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Effluent and Sanitary Sewer Monitors

by

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EFFLUENT AND SANITARY SEWER MONITORS

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ABSTRACT

Two similar instruments that monitor the liquid wastes from the plutonium facility are described. The operation of the two instruments is completely automatic and performs a continuous surveillance in the frame of Nuclear Safeguards. One instrument controls the liquids from the facility and the other checks the sanitary sewer wastes. Both have self-diagnosing capabilities and take automatic actions in case of abnormal occurrences.

I. INTRODUCTION

This manual deals with two similar instruments that monitor the effluents from the plutonium facility to prevent environmental pollution with radioactive waste and also to safeguard strategic nuclear material by avoiding its fraudulent diversion.

The first instrument, Effluent Monitor System, is the more complex; it is related to two analog chains for acquiring data from low- and medium-energy particles. The second instrument, Sanitary Sewer Monitor System, looks at low-energy particles only.

The electronic circuitry is practically the same for both instruments, the second being obtained from the first by eliminating unnecessary parts with few minor modifications.

The programs are also similar but they are arranged differently. A general description of the first instrument¹ indicates the reasons for the choice of the detectors and the hardware. The second instrument uses the same concepts and will not be described in detail here. However, full details about hardware, software, and operative procedures are outlined in the following sections.

The general description in Ref. 1 should be referred to even though additions and minor modifications have been made.

II. OPERATIVE PROCEDURES

Both instruments stand alone; they operate continuously without surveillance by the operator.

Both instruments can acquire data about radioactivity in the effluent and can take action if a preset threshold is exceeded. Both also have self-diagnosing capabilities for correct operation.

The operator has access to three switches and two pushbuttons in addition to the keyboard. The switches for Power-on, Automatic Power Restart Enable (APRE), and Audible Warning Enable (AWE) are reached by opening the front panel. The pushbuttons on the front panel stop the operation or reset the alarms. Other features can be called by the operator via the keyboard. If a key is pressed, the program answers by calling the requested procedure or by printing either WRONG INITIAL or ILLEGAL CHARACTER, depending on the first character that was typed. The legal initials are C, E,

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I, O, P, S, and T, corresponding to the available procedures CONTINUE, EXPER, INITIALIZE, OPER, PRINT, START, and TEST. ILLEGAL COMMAND is printed if the operator attempts to interrupt the calibration sequence.

The instrument starts automatically if APRE=1. The first time the power switch is set to ON, the content of the operative constants is random and it must be initialized. If the operator switches the power OFF and ON, the value of the constants stored in C-MOS RAM will not disappear and can be recovered.

When energized the instrument goes to warm up if APRE=1 or to a standby position (EXIT=HALT) if APRE=0.

The operator can call one of the listed procedures that causes a program interrupt by typing the desired name, e.g., INITIALIZE or START.

INITIALIZE allows the operator to set the values of the operative constants. Twelve messages are automatically displayed on the teletype printout for setting the values of time and number of measurements, the Alarm 1 threshold, the limits for source counting, and the values of the corrective constants for peak evaluation. The operator types an X plus carriage return (CR) if the displayed number in any particular message is correct. If it is not correct, the operator types the desired number plus carriage return, and the new number is stored in C-MOS RAM, replacing the old one. Then the next message is displayed, to the end of the twelve messages. END OF INITIALIZE is then printed followed by a prompt character (?) requesting new instructions. At this point, the operator normally will begin the operation with the START or CONTINUE command.

START forces the instrument to start with a 2-min calibration sequence composed of three phases. The three phases are (1) MOV1 (30 s), which brings the sources into the calibrating position; (2) STABILIZE (60 s), which allows for source counting (Now, the analog stabilizers are activated to compensate for drifts in the detector and the analog chain.); and (3) MOV2 (30 s) which brings the sources back to the rest position. Note that it is illegal to interrupt the calibration sequence; if the operator presses any key + CR during this 2-min time, the command is refuted and ILLEGAL COM-

MAND is printed. The only exception is PRINT, which is accepted at any time.

CONTINUE allows the operator to skip the calibration and to go directly to measurements. Normally this is done when a calibration has just been completed and the operator wishes to change, for example, the alarm threshold, and then restart immediately. In this case a new calibration is pleonastic and CONTINUE allows an immediate measurement.

EXPER is used to test the hardware with a recurrent signal that can be checked easily with the oscilloscope. This procedure sends ones and zeros alternately with one of six different infinite loops. It was reduced for the EFFLU program because it exceeded the 4096 bytes allowed by the PROMs assembled on the single-board computer. It has been used with the Effluent Monitor by neglecting ALARM 4. The SEWEFF program has this procedure as an integral part.

OPER² is used to store an auxiliary program in RAM for future use. The operator types codes in machine language terminated by a slash (/). The auxiliary program then is executed automatically. See Ref. 2 for details. Some difficulties due to the ASCII codes are outlined in Ref. 3.

PRINT sets a flag that is used by the program at the end of the measurement to print data corresponding to corrected peak areas, or at the end of the stabilization to print the source counts. The number of successive measurements printed is governed by a number stored in RAM during initialization. This procedure interrupts the calibration sequence to print the source contents. The PRINT flag is reset only at the beginning of each measurement and successive measurement results can be printed if the operator has fixed the number of prints at greater than 1. If the operator sets the PRINT flag during the last measurement before calibration there is the double effect of printing the results of that measurement plus the source contents at the end of the successive calibration.

TEST is used by the operator to gate off the connection to the building computer so that he can test conditions that provoke alarms, without sending unwanted warnings. The TEST condition can be quite dangerous if the operator forgets to reset the TEST flip-flop. To prevent this occurrence, it is reset

automatically, as is the PRINT flag, at the beginning of each measurement. The TEST flag must be set before entering the calibration sequence if it has to block Alarm 2 conditions.

The above procedures set the values of particular bytes called operative fields, which have well-defined addresses.

Addresses of the instrument are given in Table I, whereas bit assignments of the OP fields are shown in Table II.

III. FRONT PANEL INDICATIONS

Figure 1 shows the completed instrument with details of the front panel. The POWER, APRE, and AWE switches are located behind the front panel and are not accessible without opening it. Two manual commands are available on the front panel: the STOP pushbutton, which stops the operation and disables the hardware, and the MANUAL ALARM RESET, which is useful in preliminary operations.

Two vertical rows of red LED lamps indicate the operative phases and status, respectively. The names near the lamps are self-explanatory. The ENABLE status of the hardware is indicated by two lamps switched by the 30-s clock that controls the entire operation. The two lamps also provide the clock time.

The phase lamps indicate the succession of operative phases. The warm-up phase occurs at the beginning and the others follow with cyclic permutation. A preestablished number of measurements is performed before each calibration, and the operator can determine the time of each measure-

ment as well as the number of measurements in a set by the switching of the double lamp indicating the measurement phases.

Two blue lamps indicate APRE=1 and AWE=1. They warn, when lit, that automatic power restart and audible warnings, respectively, are enabled.

Five lamps indicate the alarm conditions. A very impressive flashing yellow lamp indicates Alarm 1, three red LED lamps indicate the group of Alarm 2, and a green lamp indicates the presence of power. (Lack of power will darken this lamp and set Alarm 3.) Alarms 4 and 5 use a combination of lamps, as described below.

IV. ALARMS

Different alarms warn the operator when something performs incorrectly during each phase. In these occurrences, actions will be initiated automatically. The various alarms with their consequent actions are listed below.

Alarm 1 is set if the 17-keV counts in the selected time exceed the predetermined numerical threshold. Both time and threshold are stored in CMOS memory. If Alarm 1 is set, the building computer is warned, and local actions are taken. The flashing yellow lamp goes on and a double audible warning-local and remote-starts. (Audible devices can be silenced by the operator.) At the same time data corresponding to the 17-keV counts are sent to a chart recorder via a digital-to-analog converter (DAC), and the recorder is started. The recorder uses a thermal pen because a normally idle instrument cannot use an inked pen safely. The contents

TABLE I
MEMORY ADDRESSES

<u>ITEM</u>	<u>HEX ADDR.</u>	<u>DECIMAL ADDR.</u>
On-board PROMs	0000 - 0FFF	0 - 4095
On-board RAMs	3C00 - 3FFF	15360 - 16383
C-MOS RAM	4000 - 40FF	16384 - 16639
Counters and OP fields	8000 - 8007	32768 - 32775

TABLE II
BIT ASSIGNMENT

Address (Hex)	Bit No.	Write	Hex Value	Bit No.	Read
8000	0-7	READ ONLY COUNTERS			SC 1 (Low)
8001	8-15				SC 1 (High)
8002	0-7				SC 2 (Low)
8003	8-15				SC 2 (High)
8004	0	-	01H	0	APRE
(OP1)	1	Warm-up	02H	1	Warm-up flag
	2	MOV1	04H	2	MOV1 flag
	3	Source Count Enable (Alarm 21?)	08H	3	SC flag
	4	MOV2	10H	4	MOV2 flag
	5	MEAS (Alarm 23?)	20H	5	MEAS flag
	6	SET E	40H	6	AL21
	7	-	80H	7	AL23
START	(2,6)	SET E + MOV 1	44H	(2)	Read 04H
CONTINUE	(5,6)	SET E + MEAS	60H	(5)	Read 20H
8005	0	TEST	01H	0	TEST
(OP2)	1	COUNT ENABLE (1/0)	02H	1	COUNT ENABLE
	2	PRINT	04H	2	PRINT
	3	RESET E	08H	3	-
	4	INITIALIZE (LAMP)	10H	4	-
	5	-	20H	5	SOURCE COUNT OVERFLOW
	6	-	40H	6	-
	7	-	80H	7	-
INITIALIZE	(3,4)	RESET E + INIT (LAMP)	18H	(-)	No Read
8007	0	WRITE ONLY (FALSE/TRUE AL1)			-
(OP3)					
8007	0	WRITE ONLY (FALSE/TRUE AL22)			-
(OP4)

Fig. 1.
Front Panel of the Monitor. The same port panel is used by Effluent and Sanitary Sewer Monitors.

of the three peak areas (17 keV, 59.6 keV, and 400 keV) are corrected with the equation

$$A = P - kB \quad , \quad (1)$$

where P is the content of counts between the amplitude thresholds that select a peak in one of the single-channel analyzers (SCA) and B is the total count in the background, corrected with the constant k preset by the operator and stored in C-MOS RAM.

The difference can be negative if the constant is not chosen properly or if the number of pulses is so low that statistical fluctuations reverse the normal situation. As the peak of 17 keV sets Alarm 1 if the threshold is exceeded, a suitable constant is added. The evaluation for the 17-keV area is thus

$$A = \text{Corr} + P - kB \quad , \quad (2)$$

where the constant Corr also is stored (as STOCORR) in C-MOS RAM. It is quite clear that a small negative number is seen as a large content given by the four hexadecimal digits allowed for counting. As an example, -1 is seen as FFFFH, which in decimal is 65535. The occurrence time of the alarm is not printed because it results in a duplication of the real-time counting of the building computer and it becomes meaningless after a power failure.

Last, but not least, Alarm 1 drives the holding tank controller. This is now only a provision that the hardware is performing. When the holding tank and its controller have been constructed, the effluent will be diverted automatically to the holding tank, from the first occurrence of the alarm until the end of the first nonalarmed measurement.

Alarm 2 is set up during calibration and is, in effect, a group of three alarms that take different actions. Alarm 21 is related to MOV1. If the source position is not confirmed by an optical sensor, the action is to stop the instrument completely and warn the building computer. No recovery is possible without intervention by the operator. Alarm 22 is related to source counting. If one or both source counters are outside their own high or low limits (stored in C-MOS memory), the source counts are printed automatically and a warning is sent to the building computer. The instrument is not stopped, but there is no guarantee that the analog chain will perform correctly. Alarm 23 is related to MOV2 and is similar to Alarm 21.

Alarm 3 is established by the lack of power and disables all the hardware in the instrument before the voltage is completely down, taking only the external action of warning the building computer by opening a normally closed (N.C.) connection.

Alarm 4 is very particular and is related to the lack of pulses in any one of the five pulse counters. This lack can be caused by a hardware imperfection and is software implemented only. The imperfection can be a bad contact, a broken wire, or a noninserted coaxial cable. The lack of pulses can also occur because of a failure in the detectors or in the analog chain, both in the amplification part or in one single-channel analyzer (SCA). If one of the counters receives no pulses, Alarm 4 is set. During correct operation it is impossible to have no counts, therefore a perfect zero is reason for alarm, es-

pecially because a lack of pulses in the 17-keV counter will not set Alarm 1, which is related to the main abnormal condition that the instrument has to evidence. This could be a way to tamper if a suitable diagnosis is not made. When Alarm 4 is set, a coding from Alarm 2 group is performed. Alarm 4 is indicated by the simultaneous presence of Alarm 21 + Alarm 23, which is impossible in the normal succession of phases.

Note that Alarm 4 raises the PRINT flag so that peak areas are displayed. A zero is seen in the area or areas corresponding to the incoming zero. The numbers, together with AL21 + AL23, will be quite clear to the operator. If the three areas show normal counts, this means that a zero was in one of the background counts not displayed.

It seems useful not to stop the operation because, even in this condition, other actions can be performed by the instruments before the intervention of the operator. For example, if Alarm 4 is given by a counter other than the 17 keV, Alarm 1 can be recognized afterwards and the necessary action taken.

Alarm 5 takes care of a lack in the clock interrupt circuitry. Unlike Alarm 4, this is only hardware implemented. During the operation, a contact related to the dialog between CPU and hardware can fail. Three contacts on the 100-pin connector to the hardware board can cause a clock interrupt failure, and these have been reinforced by putting a double contact on both sides of the connector. The failure is now less probable, but a suitable warning is necessary. Assuming that the operator relies on the instrument, which normally behaves regularly, he gives it perhaps only a quick glance every day. He arrives, everything seems all right, and the ENABLE lamps are switching regularly every 30 s. But if the interrupt due to clock has not been received by the CPU, the MEAS lamp is not switched. We cannot rely on the operator waiting maybe 10 min (if this is the selected measurement time) to see if the MEAS lamp switches. Assuming that the interrupt is not received by the CPU, no action is taken by the instrument, which becomes useless if no suitable diagnostics have been provided. For that purpose an appropriate diagnosis capability is provided by the hardware. A time-out failure is related to the clock, setting up the ALARM 5 flip-flop by the handshaking feature of

the Programmable Peripheral Interfaces (PPI) mounted on the single-board computer. The interrupt is set by the pulse $\overline{STB_D} = \overline{CLST}$, which provokes feedback of the $\overline{IBF_B}$ pulse. This pulse resets flip-flop U2-6A. If either pulse is lost, the flip-flop is not reset, and Alarm 5 is sent to the building computer. This is encoded as AL3 together with AL22, so it can easily be recognized.

No interrupt is established if IBF_B is lacking, so only a hardware operation can be effective.

Alarm 6 is a minor alarm. If strobe STB_B is present but nothing is received by the CPU, a software

correction is made. STB_B can be operated only by a clock or a stop. In case of a stop the operator is present and can immediately ascertain whether the significant bit is lost. If the bit indicating a clock is lost, this is considered the situation for Alarm 6. As the strobe STB_B cannot arrive without a clock, the program instructs the CPU to behave as if a clock has been received. But to show the difference from normal operation, NO CLOCK is printed.

Table III shows the alarms with their automatic actions.

TABLE III
ALARMS AND THEIR ACTIONS

<u>Alarm Type and Cause</u>	<u>Action</u>	<u>Lamps</u>	<u>Instrument Operation</u>	<u>Operator Intervention</u>
ALARM 1 Excessive radioactivity	AL1 to B.C.* Prints data Diverts effluent	Flashing yellow AL1	Continues operation	Desired
ALARM 21 MOV1 not confirmed	AL21 to B.C. Stops operation	Red AL21	Instrument disabled	Is a must
ALARM 22 Calibration not OK	AL22 to B.C. Prints source data	Red AL22	Continues operation	Should be necessary
ALARM 23 MOV2 not confirmed	AL23 to B.C. Stops operation	Red AL23	Instrument disabled	Is a must
ALARM 3 Power off	AL3 to B.C. Operation stopped	Green AL3 off	Instrument not energized	Check cause of power off
ALARM 4 Pulse counter = 0	AL21 + AL24 to B.C. Prints data	Red AL21 Red AL23	Continues operation	Requested (Check pulse lines)
ALARM 5 CLST strobe fails	AL3 + AL22 to B.C.	Red AL22 Green AL3 off	Instrument is in standby	Is a must
ALARM 6 Clock bit not received	Prints message NO CLOCK	No lamps	Continues operation	Not immediately necessary

*B. C. stands for building computer.

V. BLOCK DIAGRAMS AND ANALOG CHAINS

The Effluent and Sanitary Sewer Monitor block diagrams are shown in Figs. 2 and 3, respectively. Both analog chains for the Effluent Monitor (Fig. 2) contain the same type of units. The two detectors are the NaI type and have different dimensions to match the different ranges of energies described in Ref. 1. The units used in both chains are

Fig. 2.
Block diagram of Effluent Monitor.

Fig. 3.
Block diagram of Sanitary Sewer Monitor.

- Preamplifier,* Model TC115A (Tennelec),
- Double Amplifier, Model 221Q (Kiksort),
- Single-Channel Analyzer (SCA), Model 550 (Ortec),
- Stabilizer and SCA, Model NA 22 (Harshaw), and
- High-Voltage Supply, Model AEC-315B (Power Design).

The units are mounted in a NIM bin and have coaxial cable connections for the analog signals. The two SCAs, indicated in Fig. 2 for the sources, are contained in the stabilizers. The seven outputs from SCAs are connected to the rear panel of the monitor by coaxial cables with LEMO-type connectors. The stabilizers have an additional coaxial connector that controls the operation from the CPU. This connector was added to the rear panel and is linked to test point TP118 of the NA-22 AGC Controller. The connection is parallel to the manual switch HOLD/TRACK, which must be set to the TRACK position. TRACK means open-circuit, so the gate control will pull up and enable the stabilizer operation. Normally, the Effluent Monitor pulls down this voltage, the gates are disabled, and the stabilizer is in HOLD condition. During the 1-min STABILIZE time, the gates are enabled and the instrument can track and compensate for drifts. At the same time, the source counters receive pulses from the SCAs. After this time, the gain value achieved by the stabilizer is kept constant and the source counters are gated off until the next calibration.

The Sanitary Sewer Monitor has an identical structure except that only the FIDLER NaI detector is present. A single chain is used with two counters for 17 keV and background plus a source counter using an ^{241}Am source for 59.6 keV, as for the first chain of the Effluent Monitor. The second source for the Effluent Monitor is a ^{22}Na source providing an energy radiation of 511 keV.

An analog output is provided by the instrument by a digital-to-analog converter (DAC). This analog signal is sent to a chart recorder that starts automatically if excessive radioactivity is diagnosed.

*The preamplifiers are mounted directly on top of the photomultiplier tubes and are not indicated in the block diagram.

VI. HARDWARE GENERAL FEATURES

The complete schematic is shown in Figs. 4, 5, 6, and 7. The schematic is identical for both instruments even though many components are not necessary for the Sanitary Sewer Monitor and, in that case, it is redundant. The adoption of almost identical hardware for the two systems allows for perfect interchangeability and for storing a reserve board for either system. In effect all hardware shown in Figs. 4 to 7 is contained in a single board, which has components assembled with high density and connections made using a three-level wire wrapping. The program for the wire-wrapping machine was developed in LASL Group E-4, using only two of the three available wire-wrap levels. The third one can be used profitably for tests or modifications.

The only hardware difference between the two systems is the use of two solenoids instead of a motor for driving the source in the second system. The differences in the connections are outside the board and are explained later (Figs. 8 and 9). The four following sections refer, respectively, to the four schematics shown in Figs. 4 to 7.

VII. MEMORY-MAPPED LOGIC

Figure 4 shows the hardware related to memory-mapped logic. Table I indicates the memory addresses assigned to the different parts of the memory. The on-board PROMs and RAMs have addresses already assigned by the manufacturer of the single-board computer. The other addresses were chosen to reduce hardware decoding to a minimum. So, bit 14 of the address bus (16 bus lines named ϕ to 15) is used as a chip select for C-MOS RAM without complicated decoding. Bit 15 is used to gate the addresses for source counters and operative fields. The first four addresses in the 8000H range (Table II) are used for the source counters (Fig. 6). The operative fields have addresses 8004 through 8007. Address decoding is performed by U2-1 (Fig. 4) using bit A15 as a chip enable. The four addresses for operative fields are gated by U5-5 for "read" and "write" OP1 and OP2 (W8004, W8005, R8004, R8005) and by U1-11 (A and B) for "write only" OP3 and OP4. The latter are used to write AL1 and AL22 as 1 or 0 at the end of each measurement or at the end of the calibration, respectively. The

written number will remain until the end of the next corresponding phase.

Operative field 1 (OP1) contains information about the phase to be executed and has address 8004H. Read (R8004) and write (W8004) do not always coincide. For example, bit ϕ cannot be written but is only read from the switch APR, and it is used at the power-on as a decisional feature to go to halt (if ϕ) or to start the operation automatically (if 1).

The data bus is memorized in U2-4 during the "write" operation. (Negative logic is used for both data and address buses.) The status of U2-4 plus switch APR and Alarms 21 and 23 can be read, sending information to the data bus via the tristate buffer U2-3 and U2-2B. A very particular operation is obtained by writing bits 3 and 5. Their effect depends on the status of flip-flops MOV1 (U3-1B) and MOV2 (U3-2A). These flip-flops are set by W8004 ANDed with bits 2 and 4, respectively, in gates U3-3A and U5-3C. They start source movement by energizing the motor (Fig. 8). When the motor reaches its correct position, the flip-flop (MOV1 or MOV2, respectively) is reset. The next phase will send bits 3 or 5, respectively. Bit 3 is routed through gates U3-6A and U3-7A to set the source count flag (SCF) or to set ALARM 21 depending on confirmation of the movement on flip-flop U3-1B. Bit 5 is routed through gates U3-6D and U3-7B to set the measurement flag (MEASF) or to set ALARM 23, depending on confirmation of MOV2 on flip-flop U3-2A. WARMUP, MOV1, and MOV2 correspond directly in writing and reading.

All hardware operation is controlled by the ENABLE flip-flop (U3-9A). This is set by writing bit 6 at the address 8004H (OP1) and reset by writing bit 3 at the address 8005H (OP2). The key flip-flops and counters are reset when E=0 (ENABLE flip-flop reset).

ENABLE flip-flop is set when the operator gives the command START or CONTINUE. These commands write the values 44H and 60H in OP1, respectively, (Table II) and set MOV1 or MEAS phase together with E=1. Bit 6, corresponding to set E, is not read. This bit is used to read AL21, as explained, whereas bit 7 is used only to read AL23.

The bits of OP2 are used as follows. Bits 0 and 2 set or reset TEST flip-flop (U1-8B) and PRINT flip-flop (U1-2A), respectively. These flip-flops are always reset by the program at the beginning of each

Fig. 5.
Detailed schematic, sheet 2.

Fig. 6.

Detailed schematic, sheet 3. Note that capacitance on pin 1 of U1-5A has been changed to 220 pF.

Fig. 7.
Detailed schematic, sheet 4.

Fig. 8.
Motor control for the Effluent Monitor.

measurement, writing $OP2 = 02H$. This value (bit 1 at address 8005H) sets COUNT ENABLE (U3-2B) and resets TEST and PRINT. Bit 4 of $OP2$ is used when INITIALIZE is called by the operator to light the lamp indicating that phase. The program, when operator types INITIALIZE and CR or simply I and CR, writes $OP2 = 18H$, obtaining the dual action of disabling the hardware (standby phase) and switching on the lamp INITIALIZE and the lamp STOP. ENABLE lamps are switched off. Bits 3 and 4, corresponding to the value 18H in $OP2$, are not read. The only other bit that is read is bit 5, corresponding to 20H (source count overflow, Fig. 6), which is sent to data bus together with T, P, and CE via the tristate buffer U2-2A.

Figure 4 also contains a power failure circuit based on the amplitude comparator $\mu AF311$. This has a high-impedance FET input so that it can be connected to the 5.4-V battery used for C-MOS RAM. The output of this comparator (pin 10) is normally high, and it becomes low in case of power failure. This happens if the +5 voltage drops below about 4.5 V and the output returns to high when the voltage is higher than 4.75 V.

Fig. 9.
Solenoid Control for the Sanitary Sewer Monitor.

The noninverting input of the comparator has a 20-nF capacitor connected to ground to allow the ± 12 voltages to build up before the +5 voltage is sensed during power-on. When power goes off, decrease of the +5 voltage is sensed rapidly because the 680-k Ω resistor is short-circuited by a diode having the cathode connected to the 160- Ω resistor.

The POWER FAILURE flip-flop U3-9B is dc set and reset by the output of the comparator. In normal operation its output PF is low and $\overline{PF}$ is high. During power-up, PF increases with the supply voltage and is used to reset ENABLE and all alarm flip-flops as an initial condition. The same signal is used to reset the CPU through contact 14 on the P1 connector of the computer board.

The pulses coming from the five SCAs are gated by COUNT ENABLE flip-flop U3-2B. The Effluent Monitor has all five SCAs connected to inputs. The Sanitary Sewer Monitor has only 17 keV and BG1 connected. The pulses are ORed by U3-7D and U1-12B. The OR drives the one-shot multivibrator U2-12A, which is used like a flip-flop due to the long

time constant. Its output sets the interrupt on the CPU, strobing the PPI with the high-to-low transition on STB_A . The one-shot multivibrator is reset by the handshaking action of the CPU via the negative-going pulse IBF_A (Input Buffer Full). The CPU reads the data on the PPI and resets IBF_A .

Unused inputs cannot be left open because they will completely jam the instrument. As soon as $COUNT\ ENABLE = 1$, any open input (e.g., pin 13 on U15-14D) sets high the output of the OR U1-12B that drives the one-shot multivibrator U2-12A. This is reset by the acknowledgment IBF_A , but it is immediately restarted by the dc enabled input, causing a train of pulses during the total measurement time. This effect will not occur if negative logic is used for transmitting pulses, but we used the positive pulses directly as they were generated by the analog units. Connections to gates U5-14D, U5-15A, and U5-15C are shorted to ground at the card-cage connector in the Sanitary Sewer Monitor.

The difference between the two instruments concerning the source driving is explained by Figs. 8 and 9. The motor used for the Effluent Monitor¹ has a unidirectional rotation that drives the sources from rest to operative position or vice versa with a 180° rotation. For that purpose, both MOV1 and MOV2 drive the same winding of the motor, being ORed with open collector inverters 74LS05 (Fig. 8). The effective connection is not made on inverters U1-9C and U3-7E but is made outside the board on connector P2, shorting pins B and B1 in the block indicated as MOTOR CONTROL. This allows the two independent commands to be sent to the two solenoids of the Sanitary Sewer Monitor (Fig. 9).

The last feature shown in Fig. 4 is the ALARM MANUAL RESET used by the operator to reset all the alarms if necessary (especially during test).

VIII. OPTICAL AND ALARM CONNECTIONS

Figure 5 shows the connections to the front panel lamps, the galvanically isolated connections to the building computer, and the handshaking circuit for the clock.

The circuit for the lamps is quite evident. All the drivers are full-power open-collector inverters (type 7405) that drive the LED red lamps for phases and status indication. Two D-type flip-flops are used to switch the ENABLE lamps continuously at each clock and the MEAS lamps at each new measure-

ment. These four lamps are driven by four open collector gates (type 7403). The STOP lamp is driven by $\bar{E}$ via the inverter U3-12A so that it indicates that hardware is disabled ($E=0$). The high currents required by the ALARM 1, APRE, AWE, and ALARM 3 lamps are supplied by buffer transistors. The ALARM 1 lamp is driven by a square-wave oscillator obtained with a feedback connection on the Schmitt inverter U1-5D. The result is that the yellow lamp flashes and is thereby more impressive than the other lamps. The alarms are ORed together and drive an audible warning device mounted on the front panel. A whistle is heard in case of any alarm, and the sound is intermittent for Alarm 1. The frequency of the square wave for Alarm 1 is about 10 Hz. The audible warning is multiplied remotely via an optical isolator. If Alarm 1 is encountered with any alarm of group 2, the sound is continuous.

The circuit for the CLOCK and STOP handshaking uses a double flip-flop U2-6. The SCLST pulse (from Fig. 6) sets flip-flop CLST (U2-6A) with its trailing edge. The same pulse is presented to gate U2-7A, which is blocked by flip-flop CLST. When the flip-flop is set, the gate is enabled, but the pulse is already gone. The $\bar{Q}$ of CLST flip-flop is sent as STB_B to the PPI, which, with a small delay, sends back its acknowledgment IBF_B , resetting the flip-flop. If this acknowledgment is not received, the next clock pulse will find the gate open and will set ALARM 5 flip-flop. This in turn simultaneously sets Alarms 22 and 3, sending the double information to the building computer and turning ALARM 3 lamp off and the ALARM 22 lamp on. An open-collector gate (U2-7) has been used to drive the lamp and remote driver for Alarm 22 as wired-OR. $AL5$ drives an AND connection, with $\bar{PF}$ the Alarm 3 indication. Normally, this operates, but the absence of either input eliminates the drive so that Alarm 3 is sent to the building computer (N.C. connection), and the green lamp is switched off.

The double flip-flop operation for ALARM 5 is provided to avoid any timing problem between the duration of SCLST pulse and the arrival of IBF_B . IBF_B should arrive before the end of the SCLST pulse so that normally the double flip-flop is redundant.

The other links to the building computer are N.O. connections and are driven by the proper alarms gated by the TEST flip-flop.

IX. CLOCK CIRCUITS AND SOURCE COUNTERS

Figure 6 shows the clock circuit plus the source counters with their tristate buffers. A quartz-generated clock is taken from the SBC 80/10 board and divided via a C-MOS chain down to the 0.5-Hz frequency at the output of U4-3A. The input frequency is not accepted by the C-MOS dividers operated at 5 V. Typically, they operate at a slightly higher frequency, but the minimum guaranteed is somewhat lower. Two D-type flip-flops divide this frequency to an easy value of 512 kHz. The 2-s pulses from U4-3A are sent to the presettable divider U4-4 connected for binary operation and down counting. When the PE (Preset Enable) is set, the number 15 is entered from the parallel input. After 15 pulses, the content is zero and the $\overline{CO}$ output goes low. A suitable loop returns the pulse to the PE input so that the content 15 is reestablished. One of the 16 states is skipped. The circuit divides by 15, providing the clock of the instrument, that is, 30 s. A stretching circuit provided by an RC of about 1 μ s and the Schmitt inverter U1-5A assure that the clock is longer than the strobe.* Strobe STB_B and the clock are sent to the CPU via a double contact on opposite sides of the connector.

The source counters are two 16-bit C-MOS counters made from 4040As. Counters U4-7 and U4-11 in series provide the necessary 16 bits for the SC1 counter. A 17th bit on output Q9 of U4-11 is used to set the OVERFLOW flip-flop. The same is true for counter SC2, using output Q9 from U4-14.

The outputs from the counters are sent directly to the data bus via the C-MOS tristate buffers (type 40098), which can be driven directly by the C-MOS counters and which have sufficient power to drive the data bus.

The source counters are enabled by the control flag SCF, which also drives the TRACK/HOLD switch on the Harshaw Na22 stabilizer. The reset of the counters is sent by the CPU as RSC via a one-shot multivibrator that provides a longer pulse. (The pulse time from the CPU is insufficient to reset the cascaded counters.)

Figure 6 also shows the STOP command, which acts through the interrupt, not directly on the

hardware, and sends the strobe STB_B in OR with the clock.

X. C-MOS RAM AND DIGITAL-TO-ANALOG CONVERTER (DAC)

Figure 7 shows the C-MOS RAM circuitry plus the digital-to-analog converter. As explained before, C-MOS RAM is used to store the operative constants in low-power memories. These memories can be supplied for a long time by battery if the power fails.

The unique bit A14 from the address bus is used as a chip select for C-MOS RAM. The chip select CE1 is grounded, and CE2 would be sufficiently gated by A14 if the single-board computer had a different design. However, a gating with the OR of "memory read" and "memory write" pulses (MRDC + MWTC) is compulsory. Because the single-board computer energizes all 16 address lines when the CPU is in HALT, C-MOS RAM draws a large amount of dc current most of the time if it is not gated. The single-board computer design relies on the high-impedance state of the address bus from the CPU only for internal use. The external address bus is driven by buffers (type 8226) that drive all address lines when the CPU is disabled (high-impedance state). To avoid this inconvenience, the single-board computer controls the enables of the 8226 buffers in HOLD condition so that the addresses are at high impedance. Unfortunately, the Effluent and Sewer Monitors do not use HOLD, and the single-board computer does not gate the buffers with HALT.

The 8 least significant bits of the address bus are connected to C-MOS RAM, which can store 256 bytes. In practice only the first 16 bytes are used.

Figure 7 also shows the circuit for driving the chart-recorder analog input in case of alarm. The DAC-type AD 7520L receives the eight bits of the second PPI, port A (or port 4 in the SEC 80/10), and the two least significant bits of port C (or port 6 in the SBC 80/10) that are connected as the two most significant bits (from connector J2 pins 23, 25). The output is connected to the chart recorder via the operational amplifier U1-16. Simultaneously the alarm condition AL1 drives the normally idle motor of the chart recorder.

*The time constant has been obtained with 4.7 k Ω x 220 pF. Note that the value of 100 pF in Fig. 6 has been replaced with 220 pF. Drawing 4Y-168681 has, in effect, this value.

The content of the 17-keV counter contains.1 in the single-board computer RAM is divided by four before being sent to the output. Thus, the minimum increment to the chart recorder is four pulses. The total content of full scale is therefore 4095, instead of 1023, as with 10 bits without division.

Figure 7 also shows the circuit that charges the NiCd battery used for C-MOS RAM and one input of the power-failure comparator.

XI. SOFTWARE

The software was made using the PL/M compiler and is conceived according to the flow charts of Ref. 1 plus the statements for ALARM 4 and ALARM 6. The source programs are called EFFLU for the Effluent Monitor and SEWEFF for the Sanitary Sewer Monitor. SEWEFF was obtained from EFFLU by deleting lines where necessary. Only a few statements like absolute GO TO statements were replaced. The description that follows is of EFFLU but it can also refer to SEWEFF. Listings of both programs (including List 1, List 2, and Object) can be obtained from LASL's computing center by calling PLME and PLMS, respectively, and then disposing for printing. Program PLME and its mating program SWITCH follow.*

```
76/12/10. 14.39.37.
PROGRAM PLME
```

```
GET (EFFLU)
GET (LGO=PLM81A/UN=LIBRARY)
LGO (EFFLU,LIST1)
REPLACE (LIST1)
REWIND (TAPE22,TAPE23)
GET (SWITCH)
GET (LGO=PLM81B/UN=LIBRARY)
LGO (SWITCH,LIST2)
REPLACE (TAPE21=OBJECT)
REPLACE (LIST2)
RETURN (PLME)
READY.
```

```
76/12/10. 14.40.18.
PROGRAM SWITCH
```

```
$F=1 $G=1 $Q=1 $V=60
READY.
```

Although many comments* are inserted in the source program for the convenience of the operator, a detailed explanation of the statements is reported here.

EFFLU contains an explanation of the Intel Monitor SPC 80 use. This monitor was used in the experimental phase to run the program loaded into RAM before writing the PROMs.

EFFLU begins with a list of declarations used throughout the program. Other declarations having a limited scope are found under procedures. The only executable codes are contained under the POWERON label, which invariably drives to EXIT, where the CPU goes to HALT.

The program is entirely interrupt driven. Between events the CPU is waiting for interrupts. Interrupts are generated by (1) system clock pulses, (2) actuation of the STOP pushbutton, (3) transmission of a character from the teletype, and (4) pulses from the SCAs. Pulse input from the SCAs is disabled except in the measurement phase.

When power is applied (or returned after a failure) the program segment POWERON initializes the USART and both PPIs. It then reads bit ϕ of OP1 (address 8004H) corresponding to APRE.

If APRE= ϕ , control passes to EXIT leaving all inputs except USART disabled. The system is now ready to accept operator commands from the teletype.

If APRE=1 automatic restart is initiated. The warm-up time (WT) is set to 20 clock pulses (10 min) and the number of warm-up cycles (W) is set to 2. The warm-up flag (WUF) is set and the system clock enabled. Control then passes to exit, which establishes a halt condition while waiting for the next clock pulse.

When a clock pulse is received by PPI1, port B (SBC 80/10 port 2), an interrupt request is generated. The CPU transfers control to address 38H, where there is a jump to TOTALBREAK.

TOTALBREAK reads port C of PPI1 looking first for interrupt requests in bit ϕ (corresponding to port B interrupts) and then in bit 3 (port A interrupts). On finding bit $\phi = 1$, the control passes to CLST which, finding bit ϕ of port B, calls CLOCK.

The PL/M compiler ignores all statements included between / and */, thus everything inside those symbols is a comment. In any case some knowledge of the PL/M language is required to understand what follows.

CLOCK reads operative field OP1 calling the appropriate phase. On finding bit 1 = 1, CLOCK calls WARMUP. Then the different operative phases follow one after the other in a preestablished order. If the operator does not press the CONTINUE command, the succession of phases called by CLOCK looking at the value of OP1 is as follows: WARMUP, MOV1, STABILIZE, MOV2, MEAS, . . . MEAS, MOV1, STABILIZE, MOV2, MEAS, . . . MEAS, MOV1, . . . The cycles continue endlessly. Each phase sets at its end the value of OP1 for the next phase, therefore, the succession is automatic. The operator acts on this succession by presetting the number of consecutive MEASs and their duration. He can always interrupt the cycle by pressing STOP or setting a command from the keyboard. (The latter is not accepted during the calibration sequence.)

A detailed explanation of the PL/M procedures, listed in the same order as the program, is reported below. Reference is made to EFFLU, but no conceptual difference is encountered in SEWEFF.

PC, PS, PSCR, and PN are used to give output to the teletype via the USART contained in the single-board computer. They all refer to PC (Print Character), which has a "do while" that waits for USART to be ready and checks its status port continuously. When this port (Hex address ED) is 1, the character is sent to the output port (Hex address EC). PS and PSCR print a previously declared message. PSCR adds to the message a CR, LF (Carriage Return, Line Feed) and a sufficient number of rub-out codes (7FH) to give the teletype time to execute CR, LF (Message 13). These rub-out codes are especially necessary if a faster printer is used. PN is somewhat more complicated; it is used to call a number stored as a hexadecimal number of two or four digits and to print it as a decimal number. At the end of the procedure, Message 19 types a dash (-) and two spaces that are particularly useful during initialization.

IC and INS are used as input procedures from the USART. IC (Input Character) waits for USART to be ready and checks for value 2 of the status port. When USART is ready, the input is performed and immediately echoed to output so that the operator can see what he types. INS (Input Number String) is the reverse of PN and is used to acquire decimal numbers and to store them as hexadecimal numbers.

INITIALIZE, described in Sec. II, acquires the operative constants and stores them in C-MOS RAM. Each constant is requested by the proper printing of a message. INS can set STO=1 when a number is typed or STO= ϕ when X is typed. (In effect the procedure responds in the same way if only CR, instead of X, CR, is typed.) INITIALIZE stores the new number if it finds STO=1; if not, it proceeds to the next message. The first message requests the measurement time STOMELE (Stored Measurement Length). When the first message is called, the stored number is divided by 2 before it is printed, and when a new number is typed by the operator, it is multiplied by 2 before it is stored. This allows the operator to type the time in minutes instead of in number of clock cycles. The other messages are as follows. STONUM means the number of measurements stored in a run before going to a new calibration. STOTHRESH fixes the maximum number of pulses accepted before ALARM 1 is set. STOL1, STOH1, STOL2, and STOH2 set limits for source counting. STOK1, STOK2, and STOK3 are values of the constants K used to evaluate the peak areas, multiplied by 100. STOPRINT sets the number of successive measurements to be printed when the operator types PRINT. This constant is in normal RAM, and in case of power-off, the value is lost and set to 1 by POWERON. STOCORR is the additive constant for evaluation with Eq. (2).

START, CONTINUE, TEST, PRINT, STOP, EXPER, and OPER were described in Sec. II.

COUNTSTART is used to set the proper conditions for starting a measurement. The five counters are reset, the measurement time is set equal to STOMELE, and the overflow indicators are reset. Operative field OP2 is set to the value of 2, which means set COUNT ENABLE and reset PRINT and TEST flags as explained. This procedure is called whenever a measurement is started, that is, by CONTINUE, by end of MOV2 after calibration, and by end of MEAS to continue the series of measurements in one run. There is a small difference in the calling. The first two calls add NM=STONUM, that is, they fix the number of measurements to be done equal to the stored number STONUM. When COUNTSTART is called by the end of measurement, the value of NM is not fixed to the initial

value, but it is left at the number reached by decrementing it at each measurement.

IB (input byte) is used to acquire the bytes in machine code for procedure OPER (see Ref. 2).

PULSES is called when a pulse is received by the input PPI from one of the five SCAs connected to it via the gates enabled by COUNT ENABLE during the MEAS phase. When a pulse is received, it is stored by incrementing the corresponding counter. If one of three peak counters arrives at the maximum content, the overflow indicator (OVERSEV or OVERFIF or OVERFOH, respectively) is set to avoid other pulses overflowing the counter and eventually displaying a small number.

WARMUP is called by the first clocks after POWERON if APRE=1. The warm-up time WT is decreased by each clock and W is decreased when WT=0. Number W is set = 2 by POWERON and allows two successive runs of WARMUP if the first calibration fails. When WT=0 WARMUP sets OP1=4, that is, starts MOV1.

MOV1 should find the insertion of the sources in the calibrating position. Some variables like NOWPRINT, PT, and PRINTEXEC (but not PRINT flag) used to print data from counters are reset at the beginning of the MOV1 procedure. (Note that MOV1 does not start the movement but should terminate the 30 s allowed for this phase.) If the movement has already been confirmed by hardware, MOV1, after setting C1=2, that is, 1 min for calibration, sets OP1=8, which is the value for stabilize. If confirmation of the movement is lacking, the circuit sets AL21 as described in Sec. VII. This is read as OP1=40H and causes the output OP2=8 that means disable hardware.

STABILIZE starts the return movement when the second clock is received. OP2 is read at the end of the 1 min allowed for source counting to check if print has been requested by the operator or if overflow in either source counter occurred. Then the evaluation of counts is made, comparing each counter content with its prefixed low and high limits. If at least one of the limits is not respected or in case of overflow and if W=0, the procedure sets ALARM 22. If W=1, a new warm-up cycle is allowed. This occurs only at the power-on because during the endless succession of a run of measurements followed by a calibration the value of W is always 0. When first powered, one warm-up time of 10 min or two warm-up times for a total of 20 min are performed.

If the calibration fails at the end of the second warm-up, AL22 is set as during the normal succession of cycles and the flag for printing (PRINTSOURCE) is raised automatically. If the calibration is all right, the two statements W=0 and AL22=0 are written at the end of the procedure.

MOV2 behaves like MOV1. MEAS flag is set (OP1=20H), and AL23 is read as OP1=80H. If AL23=1, then hardware is disabled, else the value of W is checked to decide what phase should be next. If W=0, the next phase is MEAS, and this is initialized calling COUNTSTART and setting the proper number of measurements (NM). If W=1, a new warm-up is started by setting OP1 = 2.

MEAS resets the print indicator NOWPRINT to avoid printing at each clock; then the measurement time (MT) is decremented. When MT=0, one measurement is completed and COUNT ENABLE flip-flop is reset, blocking the incoming pulses. An indicator of background greater than peak (BIGBACK) is reset and will be set later if the corrected background $BG1 \cdot K1$ is greater than the content of SEV counter. Protections against wrong evaluations due to overflows or to lack of pulses are performed by this procedure. If any line is cut off, the corresponding counter receives zero pulses. If there is no hardware inconvenience, each line should have at least some random pulses even with very clean effluent. A zero in any counter is considered a reason for Alarm 4, obtained by coding group 2 alarms ($ALARM\ 4 = AL21 + AL23$). Printing is automatically performed setting PRINTEXEC=1. If any overflow indicator was set by PULSE, the corresponding area is set to FFFFH(65535). If none was set, the area is calculated with Eq. (1). The area corresponding to 17 keV is calculated with Eq. (2). If the counter SEV, FIF, or FOH has zero content, its corresponding area is not evaluated and it is set to zero. If ALARM 4 is found and no zero is printed, this means that the alarm was set by a background content = ϕ . If background is greater than the contents of the 17-keV counter (SEV), then BIGBACK is set to 1 to print the suitable message. The constant STOCORR may prevent a negative result, but if it is insufficient, ALARM 1 is probably set by the large result corresponding to a negative number. The overflows themselves are no reason for alarm, but OVERSEV=1 sets Alarm 1 because area A17 is set to FFFFH, which is undoubtedly greater than

the preset threshold. PRINTEXEC is set in case of AL1 and in case of PRINT=1 (set by operator). When one measurement is terminated, the NM is decremented and NOWPRINT is set. A printout will be performed if the AND of PRINTEXEC * NOWPRINT=1. Then the next measurement is initialized calling COUNTSTART, or the next calibration is flagged, writing OP1=4 when NM=0.

PRINTOUT is called by CLST when PRINTEXEC * NOWPRINT=1. Print indicator PRINTEXEC is reset when PT=0. NOWPRINT is always set to zero when MEAS is called, and it is set to 1 only when a measurement is finished. This avoids printouts at the end of each clock during the measurements. Number PT is set=1 by ALARM 1 or =STOPPRINT if operator types PRINT. Each call of PRINTOUT decreases PT so that a prefixed number of printouts is performed. Only one printout is available in case of alarm. The area of 17 keV is divided by four as explained in Sec. X. This area, called PINTO, is set to FFFFH if the result of the division is greater than or equal to 1024 so the full scale is sent to the DAC. This avoids the possibility of having a small number in the least significant 10 bits plus some higher bit that would not be received by the DAC. The printout on the teletypewriter has a series of messages. First, message 18 (ME18) starts the motor of the teletype, sending a series of RUBOUTs. Then, if BIGBACK=1, the message BACKGND PEAK is printed. Finally, the areas are printed with the header PEAK AREAS:. The contents of the three peak areas are printed on one line.

SPROUT is called by CLST and behaves similarly to PRINTOUT, printing the source counters content when PRINTSOURCE=1. Only one printout is made, therefore number indicators like PT in PRINTOUT are not used here. The operation is like that above, started by ME18 (series of RUBOUTs) and by a header: SOURCE COUNTS:. The contents of the two sources are printed in two lines for the Effluent Monitor. PRINTSOURCE is set to 1 if the calibration is out of the predetermined limits or if the operator types PRINT. Note that this can be done during MOV1 or STABILIZE or during the last measurement with the consequence of printing both the last measurement before calibration and the result of calibration.

CLOCK is called by CLST, which in turn is called by TOTALBREAK at each clock (or in case of stop). The series of IFs in the procedure is reversed as to

the succession of operations. This simplifies the procedure, it being necessary to write only one DO - END group containing the return instruction. This deserves more explanation. CLOCK calls one procedure corresponding to a phase defined by OP1. The content of OP1 is set by the end of the called procedure and is found by the next clock. So each procedure sets the conditions for the next one, and the procedures follow each other like a daisy chain. The end of WARMUP sets OP1 for MOV1. This writes OP1=4, which is used for STABILIZE. The end of STABILIZE sets OP1=10H, which is used to call MOV2. Finally, MOV2 sets OP1=20H, which is used by clock to call MEAS. The program executes the series of IF statements in the order they are presented so that when a procedure is called (such as STABILIZE), it returns to the statement following the call point bringing the new value of OP1 (OP1=10H), corresponding to a procedure that is called by an above statement (CALL MOV2). So a double call is impossible. The only case where a double call is feasible is in the last MEAS of a series. In this case MEAS returns with OP1=04, and CLOCK calls MOV1 without waiting 30 s. To avoid this occurrence the DO - END group containing the CALL MEAS returns directly to EXIT by the RET statement.

CLST is called by an interrupt and calls CLOCK or STOP. Bit ϕ of port B of the PPI (port address E5) indicates CLOCK and bit 1 indicates STOP. CLOCK is called both in the effective presence of bit ϕ and if no bits are set in port B. This case is considered as ALARM 6, a minor emergency, and should be recognized by the operator. It is assumed that if CLST is called by the interrupt and the operator does not operate the STOP pushbutton, the only possible cause of the call is a clock. The program in this case behaves as if a clock bit was found and in addition prints a message "NO CLOCK." This message also can arrive in periods of idle teletype when it is preceded by ME18 (series of RUBOUT). The end of CLST returns to TOTALBREAK and then to EXIT after a check of the conditions for printing is made. If the AND of PRINTOUT with NOWPRINT equals 1, PRINTOUT is called, as explained before. If PRINTSOURCE=1, SPROUT is called. STOP is called if, and only if, bit 1 is set. Due to hardware inversion, this means port B=FDH.

RECO is used to call procedures by recognizing the first letter of a procedure name typed by the operator. It is illegal to use the keyboard during calibration except for typing PRINT. The operator should wait for completion of this three-phase, 2-min operation. To avoid interrupts when sources are in calibrating position or midway, if the operator types a command different from PRINT during the 2 min corresponding to MOV1 + STABILIZE + MOV2, the command is not executed and ILI EGAL COMMAND is printed. The OR of the three-phase operation is from Table II: 00011100, that is, 1CH. All commands are accepted at any other moment. If the first character is not one of the capital letters, A to Z, a message 23 (ILLEGAL CHARACTER) is printed and no action is taken. If the initial does not correspond to one of the stated procedures, no action is taken and a message 15 (WRONG INITIAL) is printed. The legal case of a correct initial calls the desired procedure.

TOTALBREAK corresponds to the only level of interrupt allowed by the single-board computer. An input from PPI, port C (address E6 in the single-board computer) is performed to recognize if a call was due to the PPI. First, a CLST bit is checked and, second, a PULSES bit is verified. If both are absent the interrupt was certainly due to the keyboard via USART. The RECO is called. The end of TOTALBREAK returns to the calling point, that is, EXIT. In effect, the normal state of the instrument is at EXIT, that is, HALT and the return from interrupt is to the location following HALT where a jump back to EXIT is found. TOTALBREAK disables the interrupts so that the service of other interrupts when the phase is flipping from TOTALBREAK to CLST to CLOCK to one of the phases (MOV1 to MEAS) as a daisy chain is not accomplished. The return chain must be completed before the interrupts can be re-enabled by the return from TOTALBREAK to EXIT.

XII. USE OF SOFTWARE SIMULATOR

The INTERPB simulator stored in the computing facility provides a first means to check a program associated with 8080 microprocessor. The simulator allows the designer to run the program step by step and trace the status of the CPU and the registers whenever desired. The simulator must be told about

the input/output ports and instructed about the reference points where the designer wishes the program to be stopped automatically. There are provisions for enabling and disabling interrupts and simulating external occurrences so that the operator can set up an interrupt whenever he wishes. The designer can ask at any time that the program be executed to the next reference point or advance a stated number of steps. Display or alteration of memory locations is possible and the effect of a modification can be seen immediately.

The designer can use this tool to ascertain if the program is doing effectively what was intended. Access to INTERPB⁴ is gained by calling program SIMEF.

Program SIMEFF:

```
OLD: SIMEF

/ LIST
GET (TAPE21=OBJECT)
GET (LGO=INTERPB/UN=LIBRARY)
LGO.
```

The total memory capability of the INTERPB is limited, and only 16k addresses are accepted (hexadecimal values from 0 to 3FFF). EFFLU and SEWEFF have higher addresses for C-MOS RAM and OP fields (see Table I). These addresses in the range of 4000H and 8000H must be replaced by editing the source program and calling the compiler for a new object program. The addresses used by the simulator are reported in Table IV.

The simulator proved to be very useful in verifying the different procedures and testing the proper succession of the phases governed by the value of operative fields.

The only drawback of this simulator resides in the fact that many instructions have to be given at the beginning. Also, the operation is quite long and tedious and it is slowed down considerably by the heavy time-sharing load of the computer. When work is stopped, all the initialization is lost so that many consecutive work hours are needed to exploit the initial efforts.

When all the program has been tested successfully, a necessary but still insufficient condition is achieved. The next step is to use the SBC 80P Monitor, which deals with the hardware and performs a more comprehensive test.

TABLE IV
ADDRESSES FOR USE BY INTERPB SIMULATOR

Hexadecimal Addresses	Use	Comment
0000 - 0FFF	Program	As effective program
1000 - 100F	C-MOS RAM	Addresses decreased
2000 - 2007	Counters and OP Fields	Addresses decreased
3C00 - 3CFF	RAM	As effective program

XIII. USE OF THE INTEL MONITOR

Intel provides a firmware monitor contained in two 1k-byte PROMS. This SBC 80P Monitor tests instruments based on the single-board computer SBC 80/10 and uses the first two sockets allowed for PROMs on the board.

The program to be tested, called "user program," must be modified to leave at least the first two addresses for the PROMs to the monitor, and it is stored in a RAM memory during the test period.

For the Effluent Monitor, a 16k dynamic RAM memory board (type SBC-016) is used because it can be inserted in the same cardcage that contains the single-board computer and the hardware board. The addresses of this board start at 0, 4000H, 8000H, or C000H. Addresses between 1000H and 3BFF that are not used by either the monitor or the on-board RAM cannot be used with this 16k memory because they will jam the first addresses with the monitor. A 4k RAM memory can be used for this purpose, but we used the only available memory board. The addresses used are reported in Table V. Note that the addresses for the variable memory are moved. Although the RAM memory assembled on the single-board computer has addresses 3C00 to 3FFF that do not interfere with any other port, the PL/M compiler does not accept addresses for the variable memory lower than those allocated to the program. So the RAM is also moved beyond the end of the program to the 5000H field.

The modified program is loaded into RAMs, using the monitor as a direct loader. The object code from the compiler is obtained on punched tape which is

then read by a Teletype ASR 33 and loaded into the dynamic RAM.

The use of the monitor also poses other problems. The program has statements for USART initialization, but the monitor performs them before using USART. Thus, these statements are not recognized as Mode Format and Command Format when the user program gets control, so they must be removed. To maintain the strict correspondence with the final program and ensure the rigid displacement of each statement of 4000H, some NOPs must be inserted, instructing the program in POWERON to disregard the USART commands and to start from a fixed address that takes care of the skipped instructions.

The declarations in the effective program start at address 3B, which is the first free address after the jump instruction contained at address 38H to serve Interrupt 7. This address is assigned directly by the compiler, but when the monitor is used it must be forced with a numerical label to the value 403B. Moreover, some absolute GO TO statements must be replaced by adding 4000H. An address to RAM must move from 3CXX to 50XXH.

During tests it is convenient to have a system reset independent of a power-off. A suitable circuit has been made, using a double-through pushbutton connected to a debounce circuit (two 7400 gates interconnected as a flip-flop) and a one-shot multivibrator generating a pulse of 100 μ s. The circuit generates the required reset pulse, placing it in OR with the power failure detector via an open collector inverter connected to the output of the μ AF311 comparator (pin 10 of PA 3-10 in Fig. 4). Be cautious because it is easy to damage the following circuits if

TABLE V
ADDRESSES FOR USE OF SBC 80P MONITOR

Hexadecimal Addresses	Use	Comment
0000 - 07FF	Monitor	First two PROM sockets
4000 - 4FFF	Program into RAM	Program displaced by 4000H
5000 - 53FF	Variable memory	Replaces normal RAM
6000 - 600F	Simulated C-MOS RAM	C-MOS addresses occupied by program
8000 - 8007	Counters and OP fields	As effective program

the connection is made with the power on. The near pin 11 has a +12 voltage so it is preferable to make the connection with the power off. The reset circuit has been built on a breadboard, using a floating 5-V power supply.

A. Hardware Testing with 80P Monitor

The Intel 80P monitor can be used to test the hardware independently of program control. The Substitute Memory Command (S) provides read/write access to desired memory locations, particularly operative fields. Instead of giving here the exact order of testing, which depends on the problems encountered, some examples will illustrate the general method.

1. To test WUF (WARMUP flag):

Type: S8004 (SP) [(SP) indicates a space.]

The system responds: XX-

Now type: 2 (CR)

The WARMUP lamp should light.

Then type: S8004 (SP)

The system should respond:

02- (03- if APRE=1) indicating
that the warm-up flag is read.

2. To test the source counters:

S8004 XX-φ(SP) XX-8(CR)

S8004 φφ -48(CR)

The first statement disables hardware. The second statement sets OP1=48, that is, sets

ENABLE flip-flop and enables the source counters, resetting them in the process. The ENABLE lamps should come on (alternating every 30 s) and the CALIBRATE lamp should light.

S8000 φφ- φφ- φφ- φφ- 08- (CR)

The first four numbers indicate that the source counters have been reset. The fifth number corresponds to OP1, in which the previous command 48H has set the value 08, that is, source count flag has been set. The last number (if not 20H) indicates that the OVERFLOW flag has been reset.

Now place a number of pulses in source counter 1.

S8000 NN- NN- φφ- (CR)

NN- NN- should equal the number of pulses placed in source counter 1. Now, place a large number of pulses in source counter 2 (> 65535 or FFFF).

S8000 NN- NN- MM- MM- 08- 20-(CR)

MM- MM- is the number of pulses entered in source counter 2 modulo 65536. Number 20 at address 8005 (OP2) indicates overflow of the source counter.

3. To test ALARM 21:

S8004 XX-44(CR) (Start)

Before the movement of the source has been completed:

S8004 04-8 XX-8(CR)

The above statements set OP1 to 8, that is, STABILIZE, before confirmation of movement and this sets AL21 and sets OP2 to 8, that is, disable as performed by the program in case of AL21. The

ALARM 21 lamp should turn on, the SOURCE EN-TER lamp turn off, and the STOP lamp turn on. Audible indication can be tested by turning on the AWE switch. A steady tone should be heard.

Other parts of the operative fields can be tested in similar fashion by using the S command to write into the OP fields and read the results.

The 80P monitor has no direct access to the I/O ports of the SBC 80/10. These can be accessed by running a short program. To place a number in a port, place this sequence in memory:

```
OUT    DC
PORT   (PORT)
RST1   CF.
```

Output is accomplished by setting the A register to the desired number (XA command) and then transferring control to the short program. Control will revert to the monitor at the end of execution.

Input from an I/O port is similar. The program to be put in memory is

```
IN     DB
(PORT) (PORT)
RST1   CF.
```

Input is accomplished by executing the program and then examining the contents of the A register, using the XA command.

B. Running User Program Stored in RAM Card

Whenever major program changes are made, it is desirable to check these changes by running the program from RAM. To run with a RAM card, it is necessary to disable C-MOS RAM, which would occupy the same addresses on the interface board. To do this, remove the two 8226s (U2-16 and U4-16) from the interface board. Disable the RAM acknowledge by removing U5-6 from its socket, bending pin 6 out so that it does not make contact and replacing it in its socket.

The RAM board can now be placed in the bottom slot of the cardcage and will function in place of C-MOS RAM. If the 80P monitor ROMs are placed in the 80/10 CPU board, the program can now be run from the RAM card.

The Intel 80P monitor unconditionally enables interrupts before transferring control to the user program (EFFLU). Unfortunately, until PPI1 is initialized, the lines used for interrupt request are left as inputs from the previous reset. This leaves the

lines floating (high-impedance state) while being seen as a 1 by the following OR gate (A45, pins 5-6 on the SBC 80/10). This creates an interrupt request and makes it difficult to transfer control to EFFLU.

Three methods can be used to overcome this difficulty. (1) The interrupt request line (pin 14 of the CPU) can be grounded through an external connection that is removed after PPI1 has been initialized. More practically, the ground contact can be made on jumpers 46 and 49 connected to A45 pins 5-6. (2) The instruction C9 (RETURN) can be placed in location 3C3D, where control is transferred on interrupt (see Ref. 5, p. B-1), and a short preprogram written to replace this instruction with C3 (JUMP) before entering EFFLU (Table VI). (3) The enable interrupt instruction at address 339H in the monitor can be replaced by NOP ($\phi\phi$ H), avoiding interrupt enable before transfer of control to the user program.

The second method based on the software patch (Table VI) deserves more explanation. The Intel 80P monitor has a JMP to address 3C3D as a result of an external interrupt (INT7). The user program starts at address 403B (3B, effective start of EFFLU beyond the space reserved for interrupts + 4000H). The patch program arrives at one less than this address.

The execution sequence is

XS 3C $\phi\phi$ - 7FFF (Place the stack pointer where there is more room.)

S3C3D C3- C9 (Place a return instruction instead of a jump into the address reached with interrupt.)

G 4 ϕ 36 (Transfer control to the patch program.)

The routine for a GO command in the monitor is first to save the typed address on stack and second to make some operations on registers before starting the sequence EI, RET. The interrupt is immediately encountered as stated, so that a double return is consequently found, first in 3C3D and then in 33A, which is the location where the first return goes. The second return points to the typed address that was saved on stack and gives control to the user program's previous replacement of the 3C3D location with JMP to TOTALBREAK (C3, CC, 4F).

The third method has proved the most effective because most of EFFLU runs with the interrupts disabled.

TABLE VI
INTERRUPT SERVICE CONTROL FOR USE OF MONITOR SBC 80P

<u>Address Location</u>	<u>Initial Value</u>	<u>Final Value</u>
3C3D	C9 Ret (CC) No effect (4F)	C3 } JMP CC } 4F } Total break
4036	21 LXI H	
4037	3D	
4083	3C	
4039	36 MVI M	
403A	C3	
403B	Start user program	

CONCLUSIONS

The instrument, after tests of hardware and program made with the software simulator and the Monitor SP 80C, has been checked with its program loaded into 4k PROMs. An existing system for writing the PROMs was available, but unfortunately it was designed for smaller PROMs. No means was available at the moment to load the Intel 8708 PROMs directly, therefore we had to use an Exorciser Motorola that uses slightly different codes. We had available an Intel-Motorola translator program,⁶ an easy tool for obtaining the necessary object program. This program, OBJECTMOTO, was used directly with the Exorciser to burn in the PROMs and the same has been done for the Sanitary Sewer Monitor with the translated program, SEWEMOTO.

Views of the Effluent and Sanitary Sewer Monitors are shown in Figs. 10 and 11, respectively.

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Fig. 10.
Effluent Monitor: View of the complete instrument.

Fig. 11.

Sanitary Sewer Monitor: View of the complete instrument.

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