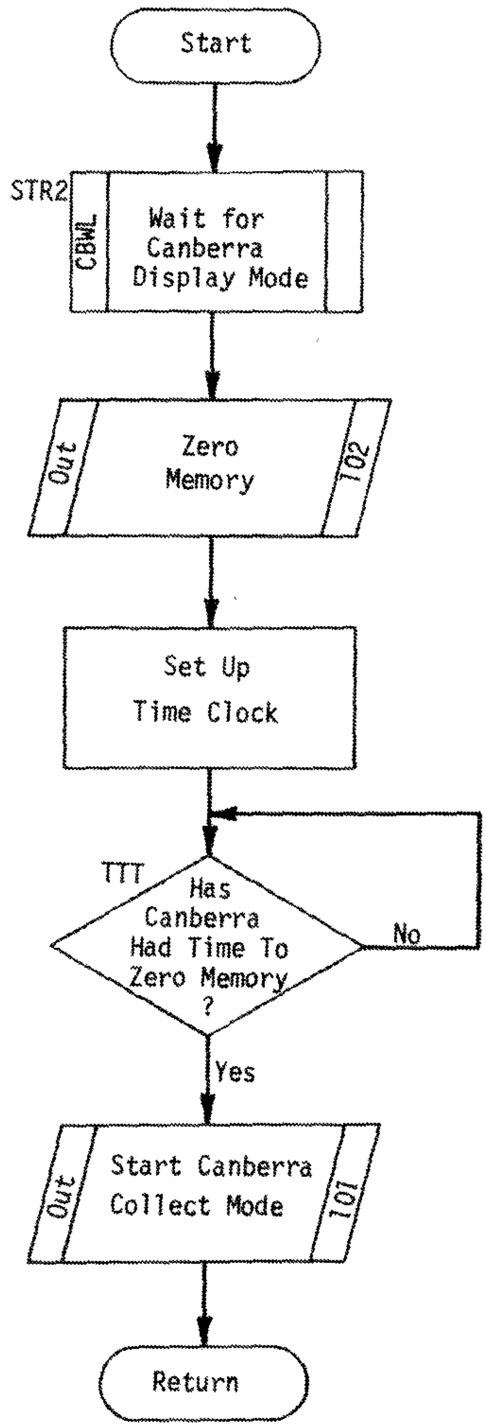
SUBROUTINE RICF

DETERMINES IF ALL TUBES IN USE CURRENTLY HAVE RABBITS IN THEM



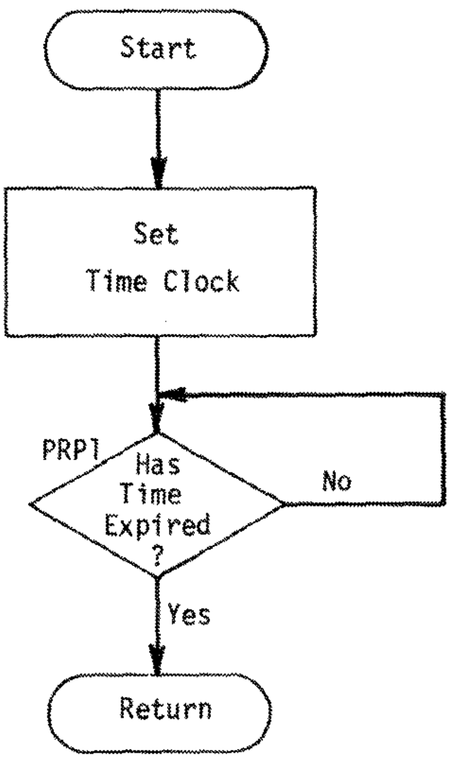
SUBROUTINE STR2

Perform Operations Required to Start Canberra Count at D2



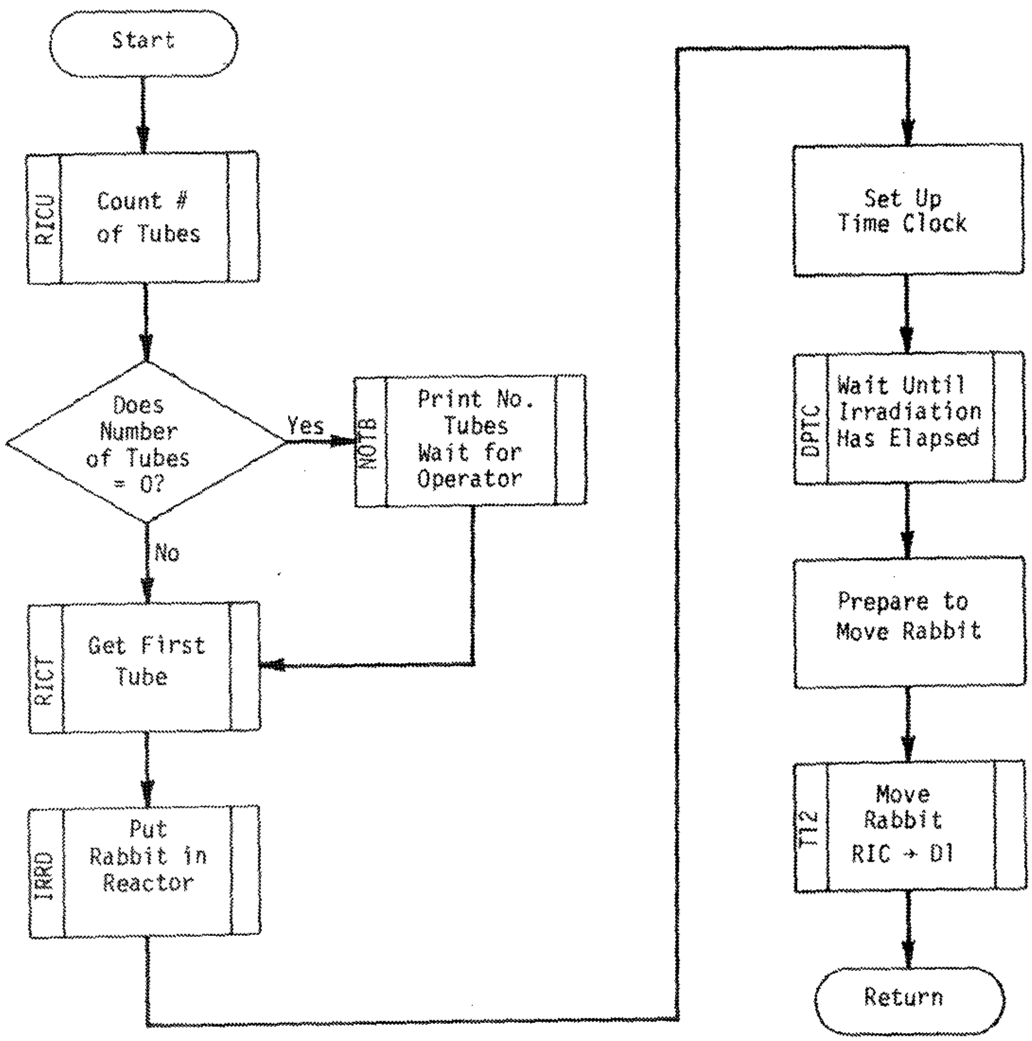
SUBROUTINE PRP

Allow Approximately 100 msec for Rabbit End to Clear Photodetector Assembly.



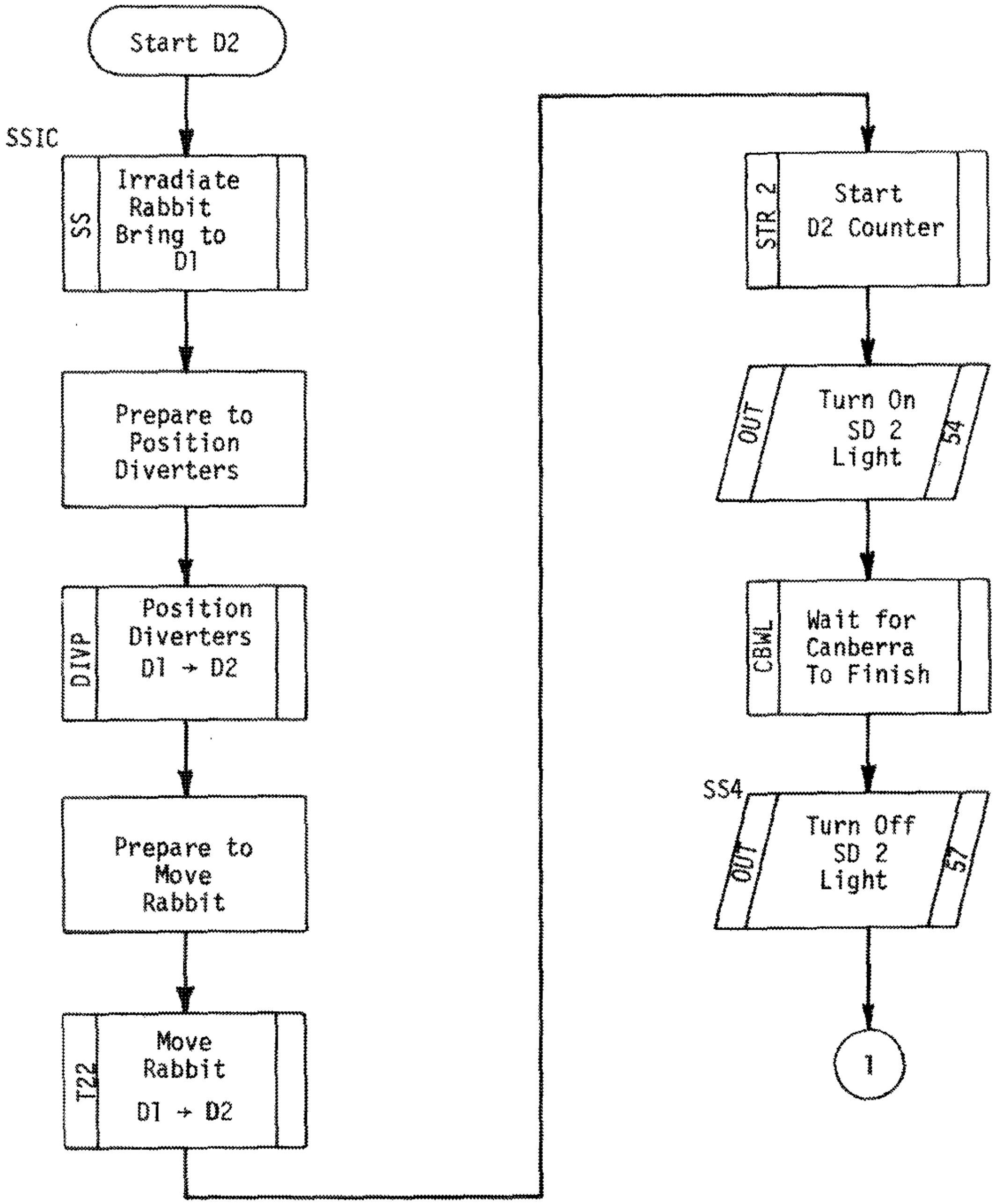
SUBROUTINE SS

Irradiate Rabbit and Move to D1

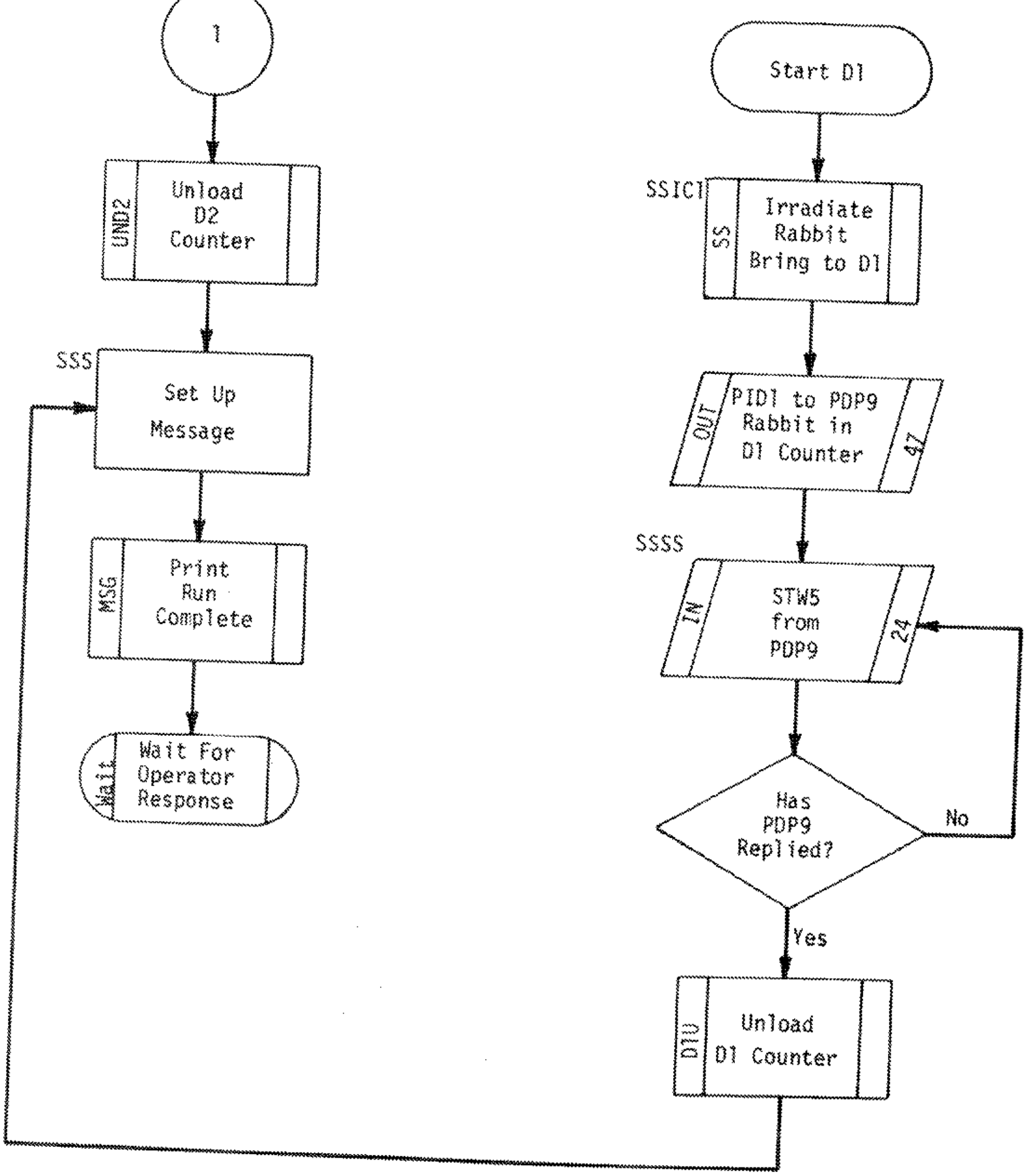


ROUTINE SSIC

Single Sample Irradiation and Count
Count in D1 or D2



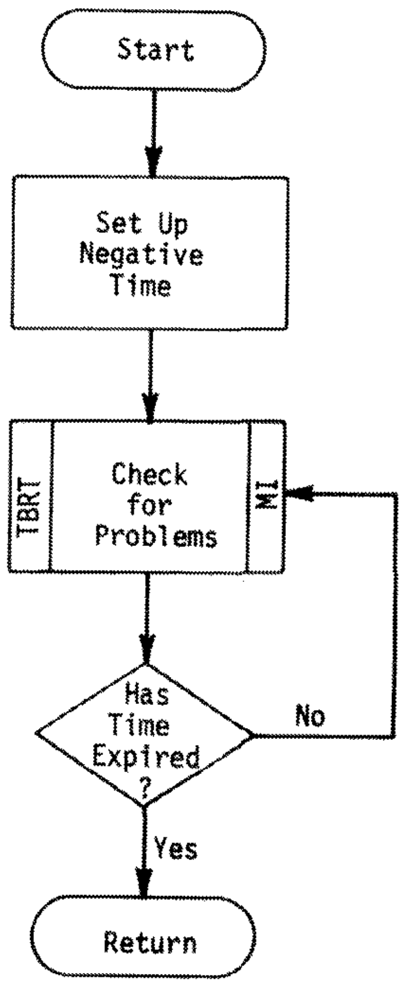
Routine SSIC (Continuation)



SUBROUTINE DPTC

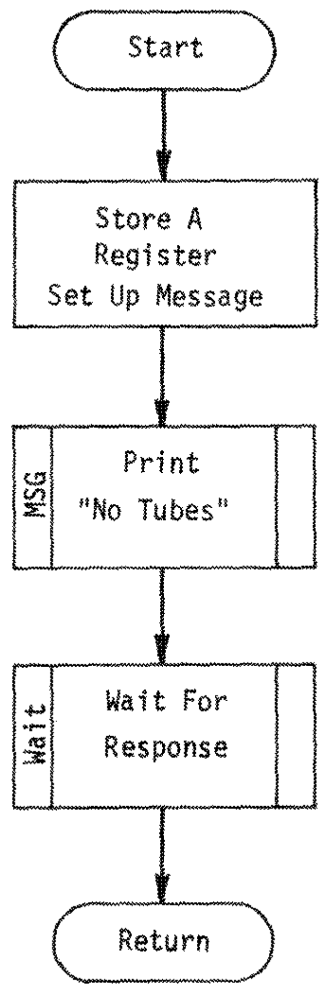
Double Precision Time Clock

Return When Time Expires



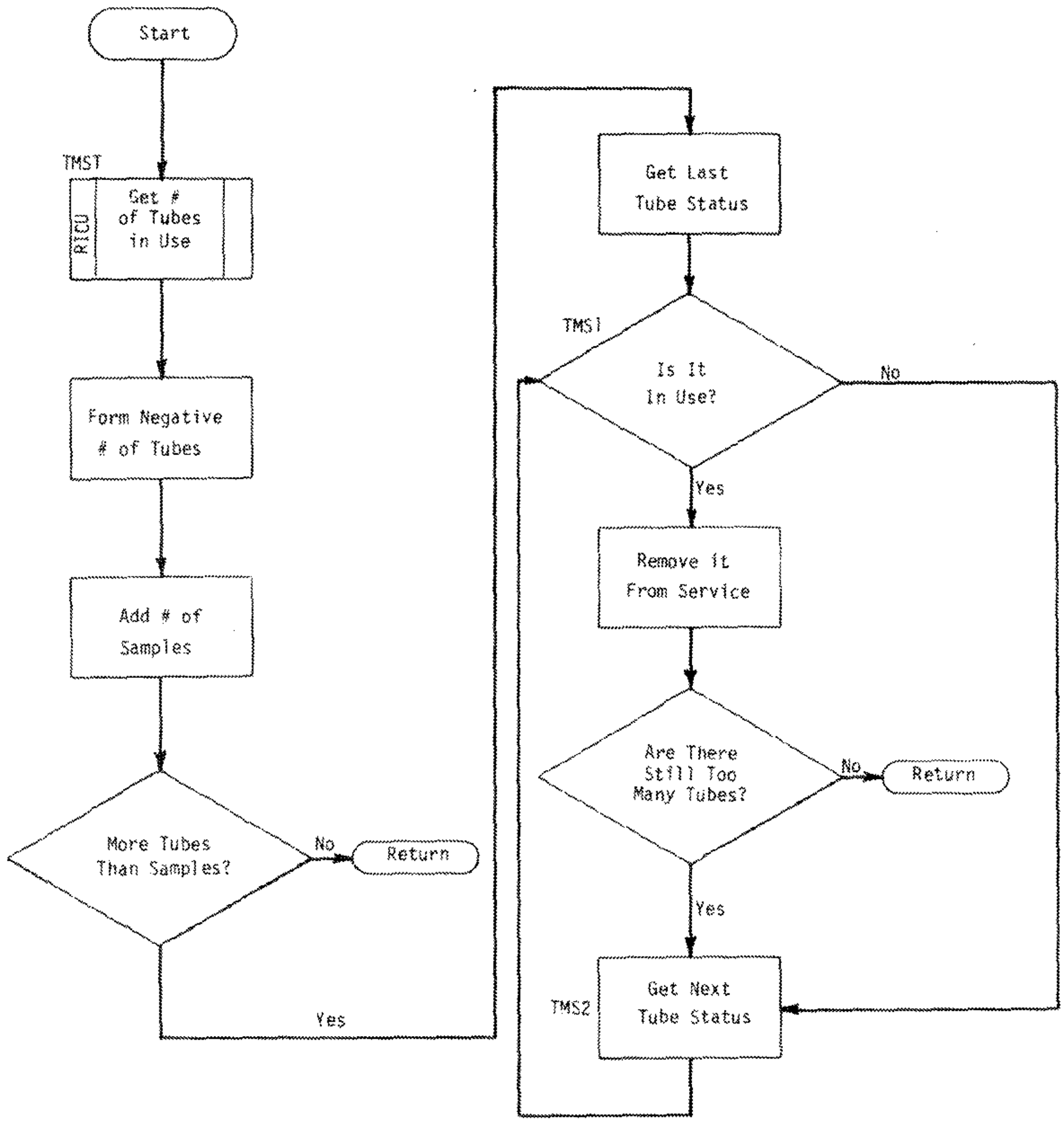
SUBROUTINE NOTB

Notify Operator that Program Was Started but no Tubes Were Specified. Gives Option to Correct and Continue.



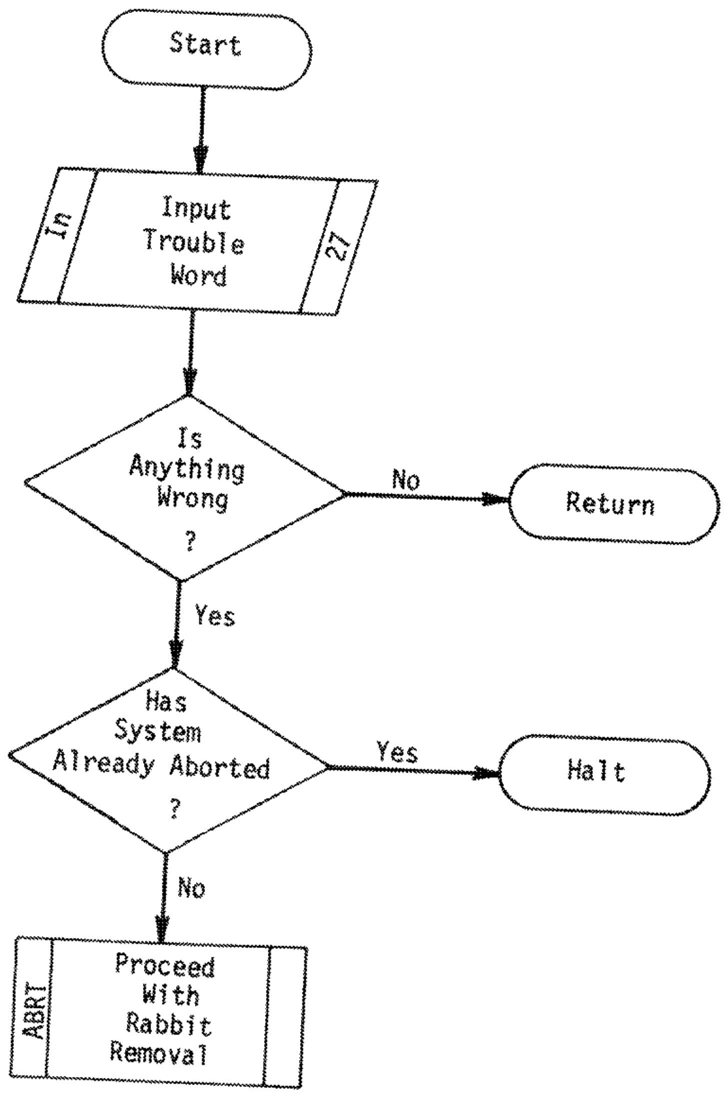
SUBROUTINE TMST

If # of Tubes is More Than # of Samples at Start, Force # of Tubes Equal to # of Samples.



SUBROUTINE TBRT

Monitor Trouble Word to Test for Conditions Warranting an Abort



APPENDIX B
PROGRAM LISTING FOR FIRMWARE IN THE NURE RABBIT CONTROLLER

The firmware program listing for the NURE Rabbit Controller is shown in this appendix. The program was written from Control Logic-M Series assembly language for Intel's 8080 microprocessor.[2,3]

```
                    /
                    /           NURE RABBIT CONTROLLER  RJS      16 JAN 76
          000 076   ODT='76 0
          021 077   CRLF='77 21
          231 077   TTYO='77 231
          157 077   OCTO='77 157
                    /           SYSTEM START UP 16 JAN 76
          000 000   *'0 0
00 000 061 370 075 LXI SP '75 370        /INITIALIZE STACK POINTER
00 003 363          DI       /DISABLE INTERRUPT
00 004 303 100 000 JMP '0 100           /START UP
          010 000   *'0 10
00 010 303 200 000 JMP '0 200           /TIMER
          020 000   *'0 20
00 020 303 000 004 JMP '4 0             /MAIN PROGRAM
          030 000   *'0 30
00 030 303 000 076 JMP '76 0            /ODT DUMP
          040 000   *'0 40
00 040 303 116 076 JMP '76 116          /ODT ?
                    /
          100 000   *'0 100 /START UP
00 100 076 000      LAI 0
00 102 323 043      OUT 43  /NORMAL SOLENOID POSITIONS
00 104 323 044      OUT 44  /ACTIVATE
00 106 323 057      OUT 57  /CLIF PDFP
00 110 323 040      OUT 40  /CLPD1
00 112 323 041      OUT 41  /CLPD2
00 114 323 042      OUT 42  /CLTBL
00 116 333 024      INP 24  /CLSTWS
00 120 076 001      LAI 1
00 122 323 100      OUT 100 /FRQSEL 0 1 HZ
00 124 076 375      LAI 375 /MASK INTERRUPTS FOR IR6
00 126 323 012      OUT 12
00 130 373          EI      /ENABLE CLOCK
00 131 303 000 004 JMP '4 0
                    /
          200 000   *'0 200 /TIMER
                    /       TIMER INTERRUPT SUBROUTINE
00 200 365          PSHX PSW            /SAVE REGISTERS
00 201 305          PSHX BC
00 202 325          PSHX DE
00 203 345          PSHX HL
00 204 052 044 075 LDHL TIME
00 207 043          INX HL
00 210 042 044 075 STHL TIME
00 213 341          POPX HL / RESTORE REGISTERS
00 214 321          POPX DE
00 215 301          POPX BC
00 216 361          POPX PSW
00 217 373          EI
00 220 311          RET
                    /
                    /
                    /
          300 000   *'0 300 /TTYI
00 300 315 317 000 TTYI,CAL REDT
00 303 062 056 075 STA HLI
00 306 315 231 077 CAL TTYO
00 311 072 056 075 LDA HLI
```

```
00 314 346 177      NDI 177
00 316 311          RET
00 317 315 250 070 REDT,CAL TBRT   /TROUBLE?
00 322 333 001      INP 1
00 324 037          RAR
00 325 323 103      OUT 103 /WAIT LIGHT
00 327 322 317 000 JFC REDT
00 332 257          XR A
00 333 323 011      OUT 11
00 335 333 000      INP 0
00 337 311          RET
       000 004      *'4 0
                    /       MAIN PROGRAM    16 JAN 76
04 000 056 000      LLI 0
04 002 046 070      LHI 70
04 004 315 247 005 CAL MSG /TITLE
04 007 315 265 005 CAL WAIT          /WAIT FOR COMMAND
                    /
04 012 315 357 015 GO,CAL RICU      /CHECK FOR TUBES
04 015 376 000      CPI 0
04 017 314 264 016 CTZ NOTB          /NO TUBES
04 022 315 051 013 CAL RICT          /FIND TUBE
04 025 052 014 075 GO1,LDHL SPL     /LOAD # SAMPLES
04 030 174          LA H
04 031 376 000      CPI 0   /CHECK FOR RABBITS GONE
04 033 302 044 004 JFZ DOR
04 036 175          LA L
04 037 376 000      CPI 0
04 041 312 175 004 JTZ RGN / RABBITS DONE
                    /       DEDUCT ONE RABBIT
04 044 026 377      DOR,LDI 377      /MINUS ONE
04 046 036 377      LEI 377
04 050 031          DADX DE
04 051 042 014 075 STHL SPL
                    /
04 054 323 052      GRXT,OUT 52    /PIF TO PDP 9 WANT TO LOAD
                    /
04 056 315 016 012 GRX1,CAL MI    /OPERATOR?
04 061 315 250 070 CAL TBRT   /TROUBLE?
04 064 333 024      INP 24     /INPUT  STWS FROM PDP9
04 066 346 017      NDI 17
04 070 376 000      CPI 0
04 072 312 056 004 JTZ GRX1
04 075 376 001      CPI 1     /ST1 CONTINUE
04 077 312 120 004 JTZ GRX2
04 102 376 002      CPI 2     /ST2 SET SAMPLES TO 0
04 104 312 112 004 JTZ GRX3
04 107 315 265 005 CAL WAIT     /ST3,ST4 - ERROR
                    /
04 112 041 000 000 GRX3,LXI HL /0 0     /SET TO 0
04 115 042 014 075 STHL SPL     /STORE SAMPLES
                    /
04 120 315 266 010 GRX2,CAL RGA /CALL REGIME A
04 123 315 020 011 CAL RGB /REGIME B
04 126 315 232 011 CAL IRGC          /INITIATE REGIME C
04 131 315 375 015 CAL RICF          /RIC FULL ?
04 134 376 000      CPI 0
04 136 302 012 004 JFZ GO  /NOT FULL
04 141 323 052      OUT 52  /SEND PIF TO PDP9
```

```
04 143 072 037 075 D2,LDA D2ST       /IS D2 FULL
04 146 376 000     CPI 0
04 150 312 164 004 JTZ TC  /EMPTY
                   /
                   /
04 153 315 325 004 CAL CBWL          /WAIT FOR CANBERRA DISPLAY MODE
04 156 315 262 011 CAL UND2          /FULL,UNLOAD
04 161 315 030 007 CAL TM5 /5 SEC
04 164 315 051 013 TC, CAL RICT      / FIND NEXT TUBE
04 167 315 234 011 CAL TRGC          / TERMINATE REGIME C
04 172 303 025 004 JMP G01
                   /
                   /        RABBITS GONE
04 175 072 032 075 RGN,LDA RICW
04 200 376 000     CPI 0
04 202 302 270 004 JFZ ABD2          /FULL
04 205 072 033 075 LDA RICX
04 210 376 000     CPI 0
04 212 302 270 004 JFZ ABD2          /
04 215 072 034 075 LDA RICY
04 220 376 000     CPI 0
04 222 302 270 004 JFZ ABD2          /
04 225 072 035 075 LDA RICZ
04 230 376 000     CPI 0
04 232 302 270 004 JFZ ABD2          /
04 235 072 037 075 LDA D2ST          /IS D2 FULL
04 240 376 000     CPI 0
04 242 312 253 004 JTZ DONE          /EMPTY
04 245 315 325 004 CAL CBWL          /WAIT FOR CANBERRA DISPLAY MODE
04 250 315 262 011 CAL UND2          /FULL,UNLOAD
                   /        PROGRAM COMPLETE
04 253 056 062     DONE,LLI 62
04 255 046 070     LHI 70
04 257 315 247 005 CAL MSG /NOTIFY COMPLETE
04 262 315 265 005 CAL WAIT          /WAIT FOR INSTRUCTIONS
04 265 303 265 005 JMP WAIT
                   /
04 270 076 001     ABD2, LAI 1       / TIME OUT FOR ABD2 TIME
04 272 323 100     OUT 100 /FRQSEL RTC 0.1 HZ
04 274 076 000     LAI 0
04 276 062 044 075 STA TIME          / ZERO ABD2 TIMER
04 301 056 022     LLI CIRT /SET UP C FINAL TIME
04 303 046 075     LHI 'CIRT
                   /
04 305 315 250 070 AB, CAL TBRT /TROUBLE?
04 310 315 016 013 CAL MI  /OPERATOR?
04 313 072 044 075 LDA TIME
04 316 226         SU M
04 317 372 305 004 JTS AB
                   /
04 322 303 143 004 JMP D2
                   /
                   /        CANBERRA STATUS 10 SEPT 75
04 325 315 016 013 CBWL,CAL MI
04 330 315 250 070 CAL TBRT
04 333 333 024     INP 24  /SENSE CANBERRA MODE
04 335 346 060     NDI 60
04 337 376 060     CPI 60  /DISPLAY MODE
04 341 302 325 004 JFZ CBWL
04 344 311         RET
```

```
                       /
                       /
                       /          SUBROUTINE BCD  RJS      8 JULY 75
                       /          BCD TO BINARY CONVERSION
                       /
04 345 016 373         BCD,LCI 373/INITIALIZE  -5
04 347 046 000         LHI 0
04 351 056 000         LLI 0
04 353 026 000         LDI 0
04 355 036 000         LEI 0
04 357 042 010 075 STHL DEC
04 362 042 012 075 STHL BIN
04 365 315 300 000 BCD1, CAL TTYI
04 370 376 072         CPI 72  /CHECK FOR DIGIT OR CR
04 372 362 062 005 JFS INVC
04 375 376 015         CPI 15
04 377 312 241 005 JTZ LNFD
05 002 326 060         SUI 60
05 004 372 062 005 JTS INVC
05 007 014             INC        /INCREMENT DIGIT COUNTER
05 010 362 062 005 JFS INVC
05 013 107             LB A       /SHIFT LEFT 4 PLACES
05 014 175             LA L
05 015 067             SETC
05 016 077             CMC
05 017 027             RAL
05 020 157             LL A
05 021 174             LA H
05 022 027             RAL
05 023 147             LH A       /
05 024 175             LA L
05 025 067             SETC
05 026 077             CMC
05 027 027             RAL
05 030 157             LL A
05 031 174             LA H
05 032 027             RAL
05 033 147             LH A       /
05 034 175             LA L
05 035 067             SETC
05 036 077             CMC
05 037 027             RAL
05 040 157             LL A
05 041 174             LA H
05 042 027             RAL
05 043 147             LH A       /
05 044 175             LA L
05 045 067             SETC
05 046 077             CMC
05 047 027             RAL
05 050 157             LL A
05 051 174             LA H
05 052 027             RAL
05 053 147             LH A       /
05 054 170             LA B
05 055 265             OR L       /ADD NEW DIGIT
05 056 157             LL A
05 057 303 365 004 JMP BCD1          /GET NEXT DIGIT
                       /          INVALID CHARACTER
05 062 056 031         INVC,LLI 31
```

```
05 064 046 070      LHI 70
05 066 315 247 005 CAL MSG
05 071 303 345 004 JMP BCD
                    /       CONVERT TO BINARY
05 074 042 010 075 CONV,STHL DEC
05 077 175          LA L    /MASK DIGIT
05 100 346 017      NDI 17
05 102 137          LE A     /STORE DIGIT IN DE
05 103 026 000      LDI 0
05 105 171          LA C
05 106 306 004      ADI 4
05 110 117          LC A
05 111 006 000      LBI 0
05 113 076 000      LAI 0
                    /
05 115 376 000      MA,CPI 0
05 117 312 140 005 JTZ ADIT          /GO TO ADD #
                    /       MULTIPLY BY 10
05 122 046 000      M10,LHI 0
05 124 056 000      LLI 0
05 126 031          DADX DE /*1
05 127 051          DADX HL /*2
05 130 051          DADX HL /*4
05 131 031          DADX DE /*5
05 132 051          DADX HL /*10
05 133 353          DE<>HL  /SWAP
05 134 075          DCA
05 135 303 115 005 JMP MA
                    /       ADD BINARY
05 140 052 012 075 ADIT,LDHL BIN
05 143 031          DADX DE
05 144 042 012 075 STHL BIN
05 147 170          LA B     /LAST DIGIT?
05 150 221          SU C
05 151 310          RTZ
05 152 052 010 075 LDHL DEC          /LOAD DECIMAL
05 155 174          LA H    /SHIFT RIGHT 4 PLACES
05 156 067          SETC
05 157 077          CMC
05 160 037          RAR
05 161 147          LH A
05 162 175          LA L
05 163 037          RAR
05 164 157          LL A    /
05 165 174          LA H
05 166 067          SETC
05 167 077          CMC
05 170 037          RAR
05 171 147          LH A
05 172 175          LA L
05 173 037          RAR
05 174 157          LL A    /
05 175 174          LA H
05 176 067          SETC
05 177 077          CMC
05 200 037          RAR
05 201 147          LH A
05 202 175          LA L
05 203 037          RAR
05 204 157          LL A    /
```

```
05 205 174          LA H
05 206 067          SETC
05 207 077          CMC
05 210 037          RAR
05 211 147          LH A
05 212 175          LA L
05 213 037          RAR
05 214 157          LL A    /
05 215 026 000      LDI 0   /STORE SHIFTED DEC
05 217 036 000      LEI 0
05 221 353          DE<>HL
05 222 031          DADX DE
05 223 042 010 075 STHL DEC
05 226 175          LA L    /MASK DIGIT
05 227 346 017      NDI 17
05 231 137          LE A
05 232 026 000      LDI 0
05 234 004          INB
05 235 170          LA B
05 236 303 115 005 JMP MA
                    /
05 241 315 021 077 LNFD,CAL CRLF
05 244 303 074 005 JMP CONV
                    /       MESSAGE ROUTINE
                    /       13 JUNE 75
                    /
05 247 315 021 077 MSG,CAL CRLF
05 252 176          MSG1,LA M
05 253 376 074      CPI 74  /CHECK FOR END OF STRING<
05 255 310          RTZ     / RETURN IF END
05 256 315 231 077 CAL TTYO
05 261 043          INX HL  / OBTAIN NEXT CHARACTER
05 262 303 252 005 JMP MSG1
                    /
                    /       SUBROUTINE WAIT 29 OCT 75       R. J. SAND
05 265 056 050      WAIT,LLI 50
05 267 046 070      LHI 70
05 271 315 247 005 CAL MSG / TYPE WAITING
05 274 315 250 070 CAL TBRT         / TEST FOR TROUBLE
05 277 315 224 015 CAL SPD / IDENTIFY CALLING ROUTINE
                    /
05 302 315 300 000 CAL TTYI
05 305 376 107      CPI "G  / G, GO
05 307 312 232 006 JTZ GOOD
05 312 376 123      CPI "S  / S, NO. OF SAMPLES
05 314 302 333 005 JFZ W1
05 317 315 345 004 CAL BCD
05 322 052 012 075 LDHL BIN
05 325 042 014 075 STHL SPL
05 330 303 265 005 JMP WAIT
                    /
05 333 376 124      W1, CPI "T        / T,     TIME
05 335 312 245 006 JTZ IRT
                    /
05 340 376 127      W2, CPI "W        / W, WHICH TUBES IN USE
05 342 302 354 005 JFZ W3
05 345 056 026      LLI WST
05 347 046 075      LHI 'WST
05 351 303 015 006 JMP ST
```

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05 354 376 130      W3, CPI "X        / X
05 356 302 370 005 JFZ W4
05 361 056 027      LLI XST
05 363 046 075      LHI \XST
05 365 303 015 006 JMP ST
                   /
05 370 376 131      W4, CPI "Y        / Y
05 372 302 004 006 JFZ W5
05 375 056 030      LLI YST
05 377 046 075      LHI \YST
06 001 303 015 006 JMP ST
                   /
06 004 376 132      W5, CPI "Z        / Z
06 006 302 060 006 JFZ W6
06 011 056 031      LLI ZST
06 013 046 075      LHI \ZST
                   /
06 015 315 300 000 ST, CAL TTYI
06 020 376 060      CPI "0  / 0, NOT IN USE
06 022 302 033 006 JFZ ONE
06 025 076 000      LAI 0   / MAKE ZERO
06 027 167          LM A
06 030 303 265 005 JMP WAIT
                   /
06 033 376 061      ONE, CPI "1     / 1, IN USE
06 035 302 046 006 JFZ BDC / BAD CHARACTER
06 040 076 001      LAI 1   / MAKE ONE
06 042 167          LM A
06 043 303 265 005 JMP WAIT
                   /
06 046 056 031      BDC, LLI 31
06 050 046 070      LHI 70
06 052 315 247 005 CAL MSG
06 055 303 265 005 JMP WAIT
                   /
06 060 376 102      W6, CPI "B        / B REGIME B CYCLES
06 062 302 101 006 JFZ W7
06 065 315 345 004 CAL BCD
06 070 052 012 075 LDHL BIN
06 073 042 051 075 STHL BCY
06 076 303 265 005 JMP WAIT
                   /
06 101 376 103      W7, CPI "C        / C CONTINUE
06 103 310          RTZ
06 104 376 117      CPI "O  / O JUMP TO ODT
06 106 312 000 076 JTZ ODT
06 111 376 101      CPI "A  / A ABORT
06 113 312 242 007 JTZ ABRT
06 116 376 104      CPI "D  / SET DETECTORS IN USE
06 120 312 375 006 JTZ DT1
06 123 376 105      CPI "E  / EXAMINE SYSTEM
06 125 312 145 006 JTZ EXM
06 130 376 060      CPI "0
06 132 312 212 006 JTZ ZERO
06 135 376 122      CPI "R  /JMP TO REGIME D
06 137 312 154 013 JTZ RGD
                             / INSERT NEW COMMANDS BEFORE NEXT LINE
                   /
06 142 303 046 006 W8.JMP BDC       / INVALID CHARACTERS
06 145 315 300 000 EXM, CAL TTYI
```

```
06 150 376 103      CPI "C  / EXAMINE COUNTERS
06 152 312 155 014 JTZ EXMC
06 155 376 124      CPI "T  / EXAMINE TUBES
06 157 312 361 014 JTZ EXMT
06 162 376 122      CPI "R  /EXAMINE IRRADIATION
06 164 312 172 006 JTZ DET
06 167 303 046 006 JMP BDC
                   /
                   /
06 172 315 300 000 DET,CAL TTYI
06 175 376 061      CPI "1  /COUNT IN D1
06 177 312 213 016 JTZ SSIC1
06 202 376 062      CPI "2  /COUNT IN D2
06 204 312 160 016 JTZ SSIC
06 207 303 046 006 JMP BDC
                   /
                   /
                        / ZERO RAM
06 212 056 010      ZERO, LLI 10
06 214 046 075      LHI 75
06 216 066 000      Z, LMI 0
06 220 054          INL
06 221 175          LA L
06 222 376 064      CPI 64
06 224 312 265 005 JTZ WAIT
06 227 303 216 006 JMP Z
                   /
                   /        INITIALIZE RICP AND GO
06 232 076 003      GOOD,LAI 3
06 234 062 036 075 STA RICP
06 237 315 301 016 CAL TMST        /CORRECT FOR MORE TUBES THAN SAMPLES
06 242 303 012 004 JMP GO
                   /
                   /
06 245 315 300 000 IRT,CAL TTYI    /TIME
06 250 376 101      CPI "A  /A TIME 255 DECIMAL MAX
06 252 302 271 006 JFZ IRT1
06 255 315 345 004 CAL BCD
06 260 052 012 075 LDHL BIN
06 263 042 016 075 STHL AIRT
06 266 303 265 005 JMP WAIT
                   /
06 271 376 102      IRT1,CPI "B     /B TIME 255 DECIMAL MAX
06 273 302 312 006 JFZ IRT2
06 276 315 345 004 CAL BCD
06 301 052 012 075 LDHL BIN
06 304 042 020 075 STHL BIRT
06 307 303 265 005 JMP WAIT
                   /
06 312 376 103      IRT2,CPI "C     /C TIME 255 DECIMAL MAX
06 314 302 333 006 JFZ IRT3
06 317 315 345 004 CAL BCD
06 322 052 012 075 LDHL BIN
06 325 042 022 075 STHL CIRT
06 330 303 265 005 JMP WAIT
                   /
06 333 376 123      IRT3,CPI "S     /SSIC TIME
06 335 302 354 006 JFZ IRT4
06 340 315 345 004 CAL BCD
06 343 052 012 075 LDHL BIN
```

```
06 346 042 024 075 STHL SIRT
06 351 303 265 005 JMP WAIT
                   /
06 354 376 104     IRT4,CPI *D      /D2 COUNT TIME
06 356 302 046 006 JFZ BDC
06 361 315 345 004 CAL BCD
06 364 052 012 075 LDHL BIN
06 367 042 063 075 STHL D2CT
06 372 303 265 005 JMP WAIT
                   /
06 375 315 300 000 DT1,CAL TTYI
07 000 376 061     CPI *1  /D1 OPERATION
07 002 302 014 007 JFZ DT2
07 005 056 041     LLI D10
07 007 046 075     LHI 'D10
07 011 303 015 006 JMP ST  /SET OPERATION
                   /
07 014 376 062     DT2,CPI *2       /D2 OPERATION
07 016 302 046 006 JFZ BDC /BAD CHARACTER
07 021 056 042     LLI D20
07 023 046 075     LHI 'D20
07 025 303 015 006 JMP ST  /SET OPERATION
                   /
                   /
                   /
                   /TMCK   5 SEC TIMER     10 JULY 75
                   /
07 030 076 062     TM5,LAI 62       /SET TIMER 5 SEC
07 032 062 043 075 STA TMK
07 035 076 004     LAI 4   /10 HZ
07 037 323 100     OUT 100 /FRQSEL RTC
07 041 076 000     LAI 0
07 043 062 044 075 STA TIME         /ZERO CLOCK
07 046 311         RET
                   /
                   /
                   /        SUBROUTINE STATUS WORD DUMP     29 OCT 75
                   /
07 047 333 020     STDM, INP 20    / INPUT PDW1-Z2, PD1
07 051 315 157 077 CAL OCTO
07 054 333 021     INP 21  / INPUT PD13-19, PD2
07 056 315 157 077 CAL OCTO
07 061 333 022     INP 22  / LIMIT SWITCHES 1-8, LS3
07 063 315 157 077 CAL OCTO
07 066 333 023     INP 23  / LIMIT SWITCHES 9-11, LS4
07 070 315 157 077 CAL OCTO
07 073 072 055 075 LDA STAD         /PLA ADDRESS
07 076 315 157 077 CAL OCTO
07 101 315 021 077 CAL CRLF
07 104 311         RET
                   / SUBROUTINE PHOTODETECTOR CHECK ONE 16 2 JULY 75
07 105 076 000     PDK1, LAI 0      / ZERO TIMER
07 107 062 060 075 STA PDF1         /ZERO FAILURE
07 112 062 044 075 STA TIME
07 115 333 025     INP 25  / INPUT TEST WORD PDT1
07 117 107         LB A
                   /
07 120 333 020     IST1, INP 20     / INPUT STATUS WORD PD1
07 122 376 000     CPI 0
07 124 312 151 007 JTZ TM  / CHECK TIME OUT
```

```
07 127 220          SU B
07 130 310          RTZ       / BOTH PD OK
                    /
07 131 026 377      LDI 377 /PD PAIR TIME CONSTANT
07 133 333 020      PK11, INP 20
07 135 220          SU B
07 136 310          RTZ       /BOTH OK
07 137 025          DCD
07 140 302 133 007  JFZ PK11
07 143 333 020      INP 20
07 145 062 060 075  STA PDF1          /STORE FAILURE
07 150 311          RET
                    /
07 151 315 157 007  TM, CAL TMCK      / CHECK TIME
07 154 303 120 007  JMP IST1          / RECHECK STATUS WORD
                    /         SUBROUTINE TIME CHECK
                    /
07 157 056 043      TMCK, LLI TMK     / LOAD TIME INTERVAL
07 161 046 075      LHI 'TMK
07 163 072 044 075  LDA TIME          / LOAD TIME
07 166 226          SU M     /
07 167 370          RTS
07 170 056 150      LLI 150 / NOTIFY TIME OUT
07 172 046 070      LHI 70
07 174 315 247 005  CAL MSG
07 177 315 047 007  CAL STDM
07 202 315 224 015  CAL SPD
07 205 315 265 005  CAL WAIT
07 210 311          RET
                    /         SUBROUTINE DIVERTER POSITION
                    /
07 211 072 055 075  DIVP, LDA STAD  / LOAD DIVERTER POSITION
07 214 323 043      OUT 43  / SET DIVERTER POSITION
07 216 323 044      OUT 44  / ACTIVATE DIVERTER VALVES
07 220 076 000      LAI 0   / RESET TIMER
07 222 062 044 075  STA TIME
                    /
07 225 333 025      DVP1, INP 25      / INPUT PDT1
07 227 107          LB A     / STORE IN B
07 230 333 022      INP 22   / INPUT LS3
07 232 220          SU B
07 233 310          RTZ       / RETURN IF IN POSITION
07 234 315 157 007  CAL TMCK          / CHECK FOR ELAPSED TIME
07 237 303 225 007  JMP DVP1
                    /         SUBROUTINE ABORT 8 SEPT 75
                    /
07 242 076 377      ABRT,LAI 377
07 244 062 047 075  STA ABTF
07 247 056 110      LLI 110
07 251 046 070      LAI 70
07 253 315 247 005  CAL MSG /ANNOUNCE ABORT
07 256 076 003      LAI 3    /INITIALIZE RICP
07 260 062 036 075  STA RICP
07 263 315 357 015  CAL RICU          /# TUBES IN USE
07 266 376 000      CPI 0
07 270 314 264 016  CTZ NOTB          /NO TUBES
07 273 137          LE A     /STORE #
                    /
07 274 315 051 013  AB1,CAL RICT      /CALCULATE UNLOAD ADDRESS
07 277 315 333 015  CAL RCST          /CALCULATE TUBE STATUS ADDRESS
```

```
07 302 176          LA M
07 303 376 001      CPI 1
07 305 312 324 007 JTZ AB3 /HAS RABBIT
                    /
07 310 173          AB2,LA E          /LOAD # TUBES
07 311 326 001      SUI 1   /DEDUCT ONE TUBE
07 313 137          LE A    /STORE # TUBES
07 314 376 000      CPI 0
07 316 312 265 005 JTZ WAIT          /ALL TUBES CHECKED
07 321 303 274 007 JMP AB1 /NOT FINISHED YET
                    /
07 324 072 055 075 AB3,LDA STAD     /SET UP UNLOAD ADDRESS
07 327 306 027      ADI 27
07 331 062 055 075 STA STAD
07 334 315 030 007 CAL TM5 /5 SEC
07 337 315 211 007 CAL DIVP          /POSITION DIVERTER RIC>D1
07 342 072 055 075 LDA STAD
07 345 074          INA
07 346 062 055 075 STA STAD
07 351 072 272 070 LDA DEL3
07 354 062 046 075 STA DELT          /DELTA T
07 357 315 236 012 CAL T12 /MOVE RABBIT RIC>D1
07 362 303 310 007 JMP AB2
                    /
                    /
                    /       SUBROUTINE LOADER SET UP          13 JULY 75
                    /
07 365 315 250 070 LDR,CAL TBRT     /TROUBLE?
07 370 315 016 013 CAL MI  /OPERATOR?
07 373 076 001      LAI 1
07 375 323 043      OUT 43  / SET UP LOADER
07 377 323 044      OUT 44  / ACTIVATE LOADER
10 001 076 000      LAI 0
10 003 062 044 075 STA TIME          / ZERO TIMER
                    /
10 006 333 023      LDR1, INP 23     / INPUT LS4 LIMIT SWITCH LOADER
10 010 346 002      NDI 2
10 012 376 002      CPI 2
10 014 310          RTZ       / CONTINUE IF IN POSITION
10 015 315 157 007 CAL TMCK          / CHECK TIME
10 020 303 006 010 JMP LDR1
                    /
                    /
                    / SUBROUTINE PHOTODETECTOR CHECK 2      16.2 JULY 75
                    /
10 023 173          PDK2,LA E
10 024 376 000      CPI 0
10 026 302 041 010 JFZ PK23
10 031 076 000      LAI 0
10 033 062 061 075 STA PDF2
10 036 303 046 010 JMP PK24
10 041 076 000      PK23,LAI 0
10 043 062 062 075 STA PDF3
10 046 062 044 075 PK24,STA TIME
10 051 333 026      INP 26  / INPUT TEST WORD PDT2
10 053 107          LB A
                    /
10 054 333 021      IST2, INP 21     / INPUT STATUS WORD PD2
10 056 346 337      NDI 337 /MASK OUT LOADER BIT 5
10 060 376 000      CPI 0
```

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10 062 312 125 010 JTZ TM1 / CHECK TIME OUT
10 065 220         SU B
10 066 310         RTZ     / BOTH PD OK
10 067 026 377     LDI 377 /PD PAIR TIME CONSTANT
                   /
10 071 333 021     PK21, INP 21
10 073 346 337     NDI 337 /MASK OUT LOADER BIT 5
10 075 220         SU B
10 076 310         RTZ     /BOTH OK
10 077 025         DCD
10 100 302 071 010 JFZ PK21
10 103 173         LA E
10 104 376 000     CPI 0
10 106 302 117 010 JFZ PK22
10 111 333 021     INP 21
10 113 062 061 075 STA PDF2          /STORE FIRST FAILURE
10 116 311         RET
                   /
10 117 333 021     PK22, INP 21
10 121 062 062 075 STA PDF3          /STORE SECOND FAILURE
10 124 311         RET
                   /
10 125 315 157 007 TM1, CAL TMCK   / CHECK TIME
10 130 303 054 010 JMP TST2          / RECHECK STATUS WORD
                   /
                   /
                   /       SUBROUTINE IRRD 14 AUGUST 75
                   /
10 133 323 041     IRRD, OUT 41      /CLPD2
10 135 333 021     INP 21  / LOAD PD2
10 137 346 040     NDI 40  / PD 18 BIT 5
10 141 376 040     CPI 40
10 143 312 160 010 JTZ IRD1
10 146 056 170     LLI 170 / SET UP EMPTY MESSAGE
10 150 046 070     LHI 70
10 152 315 247 005 CAL MSG
10 155 315 265 005 CAL WAIT
                   /
10 160 076 003     IRD1, LAI 3       / SET UP L->D1
10 162 062 055 075 STA STAD
10 165 315 030 007 CAL TM5 /5 SEC
10 170 315 211 007 CAL DIVP          / POSITION DIVERTERS
10 173 315 030 007 CAL TM5 /5 SEC
10 176 315 365 007 CAL LDR / LOAD LOADER
10 201 072 055 075 LDA STAD
10 204 074         INA
10 205 062 055 075 STA STAD          / SET UP PLA ADDRESS
10 210 072 270 070 LDA DEL1
10 213 062 046 075 STA DELT          / SETUP DELTA T
10 216 315 036 012 CAL T22 / MOVE RABBIT L -> D1
10 221 315 250 070 CAL TBRT          /TROUBLE?
10 224 315 016 013 CAL MI  /OPERATOR?
10 227 072 050 075 LDA PLAA          / FIND TUBE
10 232 306 007     ADI 7
10 234 062 055 075 STA STAD          / POSITION DIVERTERS D1 -> RIC
10 237 315 030 007 CAL TM5 /5 SEC
10 242 315 211 007 CAL DIVP
10 245 072 055 075 LDA STAD
10 250 074         INA
10 251 062 055 075 STA STAD          / SET UP ADDRESS
```

```
10 254 072 271 070 LDA DEL2
10 257 062 046 075 STA DELT          / DELTA T
10 262 315 326 012 CAL T21 / MOVE RABBIT D1 -> RIC
10 265 311         RET
                   /
                   /
                   /       SUBROUTINE REGIME A      12 SEPT 75
                   /
10 266 315 133 010 RGA,CAL IRRD      /PUT RABBIT IN REACTOR
10 271 056 016     LLI AIRT          /SET UP TIME
10 273 046 075     LHI 'AIRT
10 275 076 004     LAI 4   /10 HZ
10 277 323 100     OUT 100 /FRQSEL RTC
10 301 076 000     LAI 0
10 303 062 044 075 STA TIME          /ZERO TIMER
                   /
10 306 315 016 013 RGA1,CAL MI       /OPERATOR?
10 311 315 250 070 CAL TBRT          /TROUBLE?
10 314 072 044 075 LDA TIME
10 317 276         CP M
10 320 372 306 010 JTS RGA1
10 323 072 055 075 LDA STAD
10 326 306 016     ADI 16
10 330 062 055 075 STA STAD          /
10 333 072 272 070 LDA DEL3
10 336 062 046 075 STA DELT          /
10 341 315 236 012 CAL T12 / MOVE RABBIT RIC -> D1
10 344 323 047     OUT 47  / SET UP PID1 TO PDP9
                   /
10 346 315 250 070 RGA2,CAL TBRT   /TROUBLE?
10 351 315 016 013 CAL MI  /OPERATOR?
10 354 333 024     INP 24  / BRING IN WORD STW5
10 356 346 017     NDI 17
10 360 376 000     CPI 0
10 362 312 346 010 JTZ RGA2
10 365 376 001     CPI 1   / RETURN IF ST 1
10 367 310         RTZ
10 370 376 002     CPI 2   / REJECT SAMPLE IF ST 2
10 372 312 003 011 JTZ RGA3
10 375 315 265 005 CAL WAIT
11 000 303 265 005 JMP WAIT
                   /
11 003 056 210     RGA3, LLI 210
11 005 046 070     LHI 70
11 007 315 247 005 CAL MSG / ANNOUNCE HOT SAMPLE
11 012 315 113 014 CAL D1U /UNLOAD RABBIT  D1>U
11 015 303 025 004 JMP GO1
                   /
                   /
                   /       SUBROUTINE REGIME B      24 SEPT 75
                   /
11 020 052 051 075 RGB, LDHL BCY / SET UP B CYCLE COUNTER
11 023 042 053 075 STHL BCYW
                   /
11 026 174         RGBA, LA H
11 027 376 000     CPI 0
11 031 302 053 011 JFZ RGB2          / IF NOT DONE CONTINUE RGB2
11 034 175         LA L
11 035 376 000     CPI 0
11 037 302 053 011 JFZ RGB2
```

```
11 042 323 051     OUT 51  / PIC TO PDP9
                   /
11 044 315 250 070 CAL TBRT /TROUBLE?
11 047 315 016 013 CAL MI  /OPERATOR?
11 052 311         RET
                   /
11 053 072 055 075 RGB2, LDA STAD
11 056 326 022     SUI 22
11 060 062 055 075 STA STAD         / SET UP PLA ADDRESS
11 063 072 271 070 LDA DEL2
11 066 062 046 075 STA DELT         / SET UP DELTA T
11 071 315 326 012 CAL T21 / MOVE RABBIT D1>RIC
11 074 076 000     LAI 0
11 076 062 056 075 STA HL1
                   /
11 101 056 020     RB30,LLI BIRT    /SET UP TIME
11 103 046 075     LHI 'BIRT
11 105 076 004     LAI 4   /10 HZ
11 107 323 100     OUT 100 /FRQSEL RTC
11 111 076 000     LAI 0
11 113 062 044 075 STA TIME         /ZERO TIMER
                   /
11 116 315 016 013 RGB3,CAL MI      /OPERATOR?
11 121 315 250 070 CAL TBRT         /TROUBLE?
11 124 072 044 075 LDA TIME
11 127 276         CP M
11 130 372 116 011 JTS RGB3
11 133 072 056 075 LDA HL1
11 136 376 000     CPI 0
11 140 302 153 011 JFZ RB31
11 143 076 001     LAI 1   /DO IT TWICE
11 145 062 056 075 STA HL1
11 150 303 101 011 JMP RB30
                   /
11 153 072 055 075 RB31,LDA STAD
11 156 306 016     ADI 16
11 160 062 055 075 STA STAD
11 163 072 272 070 LDA DEL3
11 166 062 046 075 STA DELT
11 171 315 236 012 CAL T12 / MOVE RABBIT RIC>D1
11 174 323 047     OUT 47  / PID1 TO PDP9
11 176 052 053 075 LDHL BCYW
11 201 053         DCX HL
11 202 042 053 075 STHL BCYW
                   /
11 205 315 250 070 RGB4,CAL TBRT    /TROUBLE?
11 210 315 016 013 CAL MI  /OPERATOR?
11 213 333 024     INP 24  / CHECK FOR ST3
11 215 346 017     NDI 17
11 217 376 004     CPI 4
11 221 302 205 011 JFZ RGB4
11 224 052 053 075 LDHL BCYW
11 227 303 026 011 JMP RGBA        / CONTINUE
                   /
                   /      SUBROUTINE INITIATE REGIME C 4 SEPT 1975
                   /
11 232 072 055 075 IRGC, LDA STAD
11 235 326 022     SUI 22
11 237 062 055 075 STA STAD
11 242 072 271 070 LDA DEL2
```

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11 245 062 046 075 STA DELT
11 250 315 326 012 CAL T21 / MOVE RABBIT D1>RIC
11 253 315 250 070 CAL TBRT          /TROUBLE?
11 256 315 016 013 CAL MI  /OPERATOR?
11 261 311         RET
                   /        SUBROUTINE UNLOAD DELI D2        8 SEPT 75
                   /
11 262 076 053     UND2, LAI 53     / SET UP DIVERTER POSITION
11 264 062 055 075 STA STAD
11 267 315 030 007 CAL TM5 /5 SEC
11 272 315 211 007 CAL DIVP          / POSITION DIVERTERS
11 275 072 055 075 LDA STAD
11 300 074         INA
11 301 062 055 075 STA STAD          / SET UP PLA ADDRESS
11 304 072 274 070 LDA DEL5
11 307 062 046 075 STA DELT          / SET UP DELTA T
11 312 315 036 012 CAL T22 / MOVE RABBIT TO D1
11 315 315 250 070 CAL TBRT          /TROUBLE?
11 320 315 016 013 CAL MI  /OPERATOR?
11 323 315 113 014 CAL D1U /D1 TO UNLOAD
11 326 076 000     LAI 0
11 330 062 037 075 STA D2ST          / CLEAR D2 STATUS
11 333 311         RET
                   /
                   /
                   /        SUBROUTINE TERMINATE REGIME C 4 SEPT 75
                   /
11 334 072 055 075 TRGC, LDA STAD
11 337 306 027     ADI 27
11 341 062 055 075 STA STAD
11 344 315 030 007 CAL TM5 /5 SEC
11 347 315 211 007 CAL DIVP          / POSITION DIVERTERS RIC->D1
11 352 072 055 075 LDA STAD
11 355 074         INA
11 356 062 055 075 STA STAD
11 361 072 272 070 LDA DEL3
11 364 062 046 075 STA DELT
11 367 315 236 012 CAL T12 / MOVE RABBIT RIC->D1
11 372 076 047     LAI 47
11 374 062 055 075 STA STAD
11 377 315 030 007 CAL TM5 /5 SEC
12 002 315 211 007 CAL DIVP          / POSITION DIVERTERS D1->D2
12 005 072 055 075 LDA STAD
12 010 074         INA
12 011 062 055 075 STA STAD
12 014 072 273 070 LDA DEL4
12 017 062 046 075 STA DELT
12 022 315 036 012 CAL T22 / MOVE RABBIT TO D2
12 025 315 014 016 CAL STR2          /START D2 COUNTER
12 030 076 001     LAI 1
12 032 062 037 075 STA D2ST          / SET D2 STATUS TO FULL
12 035 311         RET
                   /
                   /
                   /
                   /        LOCAL TRANSPORT SUBROUTINE 14 AUGUST 1975
                   /
12 036 072 055 075 T22, LDA STAD
12 041 323 043     OUT 43  / STAD SET UP PLA STARTING ADDRESS
12 043 323 041     OUT 41  / CLEAR PHOTODETECTORS 2
```

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12 045 315 030 007 CAL TM5 /5 SEC
12 050 323 044     OUT 44  / ACTIVATE VALVES ACTV
12 052 076 000     LAI 0
12 054 062 060 075 STA PDF1
12 057 036 000     LEI 0   /FIRST PDK2
12 061 315 023 010 CAL PDK2         / VERIFY DEPARTURE
12 064 315 055 016 CAL PRP /PAUSE FOR RABBIT PASSAGE
12 067 323 041     OUT 41  / CLEAR PHOTODETECTORS 2
12 071 315 030 007 CAL TM5 /5 SEC
12 074 072 055 075 LDA STAD
12 077 074         INA     / INCREMENT ADDRESS
12 100 062 055 075 STA STAD
12 103 323 043     OUT 43
12 105 036 001     LEI 1   /SECOND PDK2
12 107 315 023 010 CAL PDK2         / VERIFY ARRIVAL
12 112 315 055 016 CAL PRP /PAUSE FOR RABBIT PASSAGE
                   /
                   /
12 115 315 121 012 CAL TRT /TERMINATE TRANSPORT
12 120 311         RET
                   /
                   /
                   /       TERMINATE TRANSPORT SUBROUTINES 16.2 JULY 75
12 121 323 044     TRT, OUT 44      / ACTIVATE VALVES
12 123 076 010     LAI 10  /100 HZ
12 125 323 100     OUT 100 /FRQSEL RTC
12 127 076 000     LAI 0
12 131 062 044 075 STA TIME         / RESET TIMER
12 134 056 046     LLI DELT         / LOAD DELTA T
12 136 046 075     LHI ^DELT
                   /
12 140 072 044 075 TME, LDA TIME    / LOAD TIME
12 143 226         SU M
12 144 372 140 012 JTS TME / TEST LOOP
12 147 072 055 075 LDA STAD
12 152 074         INA     / INCREMENT PLA ADDRESS
12 153 062 055 075 STA STAD
12 156 323 043     OUT 43  / SET UP NORMAL VALVE POSITION
12 160 323 044     OUT 44  / ACTIVATE VALVES
12 162 072 060 075 LDA PDF1         /PD FAILURE REGISTER
12 165 376 000     CPI 0
12 167 302 210 012 JFZ TRT1         /DUMP IF FAILURE
12 172 072 061 075 LDA PDF2
12 175 376 000     CPI 0
12 177 302 210 012 JFZ TRT1
12 202 072 062 075 LDA PDF3
12 205 376 000     CPI 0
12 207 310         RTZ
                   /
12 210 072 060 075 TRT1, LDA PDF1
12 213 315 157 077 CAL OCTO         /DUMP PD1
12 216 072 061 075 LDA PDF2
12 221 315 157 077 CAL OCTO         /DUMP PD2 FIRST
12 224 072 062 075 LDA PDF3
12 227 315 157 077 CAL OCTO         /DUMP PD2 SECOND
12 232 315 021 077 CAL CRLF
12 235 311         RET
                   /
                   /CROSSCOUNTRY TRANSPORT SUBROUTINE 4 SEPT 75
```

```
12 236 072 055 075 T12, LDA STAD
12 241 323 043      OUT 43  / STAD SET UP PLA STARTING ADDRESS
12 243 323 040      OUT 40  / CLEAR PHOTODETECTORS 1
12 245 315 030 007 CAL TM5 /5 SEC
12 250 323 044      OUT 44  / ACTIVATE VALVES ACTV
12 252 315 105 007 CAL PDK1        / VERIFY DEPARTURE
12 255 323 050      OUT 50  / PIRIC TO PDP9
12 257 315 333 015 CAL RCST        /CLEAR TUBE STATUS
12 262 066 000      LMI 0
12 264 315 055 016 CAL PRP /PAUSE FOR RABBIT PASSAGE
12 267 323 041      OUT 41  / CLEAR PHOTODETECTORS 2
12 271 315 030 007 CAL TM5 /5 SEC
12 274 072 055 075 LDA STAD
12 277 074          INA      / INCREMENT ADDRESS
12 300 062 055 075 STA STAD
12 303 323 043      OUT 43
12 305 076 000      LAI 0
12 307 062 062 075 STA PDF3
12 312 036 000      LEI 0
12 314 315 023 010 CAL PDK2        / VERIFY ARRIVAL
12 317 315 055 016 CAL PRP /PAUSE FOR RABBIT PASSAGE
12 322 315 121 012 CAL TRT /TERMINATE TRANSPORT
12 325 311          RET
                    /
                    /CROSS COUNTRY TRANSPORT SUBROUTINE 4 SEPT 75
                    /
12 326 072 055 075 T21, LDA STAD
12 331 323 043      OUT 43  / STAD SET UP PLA STARTING ADDRESS
12 333 323 041      OUT 41  / CLEAR PHOTODETECTORS 2
12 335 315 030 007 CAL TM5 /5 SEC
12 340 323 044      OUT 44  / ACTIVATE VALVES ACTV
12 342 076 000      LAI 0
12 344 062 062 075 STA PDF3
12 347 036 000      LEI 0
12 351 315 023 010 CAL PDK2        / VERIFY DEPARTURE
12 354 315 055 016 CAL PRP /PAUSE FOR RABBIT PASSAGE
12 357 323 040      OUT 40  / CLEAR PHOTODETECTORS 2
12 361 315 030 007 CAL TM5 /5 SEC
12 364 072 055 075 LDA STAD
12 367 074          INA      / INCREMENT ADDRESS
12 370 062 055 075 STA STAD
12 373 323 043      OUT 43
12 375 315 105 007 CAL PDK1        / VERIFY ARRIVAL
13 000 323 050      OUT 50  /PIRIC TO PDP9
13 002 315 333 015 CAL RCST        /SET TUBE STATUS
13 005 066 001      LMI 1
13 007 315 055 016 CAL PRP /PAUSE FOR RABBIT PASSAGE
13 012 315 121 012 CAL TRT /TERMINATE TRANSPORT
13 015 311          RET
                    /
                    /                               .
                    /
                    /        MANUAL INTERRUPT SUBROUTINE      19 JUNE 75
                    /
13 016 333 000      MI, INP 0       /INPUT ANYTHING FROM TTY
13 020 376 311      CPI 311 /CHECK FOR I INTERRUPT
13 022 312 026 013 JTZ MI1
13 025 311          RET
13 026 341          MI1, POPX HL
13 027 174          LA H
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13 030 346 077      NDI 77
13 032 315 157 077 CAL OCTO
13 035 175          LA L
13 036 315 157 077 CAL OCTO
13 041 345          PSHX HL
13 042 315 021 077 CAL CRLF
13 045 315 265 005 CAL WAIT
13 050 311          RET
                    /
                    /NEXT RIC TUBE TESTER SUBROUTINE         6 JUNE 75
                    /
13 051 072 036 075 RICT,LDA RICP    /LOAD POINTER
13 054 376 003      CPI 3   /CHECK FOR TUBE Z
13 056 302 063 013 JFZ RCT1
13 061 076 377      LAI 377
                    /
13 063 074          RCT1,INA          /NEXT TUBE
13 064 062 036 075 STA RICP
13 067 376 000      CPI 0   /TUBE W?
13 071 312 132 013 JTZ WRIC
13 074 376 001      CPI 1   /         X?
13 076 312 140 013 JTZ XRIC
13 101 376 002      CPI 2   /         Y?
13 103 312 146 013 JTZ YRIC
13 106 072 031 075 LDA ZST /          Z!
                    /
13 111 376 000      RCT2,CPI 0        /IS IT IN USE?
13 113 312 051 013 JTZ RICT          /NO
13 116 072 036 075 LDA RICP          /YES *1
13 121 207          AD A    /         *2
13 122 207          AD A    /         *4
13 123 062 055 075 STA STAD
13 126 062 050 075 STA PLAA
13 131 311          RET
                    /
13 132 072 026 075 WRIC,LDA WST
13 135 303 111 013 JMP RCT2
13 140 072 027 075 XRIC,LDA XST
13 143 303 111 013 JMP RCT2
13 146 072 030 075 YRIC,LDA YST
13 151 303 111 013 JMP RCT2
                    /
                    /
                    /         REGIME D          30"D OCT 75
                    /
13 154 052 014 075 RGD, LDHL SPL    /LOAD # SAMPLES
13 157 174          LA H
13 160 376 000      CPI 0   /CHECK FOR RABBITS GONE
13 162 302 173 013 JFZ RGD1          /DEDUCT ONE RABBIT
13 165 175          LA L
13 166 376 000      CPI 0
13 170 312 344 013 JTZ RGD7          /ALL GONE
                    /
13 173 026 377      RGD1,LDI 377      /MINUS ONE
13 175 036 377      LEI 377
13 177 031          DADX DE
13 200 042 014 075 STHL SPL
13 203 323 041      OUT 41  /CLPD2
13 205 333 021      INP 21  /LOAD PD2
13 207 346 040      NDI 40  /PD 18  BIT 5
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13 211 376 040     CPI 40
13 213 312 230 013 JTZ RGD2
13 216 056 170     LLI 170
13 220 046 070     LHI 70
13 222 315 247 005 CAL MSG /EMPTY MESSAGE
13 225 315 265 005 CAL WAIT
                   /
13 230 076 003     RGD2,LAI 3        /SET UP L>D1
13 232 062 055 075 STA STAD
13 235 315 030 007 CAL TM5 /5 SEC
13 240 315 211 007 CAL DIVP          /POSITION DIVERTER
13 243 315 030 007 CAL TM5 /5 SEC
13 246 315 365 007 CAL LDR /LOAD LOADER
13 251 072 055 075 LDA STAD
13 254 074         INA
13 255 062 055 075 STA STAD          /SET UP PLA ADDRESS
13 260 072 270 070 LDA DEL1
13 263 062 046 075 STA DELT          /SET UP DELTA T
13 266 315 036 012 CAL T22 /MOVE RABBIT L>D1
13 271 076 001     LAI 1
13 273 062 040 075 STA D1ST          /SET D1 TO FULL
13 276 323 047     OUT 47  /PID1 TO PDP 9
13 300 315 016 013 RGD5,CAL MI       /OPERATOR?
13 303 333 024     INP 24  /INPUT STW5 FROM PDP9
13 305 346 017     NDI 17
13 307 376 000     CPI 0
13 311 312 300 013 JTZ RGD5
13 314 376 002     CPI 2   /ST2     REJECT  REMOVE RABBIT
13 316 312 336 013 JTZ RGD6
13 321 376 001     CPI 1   /ST1 COUNT THIS RABBIT
13 323 312 376 013 JTZ RGD8
13 326 376 004     CPI 4   /ST3 COUNT COMPLETE REMOVE RABBITS
13 330 312 055 014 JTZ RGD9
13 333 315 265 005 CAL WAIT
                   /
13 336 315 113 014 RGD6,CAL D1U      /D1>UNLOAD
13 341 303 154 013 JMP RGD
                   /
13 344 072 037 075 RGD7,LDA D2ST    /CHECK IF D2 FULL
13 347 376 000     CPI 0
13 351 312 364 013 JTZ RGDD          /D2 NOT FULL
13 354 315 325 004 CAL CBWL          /WAIT FOR CANBERRA DISPLAY MODE
13 357 323 057     OUT 57  /TURN OFF SD2 LIGHT
13 361 315 262 011 CAL UND2          /UNLOAD D2
13 364 056 062     RGDD,LLI 62       /RUN COMPLETE
13 366 046 070     LHI 70
13 370 315 247 005 CAL MSG
13 373 303 265 005 JMP WAIT
                   /
13 376 072 042 075 RGD8,LDA D2O     /IS D2 IN OPERATION
14 001 376 000     CPI 0
14 003 312 300 013 JTZ RGD5
14 006 072 037 075 LDA D2ST          /IS D2 FULL
14 011 376 001     CPI 1
14 013 312 300 013 JTZ RGD5          /NO
14 016 315 306 014 CAL LSD2
14 021 323 052     OUT 52  /PIF TO PDP9
14 023 072 041 075 LDA D1O /IS D1 IN OPERATION
14 026 376 000     CPI 0
14 030 312 300 013 JTZ RGD5          /NO
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14 033 052 014 075 LDHL SPL         /ANY MORE RABBITS
14 036 174         LA H
14 037 376 000     CPI 0
14 041 302 173 013 JFZ RGD1         /MORE
14 044 175         LA L
14 045 376 000     CPI 0
14 047 312 300 013 JTZ RGD5         /NO MORE
14 052 303 173 013 JMP RGD1         /MORE
                   /
14 055 072 040 075 RGD9,LDA D1ST    /IS D1 FULL
14 060 376 000     CPI 0
14 062 312 070 014 JTZ RGDZ         /NOT FULL
14 065 315 113 014 CAL D1U /FULL UNLOAD D1
                   /
14 070 072 037 075 RGDZ,LDA D2ST    /IS D2 FULL
14 073 376 000     CPI 0
14 075 312 154 013 JTZ RGD /NOT FULL
14 100 315 325 004 CAL CBWL         /WAIT FOR CANBERRA DISPLAY MODE
14 103 323 057     OUT 57  /TURN OFF SD2 LIGHT
14 105 315 262 011 CAL UND2         /UNLOAD D2
14 110 303 154 013 JMP RGD
                   /
                   /
                   /        D1>UNLOAD         27 AUGUST 75
                   /
14 113 076 057     D1U,LAI 57       /SET UP D1 > U
14 115 062 055 075 STA STAD
14 120 315 030 007 CAL TM5 /5 SEC
14 123 315 211 007 CAL DIVP         /DIVERTERS
14 126 072 055 075 LDA STAD
14 131 074         INA
14 132 062 055 075 STA STAD
14 135 072 275 070 LDA DEL6
14 140 062 046 075 STA DELT
14 143 315 036 012 CAL T22 /MOVE RABBIT D1>U
14 146 315 030 007 CAL TM5 /5 SEC
14 151 315 254 015 CAL UNL
14 154 311         RET
                   /
                   /
                   /        ROUTINE EXAMINE COUNTERS        29 OCT 75
14 155 323 041     EXMC,OUT 41      /CLPD2
14 157 333 021     INP 21  /LOAD PD2
14 161 346 040     NDI 40  /PD 18 BIT 5
14 163 376 040     CPI 40
14 165 312 202 014 JTZ EXM1
14 170 056 170     LLI 170 /EMPTY MESSAGE
14 172 046 070     LHI 70
14 174 315 247 005 CAL MSG
14 177 315 265 005 CAL WAIT
                   /
14 202 076 003     EXM1,LAI 3       /SET UP L>D1
14 204 062 055 075 STA STAD
14 207 315 030 007 CAL TM5 /5 SEC
14 212 315 211 007 CAL DIVP         /POSITION DIVERTERS
14 215 315 030 007 CAL TM5 /5 SEC
14 220 315 365 007 CAL LDR /LOAD LOADER
14 223 072 055 075 LDA STAD
14 226 074         INA
14 227 062 055 075 STA STAD         /SET UP PLA ADDRESS
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14 232 072 270 070 LDA DEL1
14 235 062 046 075 STA DELT          /SET UP DELTA T
14 240 315 036 012 CAL T22 /MOVE RABBIT L>D1
14 243 323 047     OUT 47  /PID1 TO PDP9
                   /
14 245 333 024     EXM2,INP 24      /STW5 FROM PDP9
14 247 346 017     NDI 17
14 251 376 000     CPI 0
14 253 312 245 014 JTZ EXM2
14 256 315 306 014 CAL LSD2         /LOAD AND START D2
                   /
14 261 315 325 004 CAL CBWL         /WAIT FOR CANBERRA DISPLAY MODE
14 264 323 057     OUT 57  /TURN OFF SD2 LIGHT
14 266 315 262 011 CAL UND2         /UNLOAD D2
14 271 056 062     LLI 62
14 273 046 070     LHI 70
14 275 315 247 005 CAL MSG /RUN COMPLETE
14 300 315 265 005 CAL WAIT
14 303 303 265 005 JMP WAIT
                   /
                   /LOAD AND START D2       30 OCT 75
                   /
                   /
14 306 076 000     LSD2,LAI 0
14 310 062 040 075 STA D1ST         /SET D1 TO EMPTY
14 313 076 047     LAI 47
14 315 062 055 075 STA STAD         /POSITION DIVERTER D1>D2
14 320 315 030 007 CAL TM5 /5 SEC
14 323 315 211 007 CAL DIVP
14 326 072 055 075 LDA STAD
14 331 074         INA
14 332 062 055 075 STA STAD
14 335 072 273 070 LDA DEL4
14 340 062 046 075 STA DELT
14 343 315 036 012 CAL T22 /MOVE RABBIT D1>D2
14 346 315 014 016 CAL STR2         /START D2 COUNTERS
14 351 323 054     OUT 54  /TURN ON SD2 LIGHT
14 353 076 001     LAI 1
14 355 062 037 075 STA D2ST         /SET D2 TO FULL
14 360 311         RET
                   /
                   /
                   /
                   / ROUTINE EXAMINE TUBES 29 OCT 75 RJS
                   /
14 361 076 003     EXMT,LAI 3
14 363 062 036 075 STA RICP         /INITIALIZE POINTER
14 366 323 041     OUT 41  /CLPD2
14 370 333 021     INP 21  /LOAD PD2
14 372 346 040     NDI 40  /PD 10  BIT 5
14 374 376 040     CPI 40
14 376 312 013 015 JTZ XMT1
15 001 056 170     LLI 170
15 003 046 070     LHI 70
15 005 315 247 005 CAL MSG /EMPTY MESSAGE
15 010 315 265 005 CAL WAIT
                   /
15 013 076 003     XMT1,LAI 3       /SET UP L>D1
15 015 062 055 075 STA STAD
15 020 315 030 007 CAL TM5 /5 SEC
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15 023 315 211 007 CAL DIVP          /POSITION DIVERTERS
15 026 315 030 007 CAL TM5 /5 SEC
15 031 315 365 007 CAL LDR /LOAD LOADER
15 034 072 055 075 LDA STAD
15 037 074         INA
15 040 062 055 075 STA STAD          /SET UP PLA ADDRESS
15 043 072 270 070 LDA DEL1
15 046 062 046 075 STA DELT          /SET UP DELTA T
15 051 315 036 012 CAL T22 /MOVE RABBIT L>D1
                   /
15 054 315 357 015 XMT2,CAL RICU    /COUNT TUBES IN USE
15 057 117         LC A
                   /
15 060 376 000     XMT3,CPI 0        /SEE IF ALL TUBES CHECKED
15 062 312 154 015 JTZ XMT4
15 065 315 051 013 CAL RICT          /GET TUBE ADDRESS
15 070 072 055 075 LDA STAD          /LOAD PLA ADDRESS
15 073 306 007     ADI 7
15 075 062 055 075 STA STAD
15 100 315 030 007 CAL TM5 /5 SEC
15 103 315 211 007 CAL DIVP          /POSITION DIVERTERS D1>RIC
15 106 072 055 075 LDA STAD
15 111 074         INA
15 112 062 055 075 STA STAD
15 115 072 271 070 LDA DEL2
15 120 062 046 075 STA DELT
15 123 315 326 012 CAL T21 /MOVE RABBIT D1>RIC
15 126 072 055 075 LDA STAD
15 131 306 016     ADI 16
15 133 062 055 075 STA STAD
15 136 072 272 070 LDA DEL3
15 141 062 046 075 STA DELT
15 144 315 236 012 CAL T12 /MOVE RABBIT RIC > D1
15 147 015         DCC      /DECREMENT COUNTER
15 150 171         LA C
15 151 303 060 015 JMP XMT3
                   /
15 154 076 047     XMT4,LAI 47
15 156 062 055 075 STA STAD
15 161 315 030 007 CAL TM5 /5 SEC
15 164 315 211 007 CAL DIVP
15 167 072 055 075 LDA STAD
15 172 074         INA
15 173 062 055 075 STA STAD
15 176 072 273 070 LDA DEL4
15 201 062 046 075 STA DELT
15 204 315 036 012 CAL T22 /MOVE RABBIT D1>D2
15 207 315 262 011 CAL UND2         /UNLOAD D2>U
15 212 056 062     LLI 62
15 214 046 070     LHI 70
15 216 315 247 005 CAL MSG /RUN COMPLETE
15 221 303 265 005 JMP WAIT
                   /
                   /
                   /
                   /     STACK POINTER DUMP       13 JUNE 75
                   /
15 224 341         SPD, POPX HL
15 225 042 056 075 STHL HL1
15 230 341         POPX HL /GET ADDRESS TO WHICH CALLING
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15 231 174          LA H    /ROUTINE WOULD HAVE RETURNED
15 232 346 077      NDI 77
15 234 315 157 077 CAL OCTO
15 237 175          LA L
15 240 315 157 077 CAL OCTO         /WRITE PAGE, LOCATION
15 243 345          PSHX HL
15 244 052 056 075 LDHL HL1
15 247 345          PSHX HL
15 250 315 021 077 CAL CRLF
15 253 311          RET
                    /
                    /
                    /       UNLOADER SUBROUTINE      10 JULY 75
15 254 333 023      UNL,INP 23        /INPUT PRESSURE IN UNLOADER
15 256 346 004      NDI 4
15 260 376 004      CPI 4
15 262 312 273 015 JTZ UNL1          /UNLOAD RABBIT IF PRESSURE IS DOWN
15 265 315 157 007 CAL TMCK          /CHECK FOR ELAPSED TIME
15 270 303 254 015 JMP UNL
                    /
15 273 323 041      UNL1,OUT 41       /CLEAR EXIT PHOTO DETECTOR
15 275 076 063      LAI 63  /SET UP UNLOADER INSTRUCTION
15 277 323 043      OUT 43
15 301 323 044      OUT 44  /ACTIVATE SOLENOID
15 303 074          INA
15 304 323 043      OUT 43  /SET UP FOR CLOSING
15 306 315 030 007 CAL TM5
                    /
15 311 333 021      UNL2,INP 21       /INPUT PHOTODETECTOR UNLOADER EXIT
15 313 346 100      NDI 100
15 315 376 100      CPI 100
15 317 312 330 015 JTZ UNLC          /CLOSE IF OUT
15 322 315 157 007 CAL TMCK
15 325 303 311 015 JMP UNL2
                    /
15 330 323 044      UNLC,OUT 44       /CLOSE
15 332 311          RET
                    /
                    /
                    /
                    /
                    /       RIC TUBE STATUS SUBROUTINE       10 SEPT 75
15 333 171          RCST,LA C
15 334 062 056 075 STA HL1
15 337 056 032      LLI RICW          /LOAD RIC TUBE CONTENTS
15 341 046 075      LHI 'RICW
15 343 072 036 075 LDA RICP
15 346 117          LC A
15 347 006 000      LBI 0
15 351 011          DADX BC /CALCULATE ADDRESS OF
15 352 072 056 075 LDA HL1
15 355 117          LC A
15 356 311          RET     /CURRENT RIC STATUS
                    /
                    /
                    /
                    /       RIC IN USE SUBROUTINE   13 JUNE 75
15 357 056 026      RICU,LLI WST    /W IN USE
15 361 046 075      LHI 'WST
15 363 076 000      LAI 0
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```
15 365 206          AD M
15 366 043          INX HL  /X IN USE
15 367 206          AD M
15 370 043          INX HL  /Y IN USE
15 371 206          AD M
15 372 043          INX HL  /Z IN USE
15 373 206          AD M
15 374 311          RET
                    /
                    /
                    /
                    /         RTC FULL SUBROUTINE       13 JUNE 75
15 375 315 357 015 RICF,CAL RICU   /# TUBES IN USE
16 000 056 032      LLI RICW        /W FULL
16 002 046 075      LHI 'RICW
16 004 226          SU M
16 005 043          INX HL  /X FULL
16 006 226          SU M
16 007 043          INX HL  /Y FULL
16 010 226          SU M
16 011 043          INX HL  /Z FULL
16 012 226          SU M    /ZERO FULL        + NOT FULL
16 013 311          RET
                    /
                    /
                    /
                    /         START D2 COUNTER         10 SEPT 75
                    /
16 014 315 325 004 STR2,CAL CBWL   /WAIT FOR CANBERRA DISPLAY MODE
16 017 076 000      LAI 0
16 021 062 044 075 STA TIME
16 024 323 102      OUT 102 /ZERO MEMORY
16 026 076 015      LAI 15  /130 MSEC
16 030 062 043 075 STA TMK
16 033 076 010      LAI 10  /100 HZ
16 035 323 100      OUT 100 /FRQSEL RTC
16 037 056 043      LLI TMK
16 041 046 075      LHI 'TMK
16 043 072 044 075 TTT, LDA TIME
16 046 226          SU M
16 047 372 043 016 JTS TTT
16 052 323 101      OUT 101 /START D2
16 054 311          RET
                    /
                    /
                    /
                    /PAUSE FOR RABBIT TO PASS DETECTOR 14 AUGUST 75
                    /
                    /
16 055 076 010      PRP,LAI 10        /100 HZ
16 057 323 100      OUT 100 /SET RTC
16 061 076 366      LAI 366 /-100 MSEC
16 063 062 044 075 STA TIME
16 066 072 044 075 PRP1,LDA TIME
16 071 376 000      CPI 0
16 073 302 066 016 JFZ PRP1
16 076 311          RET
                    /
                    /
                    /
```

```
                    /SINGLE SAMPLE IRRADIATION AND COUNT 29 OCT 75
                    /
                    /
16 077 315 357 015 SS,CAL RICU        /CHECK FOR TUBES
16 102 376 000     CPI 0
16 104 314 264 016 CTZ NOTB           /NO TUBES
16 107 315 051 013 CAL RICT           /GET ACTIVE TUBE
16 112 315 133 010 CAL IRRD           /PUT RABBIT IN REACTOR
                    /
16 115 076 002     LAI 2   /1 HZ
16 117 323 100     OUT 100 /SET RTC
16 121 076 000     LAI 0
16 123 147         LH A
16 124 157         LL A
16 125 042 044 075 STHL TIME          /ZERO TIME
16 130 052 024 075 LDHL STRT
16 133 315 237 016 CAL DPTC
                    /
16 136 072 055 075 SS2,LDA STAD
16 141 306 016     ADI 16
16 143 062 055 075 STA STAD
16 146 072 272 070 LDA DEL3
16 151 062 046 075 STA DELT
16 154 315 236 012 CAL T12 /RIC>D1
16 157 311         RET .
                    /
                    /
16 160 315 077 016 SSIC,CAL SS
16 163 315 306 014 CAL LSD2           /LOAD AND START D2
                    /
16 166 315 325 004 CAL CBWL           /WAIT FOR CANBERRA DISPLAY MODE
                    /
16 171 323 057     SS4,OUT 57         /TURN OFF SD2 LIGHT
16 173 315 262 011 CAL UND2           /UNLOAD D2
16 176 056 062     SSS,LLI 62
16 200 046 070     LHI 70
16 202 315 247 005 CAL MSG /RUN COMPLETE
16 205 315 265 005 CAL WAIT
16 210 303 265 005 JMP WAIT
                    /
                    /
16 213 315 077 016 SSIC1,CAL SS
16 216 323 047     OUT 47  /PID1 TO PDP9
                    /
16 220 333 024     SSSS,INP 24        /STWS FROM PDP9
16 222 346 017     NDI 17
16 224 376 000     CPI 0
16 226 312 220 016 JTZ SSSS
16 231 315 113 014 CAL D1U
16 234 303 176 016 JMP SSS
                    /
                    /
                    /
16 237 174         DPTC,LA H          /TWO'S COMPLEMENT H + L 25 AUGUST 75
16 240 057         CMA
16 241 107         LB A
16 242 175         LA L
16 243 057         CMA
16 244 117         LC A
16 245 003         INX BC
```

```
16 246 315 016 013 TCS1,CAL MI      /OPERATOR
16 251 315 250 070 CAL TBRT         /TROUBLE
16 254 052 044 075 LDHL TIME
16 257 011         DADX BC
16 260 322 246 016 JFC TCS1
16 263 311         RET
                   /
                   /
                   /
                   /        NO TUBES MESSAGE         4 SEPT 75
                   /
16 264 107         NOTB,LB A        /STORE A
16 265 056 035     LLI 35
16 267 046 070     LHI 70
16 271 315 247 005 CAL MSG /NO TUBES
16 274 315 265 005 CAL WAIT
16 277 170         LA B     /RESTORE A
16 300 311         RET
                   /
                   /        TUBE MINUS SAMPLE TESTER         12 SEPT 75
16 301 315 357 015 TMST,CAL RICU   /GET # TUBES IN USE
16 304 057         CMA
16 305 074         INA      /GET NEGATIVE # TUBES
16 306 117         LC A
16 307 076 000     LAI 0
16 311 057         CMA
16 312 107         LB A     /LOAD BC WITH -# TUBES
16 313 052 014 075 LDHL SPL         /LOAD HL WITH # OF SAMPLES
16 316 011         DADX BC /FIND DIFFERENCE
16 317 330         RTC      /SAMPLES >= TUBES
16 320 353         DE<>HL   /STORE DIFFERENCE IN DE
16 321 056 031     LLI ZST
16 323 046 075     LHI 'ZST
16 325 076 000     LAI 0
                   /
16 327 276         TMS1,CP M        /IS LAST TUBE IN USE?
16 330 312 337 016 JTZ TMS2         /NO      GET NEXT LAST TUBE
16 333 066 000     LMI 0
16 335 034         INE      /ANY MORE EXTRA TUBES?
16 336 310         RTZ /    NO MORE
                   /
16 337 076 000     TMS2,LAI 0       /FORM TWO BYTE MINUS ONE
16 341 057         CMA
16 342 107         LB A
16 343 117         LC A
16 344 011         DADX BC /GET NEXT TUBE
16 345 303 327 016 JMP TMS1
                   /
                   /
                   /
                   /
                   /MESSAGE         8 SEPT 75
       000 070     *'70 0
70 000 116         TEXT 30 NURE RABBIT CONTROLLER
70 001 125
70 002 122
70 003 105
70 004 040
70 005 122
70 006 101
```

```
70 007 102
70 010 102
70 011 111
70 012 124
70 013 040
70 014 103
70 015 117
70 016 116
70 017 124
70 020 122
70 021 117
70 022 114
70 023 114
70 024 105
70 025 122
70 026 015
70 027 012
70 030 074         TEXT 4 <?
70 031 077
70 032 015
70 033 012
70 034 074         TEXT 13 <NO TUBES
70 035 116
70 036 117
70 037 040
70 040 124
70 041 125
70 042 102
70 043 105
70 044 123
70 045 015
70 046 012
70 047 074         TEXT 1 <
       050 070     *'70 50
70 050 127         TEXT 11 WAITING
70 051 101
70 052 111
70 053 124
70 054 111
70 055 116
70 056 107
70 057 015
70 060 012
70 061 074         TEXT 17 <RUN COMPLETE
70 062 122
70 063 125
70 064 116
70 065 040
70 066 103
70 067 117
70 070 115
70 071 120
70 072 114
70 073 105
70 074 124
70 075 105
70 076 015
70 077 012
70 100 074         TEXT 1 <
       110 070     *'70 110
```

```
70 110 101          TEXT 7 ABORT
70 111 102
70 112 117
70 113 122
70 114 124
70 115 015
70 116 012
70 117 074          TEXT 1 <
       150 070      *'70 150
70 150 124          TEXT 12 TIME OUT
70 151 111
70 152 115
70 153 105
70 154 040
70 155 117
70 156 125
70 157 124
70 160 015
70 161 012
70 162 074          TEXT 1 <
       170 070      *'70 170
70 170 114          TEXT 16 LOADER EMPTY
70 171 117
70 172 101
70 173 104
70 174 105
70 175 122
70 176 040
70 177 105
70 200 115
70 201 120
70 202 124
70 203 131
70 204 015
70 205 012
70 206 074          TEXT 1 <
       210 070      *'70 210
70 210 110          TEXT 14 HOT SAMPLE
70 211 117
70 212 124
70 213 040
70 214 123
70 215 101
70 216 115
70 217 120
70 220 114
70 221 105
70 222 015
70 223 012
70 224 074          TEXT 1 <
                    /
       250 070      *'70 250
                    /         SUBROUTINE TEST ABORT 10 SEPT 75
                    /
70 250 333 027      TBRT, INP 27    /TEST FOR TBL ABORT CONDITION
70 252 376 000      CPI 0
70 254 310          RTZ
70 255 072 047 075  LDA ABTF
70 260 376 377      CPI 377
70 262 302 242 007  JFZ ABRT
```

```
70 265 303 000 076 JMP ODT
                   /
                   /
                   /
                   /
                   /
                   /
                   /
70 270 012         DEL1,01 12       /DELTA T1 FOR TRANSPORT ROUTINE
70 271 012         DEL2,01 12
70 272 012         DEL3,01 12
70 273 000         DEL4,01 0
70 274 012         DEL5,01 12
70 275 000         DEL6,01 0
                   /
       010 075     *'75 10 /VARIABLE RANDOM ACCESS 29 OCT 75
75 010 000 000     DEC,02  /BINARY CODED DECIMAL STORAGE
75 012 000 000     BIN,02  /BINARY STORAGE
75 014 000 000     SPL,02  /# OF SAMPLES
75 016 000 000     AIRT,02 /A IRRADIATION TIME
75 020 000 000     BIRT,02 /B IRRADIATION TIME
75 022 000 000     CIRT,02 /C IRRADIATION TIME
75 024 000 000     SIRT,02 /SSIC IRRADIATION TIME
75 026 000         WST,01  /TUBE STATUS 1 IN USE 0 OUT OF USE
75 027 000         XST,01
75 030 000         YST,01
75 031 000         ZST,01
75 032 000         RICW,01 /TUBE CONTENTS 1 FULL 0 EMPTY
75 033 000         RICX,01
75 034 000         RICY,01
75 035 000         RICZ,01
75 036 000         RICP,01 /TUBE POINTER
75 037 000         D2ST,01 /D2 STATUS 1 FULL 0 EMPTY
75 040 000         D1ST,01 /D1 STATUS      1 FULL 0 EMPTY
75 041 000         D1O,01  /D2 OPERATION   1 IN USE         0 OUT OF USE
75 042 000         D2O,01  /D2 OPERATION   1 IN USE 0 OUT OF USE
75 043 000         TMK,01  /TIME CHECK TIME INTERVAL
75 044 000 000     TIME,02 /RESETTABLE TIMER ACCESSED BY INTERRUPT
75 046 000         DELT,01 /DELTA T FOR TRANSIT SEQUENCING
75 047 000         ABTF,01 /ABORT FLAG      377=ABORTED
75 050 000         PLAA,01 /PLA ADDRESS
75 051 000 000     BCY,02  /B CYCLE TIMES
75 053 000 000     BCYW,02 /B CYCLE COUNTER
75 055 000         STAD,01 / PLA STARTING ADDRESS
75 056 000 000     HL1,02  /TEMP 2 BYTE STORAGE
75 060 000         PDF1,01 /PD1 FAILURE STORAGE
75 061 000         PDF2,01 /PD2 FIRST FAILURE STORAGE
75 062 000         PDF3,01 /PD2 SECOND FAILURE STORAGE
75 063 000 000     D2CT,02 /CANBERRA COUNT TIME
                   /
                   $
```

```
ODT     0 000 000 076
CRLF    0 000 021 077
TTYO    0 000 231 077
OCTO    0 000 157 077
TTYI    0 000 300 000
REDT    0 000 317 000
GO      0 000 012 004
GO1     0 000 025 004
DOR     0 000 044 004
GRXT    0 000 054 004
GRX1    0 000 056 004
GRX3    0 000 112 004
GRX2    0 000 120 004
D2      0 000 143 004
TC      0 000 164 004
RGN     0 000 175 004
DONE    0 000 253 004
ABD2    0 000 270 004
AB      0 000 305 004
CBWL    0 000 325 004
BCD     0 000 345 004
BCD1    0 000 365 004
INVC    0 000 062 005
CONV    0 000 074 005
MA      0 000 115 005
M10     0 000 122 005
ADIT    0 000 140 005
LWFD    0 000 241 005
MSG     0 000 247 005
MSG1    0 000 252 005
WAIT    0 000 265 005
W1      0 000 333 005
W2      0 000 340 005
W3      0 000 354 005
W4      0 000 370 005
W5      0 000 004 006
ST      0 000 015 006
ONE     0 000 033 006
BDC     0 000 046 006
W6      0 000 060 006
W7      0 000 101 006
W8      0 000 142 006
EXM     0 000 145 006
DET     0 000 172 006
ZERO    0 000 212 006
Z       0 000 216 006
GOOO    0 000 232 006
IRT     0 000 245 006
IRT1    0 000 271 006
IRT2    0 000 312 006
IRT3    0 000 333 006
IRT4    0 000 354 006
DT1     0 000 375 006
DT2     0 000 014 007
TM5     0 000 030 007
STDM    0 000 047 007
PDK1    0 000 105 007
IST1    0 000 120 007
PK11    0 000 133 007
```

TM	0	000	151	007
TMCK	0	000	157	007
DIVP	0	000	211	007
DVP1	0	000	225	007
ABRT	0	000	242	007
AB1	0	000	274	007
AB2	0	000	310	007
AB3	0	000	324	007
LDR	0	000	365	007
LDR1	0	000	006	010
PDK2	0	000	023	010
PK23	0	000	041	010
PK24	0	000	046	010
IST2	0	000	054	010
PK21	0	000	071	010
PK22	0	000	117	010
TM1	0	000	125	010
IRRD	0	000	133	010
IRD1	0	000	160	010
RGA	0	000	266	010
RGA1	0	000	306	010
RGA2	0	000	346	010
RGA3	0	000	003	011
RGB	0	000	020	011
RGBA	0	000	026	011
RGB2	0	000	053	011
RB30	0	000	101	011
RGB3	0	000	116	011
RB31	0	000	153	011
RGB4	0	000	205	011
IRGC	0	000	232	011
UND2	0	000	262	011
TRGC	0	000	334	011
T22	0	000	036	012
TRT	0	000	121	012
TME	0	000	140	012
TRT1	0	000	210	012
T12	0	000	236	012
T21	0	000	326	012
MI	0	000	016	013
MI1	0	000	026	013
RICT	0	000	051	013
RCT1	0	000	063	013
RCT2	0	000	111	013
WRIC	0	000	132	013
XRIC	0	000	140	013
YRIC	0	000	146	013
RGD	0	000	154	013
RGD1	0	000	173	013
RGD2	0	000	230	013
RGD5	0	000	300	013
RGD6	0	000	336	013
RGD7	0	000	344	013
RGDD	0	000	364	013
RGD8	0	000	376	013
RGD9	0	000	055	014
RGDZ	0	000	070	014
D1U	0	000	113	014
EXMC	0	000	155	014
EXM1	0	000	202	014
EXM2	0	000	245	014
LSD2	0	000	306	014
EXMT	0	000	361	014
XMT1	0	000	013	015
XMT2	0	000	054	015
XMT3	0	000	060	015
XMT4	0	000	154	015
SPD	0	000	224	015
UNL	0	000	254	015
UNL1	0	000	273	015
UNL2	0	000	311	015
UNLC	0	000	330	015
RCST	0	000	333	015
RICU	0	000	357	015
RICF	0	000	375	015
STR2	0	000	014	016
TTT	0	000	043	016
PRP	0	000	055	016
PRP1	0	000	066	016
SS	0	000	077	016
SS2	0	000	136	016
SSIC	0	000	160	016
SS4	0	000	171	016
SSS	0	000	176	016
SSIC1	0	000	213	016
SSSS	0	000	220	016
DPTC	0	000	237	016
TCS1	0	000	246	016
NUTE	0	000	264	016
TMST	0	000	301	016
TMS1	0	000	327	016
TMS2	0	000	337	016
TBRT	0	000	250	070
DEL1	0	000	270	070
DEL2	0	000	271	070
DEL3	0	000	272	070
DEL4	0	000	273	070
DEL5	0	000	274	070
DEL6	0	000	275	070
DEC	0	000	010	075
BIN	0	000	012	075
SPL	0	000	014	075
AIRT	0	000	016	075
BIRT	0	000	020	075
CIRT	0	000	022	075
SIRT	0	000	024	075
WST	0	000	026	075
XST	0	000	027	075
YST	0	000	030	075
ZST	0	000	031	075
RICW	0	000	032	075
RICX	0	000	033	075
RICY	0	000	034	075
RICZ	0	000	035	075
RICP	0	000	036	075
D2ST	0	000	037	075
D1ST	0	000	040	075
D10	0	000	041	075
D20	0	000	042	075
TMK	0	000	043	075
TIME	0	000	044	075
DELT	0	000	046	075
ABTF	0	000	047	075
PLAA	0	000	050	075
BCY	0	000	051	075
BCYW	0	000	053	075
STAD	0	000	055	075
HL1	0	000	056	075
PDF1	0	000	060	075
PDF2	0	000	061	075
PDF3	0	000	062	075
D2CT	0	000	063	075

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