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AUTOMATED PRIMARY PRODUCTIVITY INSTRUMENT

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ABSTRACT

Primary productivity is generally accepted by oceanographers and limnologists as a fundamental measurement of biological activity in surface water. It measures the rate at which inorganic carbon is transformed into living matter by photosynthesis. Primary productivity measurements in surface waters can establish a baseline to determine the onset and trends in eutrophication. The effects of pollutants on phytoplankton can also be assessed. In addition, inasmuch as primary productivity is a measure of the first process of the food chain, the assay can help in predicting fish harvest yields and areas. Despite the importance of this measurement in surface water technology, its current use has been confined mostly to research studies because the determination must be performed manually and the techniques are too complicated and time-consuming for routine use.

Under U. S. Atomic Energy Commission support, the authors have undertaken development of the Automated Primary Productivity Instrument (APPI). It is designed to: (1) provide long-term, automated monitoring of primary productivity; (2) eliminate the "art" from the complex procedure; and (3) permit the conduct of measurements *in situ*. Network use of this device is envisioned to provide synoptic measurements of primary productivity with data retrieval accomplished automatically or upon interrogation.

The APPI development program has been completed and the instrument subjected to a series of tests in the laboratory and at the Occoquan Reservoir in Fairfax County, Virginia, and at Lake Lanier, Georgia. These tests demonstrated the feasibility of automating the *in situ* biological assay. They also indicate a distinct advantage for the *in situ* approach over the manual method which is thought to inhibit primary productivity of the sample by altering its environmental conditions. However, additional comparative testing of the APPI versus the manual technique will be necessary before this advantage can be firmly established.

I. INTRODUCTION

The overall objective of this program was the development for the commercial market of an instrument to perform *in situ*, radiocarbon primary productivity tests for periods of several months of unattended, continual operation. The instrument will permit the routine determination of this fundamental parameter in the conduct of research and applied studies by oceanographers, limnologists, and pollution control workers. Advantages for the instrument are a reduction in the time and money expended in obtaining data, elimination of the variables introduced by the "art" of the manual procedure, and protection of the samples against the environmental shocks introduced by the manual assay.

shown in Figure 1, is contained in a hull 13 inches in diameter by 32 inches in length. The top end of the cylindrical hull is the transparent plate shown in Figure 2 which contains the photosynthesis incubation chamber. The hull contains all supplies, reagents, receptacles, mechanisms, electronics, logic system, and a programmer to perform a series of ten primary productivity determinations. The functions which are automatically performed by the instrument are:

(1) Cleansing and preparation of instrument for the sample

(2) Taking of the sample

(3) Injection of metered quantity of radioisotope into sample

(4) Division of the sample into light and dark incubators

(5) Timing of two-hour incubation period

(6) Filtration of dark bottle sample

(7) Filtration of light bottle sample

(8) Drying of filter tape

(9) Radioassay of dark bottle filter

(10) Radioassay of light bottle filter

(11) Expulsion of samples

II. INSTRUMENTATION DESCRIPTION

The block diagram shown in Figure 3 details the elements which comprise the APPI instrument system. The instrument automatically performs a simple series of operations to assay a sample for primary productivity. The assay commences by the acquisition of the water sample through a protected inlet, adding a metered quantity of sterile $NaH^{14}CO_3$ solution to the sample, delivering 100 ml of the labeled sample into the photosynthesis chamber, retaining a duplicate 100 ml in a dark chamber, conducting a two-hour incubation period, sequentially filtering the samples through respective 47 mm diameter areas of a membrane filter tape, advancing the tape through a heating chamber to dry the filtered areas, and then advancing the filtered areas to a Geiger tube chamber for counting of radioactivity. The data are recovered in realtime on a shore or boat-based display. The tape is retained in the instrument for possible future examination of the organisms or verification of the radioactivity counts. Automated housekeeping operations include: preassay wiping of the photosynthesis chamber optical window to prevent fouling or the accumulation of sediment, post-assay rinsing of the entire plumbing system to prevent fouling, onboard storage of all waste streams, chemical scrubbing of $^{14}CO_2$ released (primarily in the drying step) within the hull to suppress noise, and verification of each completed function.

It was recognized from the outset of the program that the most difficult problem would be that of preventing fouling of the photosynthesis chamber window, in particular, and other sensitive portions of the instrument as a result of growths occurring over weeks or months. A windshield wiper mounted on the exterior of the glass end-window was evaluated in a highly eutrophic portion of the Chesapeake Bay where silting and fouling were intense. A mock-up of this unit is shown in Figure 4 (along with several other test devices which were used to evaluate the design concepts before fabricating the final model).

Results from a variety of tests showed that the wiper unit provided the best practical solution to the problem. After over two months of continuous operation, the glass surface remained completely free of any undesirable material buildup and without physical degradation due to scratches, etc., as shown in Figure 5. The rubber wiper blades showed no signs of degradation. Some filamentous algae became attached to the wiper arm, but this did not affect the unit's performance. In operation on the APPI, the wiper arms are positioned away from the sample photosynthesis chamber so that such algae would have no practical screening effect on the light entering the chamber.

Internal fouling of the various chambers was prevented through the wiping action created by an O-ring sealing the floating piston to the inner wall of the chamber. The internal surface of the photosynthesis chamber is kept clean by the movement of this piston. The internal plumbing and surfaces of the remainder of the instrument were maintained free from fouling by a system designed to apply repeated aliquots of a wash solution between test cycles.

One of the signal developments of the program was the creation of a miniature motor driven, anvil type valve used in the liquid transfer systems. A high torque motor drives a hammer against an anvil to pinch the flexible tubing sufficiently tight to ensure closure. No leakage from the system is possible since there are no mechanical seals. In the open position, these valves present no head loss to the stream, nor do they come in contact with it. The valve tubing selected was tested through thousands of valve cycles with no evident deterioration. Seven of these valves were used on the APPI cluster mounted around the sample pump as shown in Figure 6. The cluster design kept the tubing lengths as short as possible to minimize the hangup of fluid within the tubing.

The difficult problem of loading and storing the ^{14}C solution in sterile conditions was solved through the use of sterile blood bags which receive the isotope solution through a membrane filter for storage. Back contamination of the reservoir by the sample was also prevented in this manner.

Another difficult task successfully solved was that of effecting a leak-proof filter tape transport system shown in Figure 7. This was accomplished by the use of nylon backed membrane filter tape which is fed from roll-to-roll. The portion for use is held and supported firmly in the jaws of the filter block which prevents lateral movement of the water. Upon release of a detent to permit the tape to be advanced to the drying station, peripheral suction is maintained on the downstream side of the filter apparatus to preclude dripping from hangup.

A radioactivity counting station utilizing an end-window Geiger tube accommodating the 47 mm diameter filter spots on the tape was developed with a counting efficiency of 14%.

The programming electronics shown in Figure 8 were designed in accordance with the optimized manual assay procedure selected by the laboratory effort. Highly flexible control programs on a continuous tape loop are administered by the punched tape reader shown in Figure 9. Unit functions and elapsed times are isolated so that wide variations in program logic and timing can be introduced, if desired, through the preparation of new tape loops. Not only is this approach desirable for an experimental model of the APPI, but it will permit users of the final instrument wide latitude in conducting the assay should they desire to effect certain changes in specific study situations. These changes will be possible without requiring any reworking of mechanisms or electronics.

The power supply for the APPI was reduced to a simple 12-volt DC source. In the feasibility model this consisted of shore or ship-based automobile storage batteries connected to the buoy through a waterproof cable. The same cable carries signals from the radioactivity readings and house-keeping data from the instrument back to the base. The shore based support equipment is shown in Figure 10. In the ultimate APPI, the power supply and readout units will be housed with the data system in the buoy hull so that the entire operation will be self-contained.

One additional feature developed for the APPI was the electronic display unit shown in Figure 11 which monitors and displays housekeeping data so that the otherwise undetectable functions of the submerged device can be followed.

III. FIELD TESTING OF THE APPI

Upon completion of the instrument development program, a laboratory test program was undertaken in which samples were split and simultaneously under nearly identical conditions in the APPI and by the manual method. The two systems were found to correlate well. Field testing of the instrument was then undertaken with the first test run in the Occoquan Reservoir of the Fairfax County Water Authority. The instrument was deployed into the water from the dam face and manual samples were obtained in its vicinity and processed simultaneous with the operation of the instrument. As in the laboratory tests, satisfactory correlation was again achieved.

A final field test was performed at Lake Lanier, Georgia, in conjunction with the Southeast Water Laboratory of the Environmental Protection Agency (EPA). The data from these tests along with the testing at the Occoquan Reservoir is tabulated in Table 1. Several mechanical problems developed during this test which involved the failure of the sample pump drive motor, stripping of the lead-screw within the pump, and minor leakage caused by slight corrosion-induced pitting of the hull head flange seal. These problems were relatively minor. However, a major question was raised by the data obtained in these tests.

The data produced by the APPI in the Lake Lanier tests were significantly (up to severalfold) higher than the corresponding data from the manual samples. In a subsequent detailed study of the instrument, no design errors or malfunctions of the mechanisms or electronics which could have been responsible for these large differences were found. Nor were any flaws in the conduct of the manual technique detected.

The indication is that the data discrepancy is caused by stresses placed on the photosynthetic organisms by manipulations required in executing the manual primary productivity assay. The phytoplankton encountered in Lake Lanier, a highly eutrophic and polluted body of water containing dense algal populations at the time of testing, may have been shocked by the sunlight or changes in oxygen tension when the samples were brought to the surface and manipulated in open glass vessels. Additional tests are required to augment the data obtained in this engineering program before such an indication can be established as a conclusion. If such confirmation is obtained, it would open to question primary productivity data obtained by manual assay techniques.

Table 1

Summary of Primary Productivity Data from *
Occoquan Reservoir and Lake Lanier Tests

pH	Inorganic C (mg/m^3)	Primary Productivity $\frac{mgC}{m^3 \cdot hr.}$ APPI	Manual
Occoquan Reservoir, Virginia			
6.6	17,000	96	110
6.8	13,400	226	224
6.8	12,800	118	113
7.0	10,200	505	388
Lake Lanier, Georgia			
6.6	5,420	77	33
6.8	6,080	354	154
7.1	4,200	16	2.6
7.1	3,640	9.1	2.9
7.4	5,400	374	186 95 (EPA - Average) 176 (EPA - High) 68 (EPA - Low)
9.6	3,960	708	323 189 (EPA - Average) 246 (EPA - High) 74 (EPA - Low)
8.2	3,600	7.2	1.1
7.0	3,830	2.4	1.0
7.0	5,220	2.0	.8 1.2 (EPA - Average) 2.2 (EPA - High) 0.9 (EPA - Low)

* These data were computed from primary productivity equation shown in Section VI using L-D data from Tables 17 and 18. R for APPI = 1.55×10^6, for Manual = 1.26×10^6, for EPA = 6.40×10^6, and EPA = 1.29×10^7.

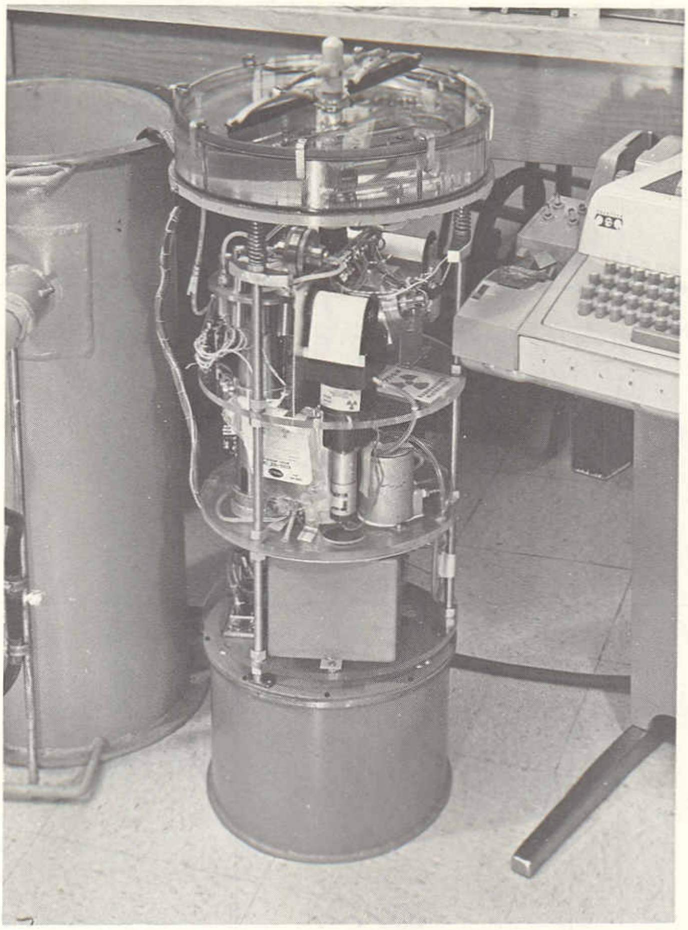

Figure 1. The instrument chassis of the APPI removed from the pressure hull.

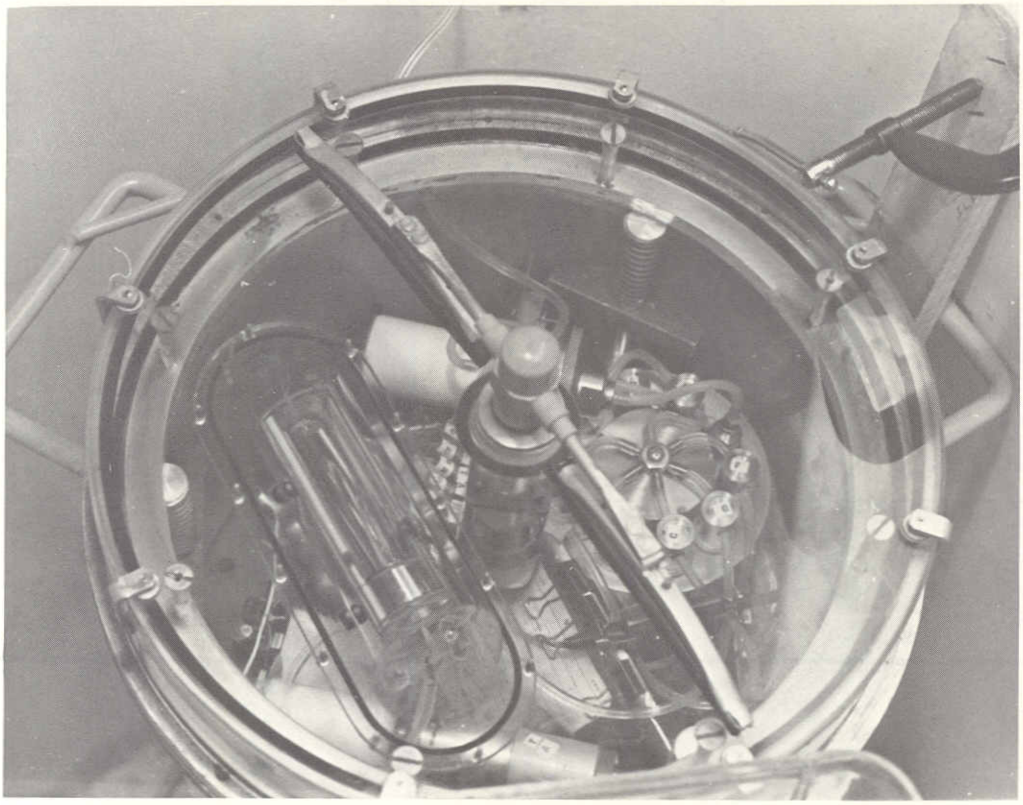

Figure 2. Top view of APPI showing the transparent hull cover with photosynthesis chamber. A dual windshield wiper is used to keep the optical surface free from fouling and sedimentation.

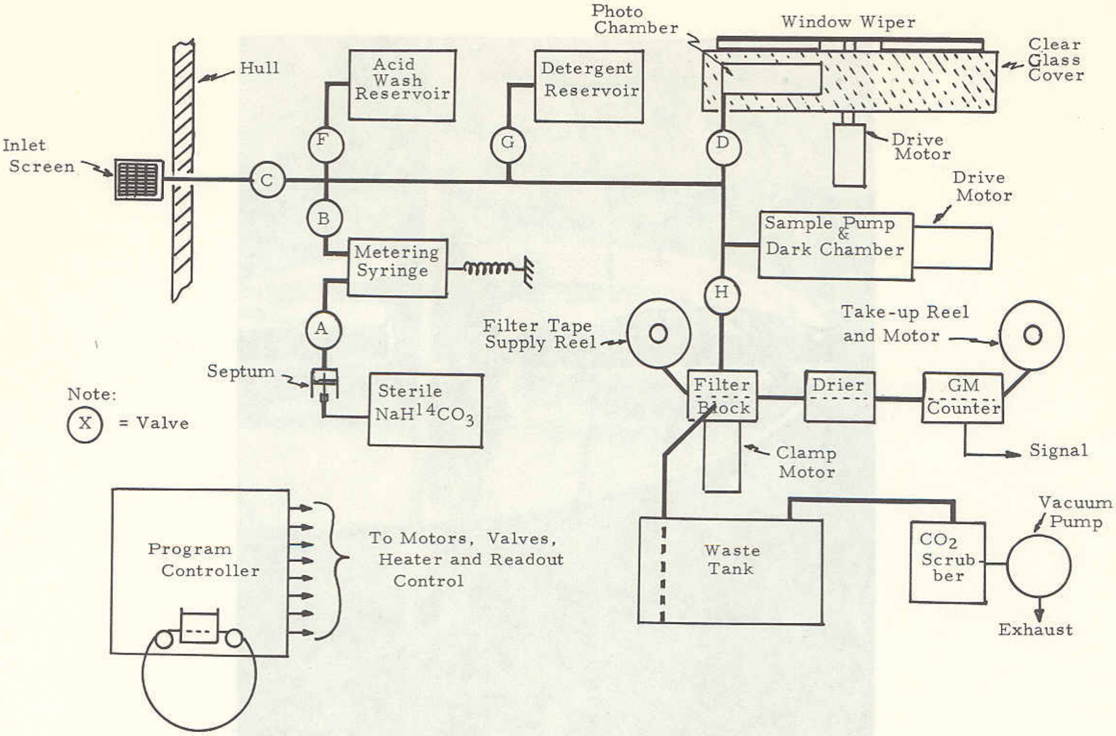

Figure 3. Block diagram of automated primary productivity instrument.

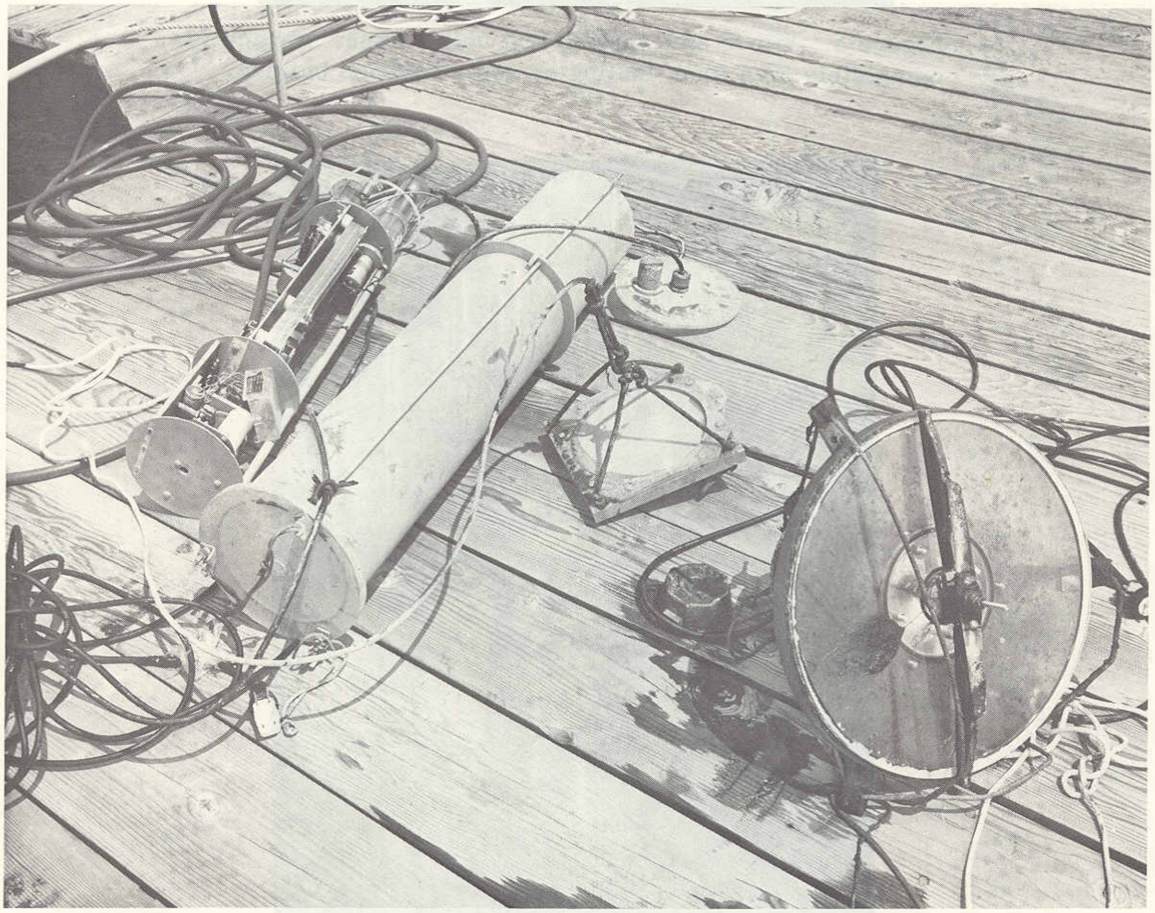

Figure 4. Preliminary Test Apparatus.
At the left: APPI mechanism mock-up next to its clear plastic case.
Center: Goodyear "No-Foul" material.
Right: Wiper system.

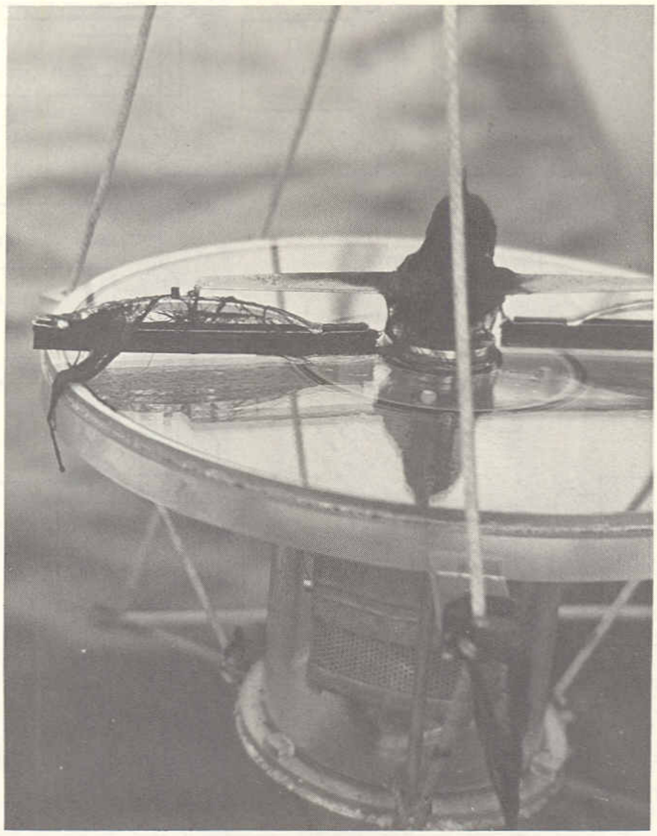

Figure 5. Wiper anti-fouling test unit. Upper surface is completely free from fouling or sedimentation buildup.

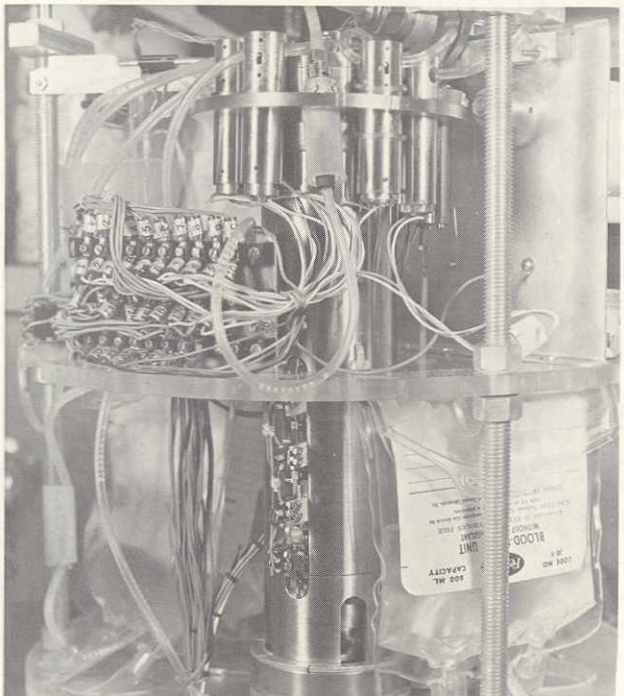

Figure 6. View of sample pump with its volume switches. Motorized pinch valves can be seen clustered at the top of the sample pump along with the sterile septum which is used to couple the replaceable isotope reservoir.

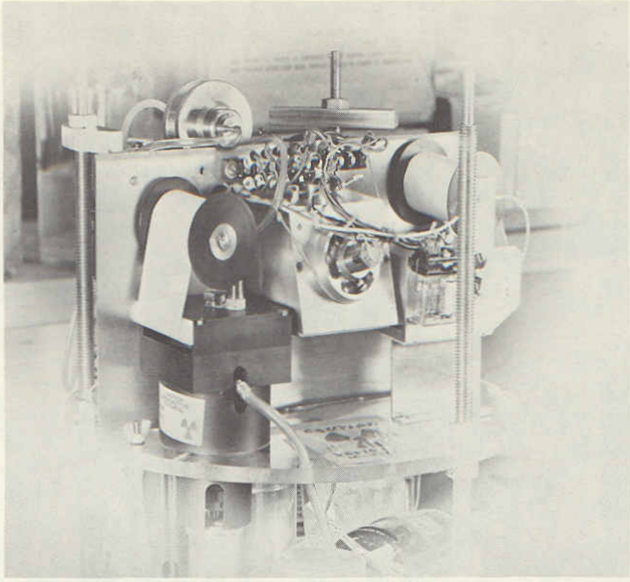

Figure 7. Tape filtration system which includes the tape supply, filter block dryer, Geiger counter and take-up reel.

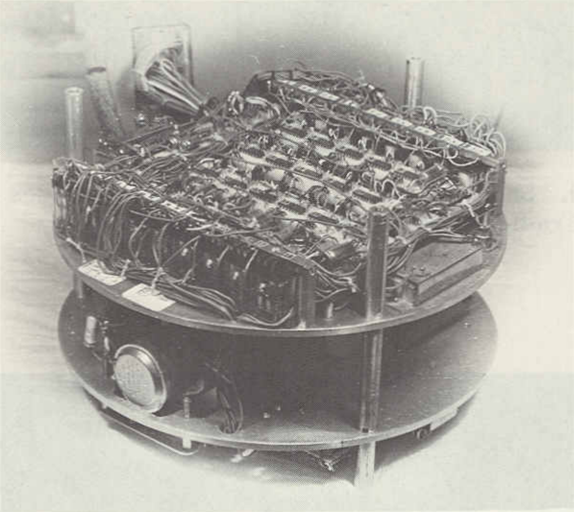

Figure 8. APPI programming electronics system using integrated circuitry coupled to the electromechanical system through relay drivers.

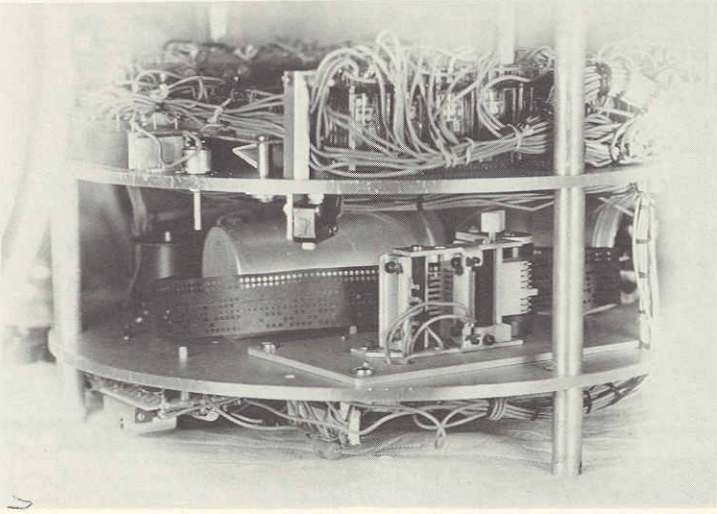

Figure 9. The continuous loop punched tape reader provides programming data.

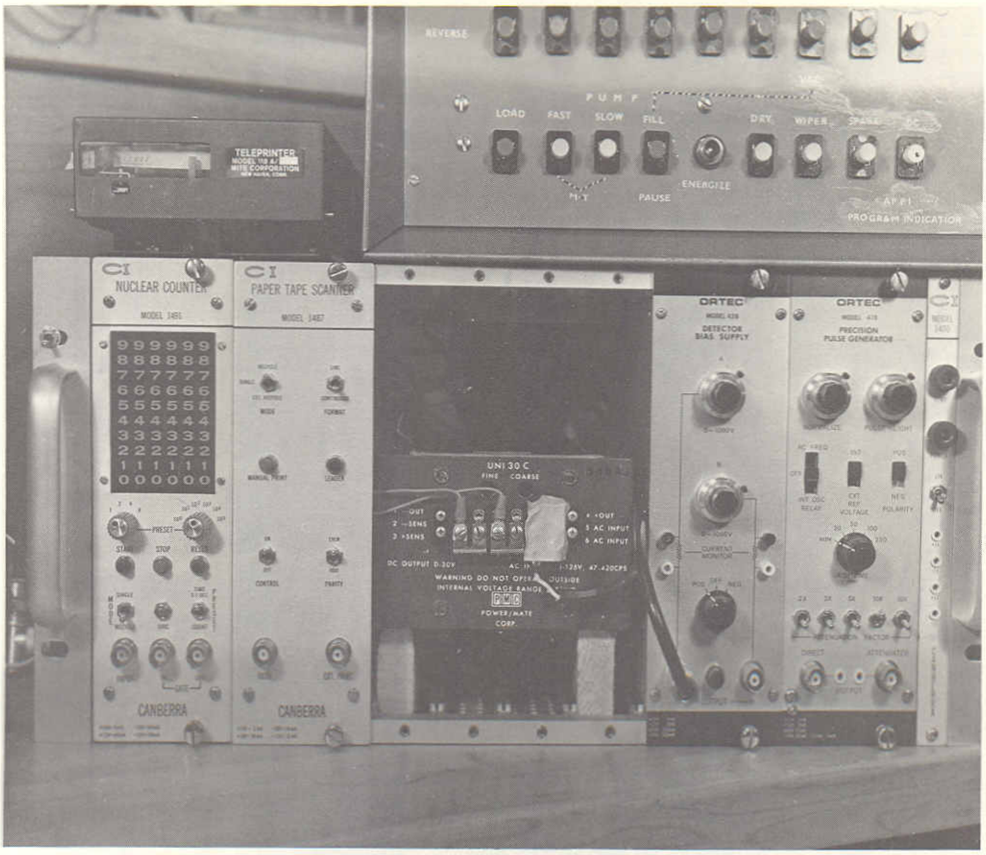

Figure 10. Shore based support equipment provides printed record of radioactivity assay for each sample.

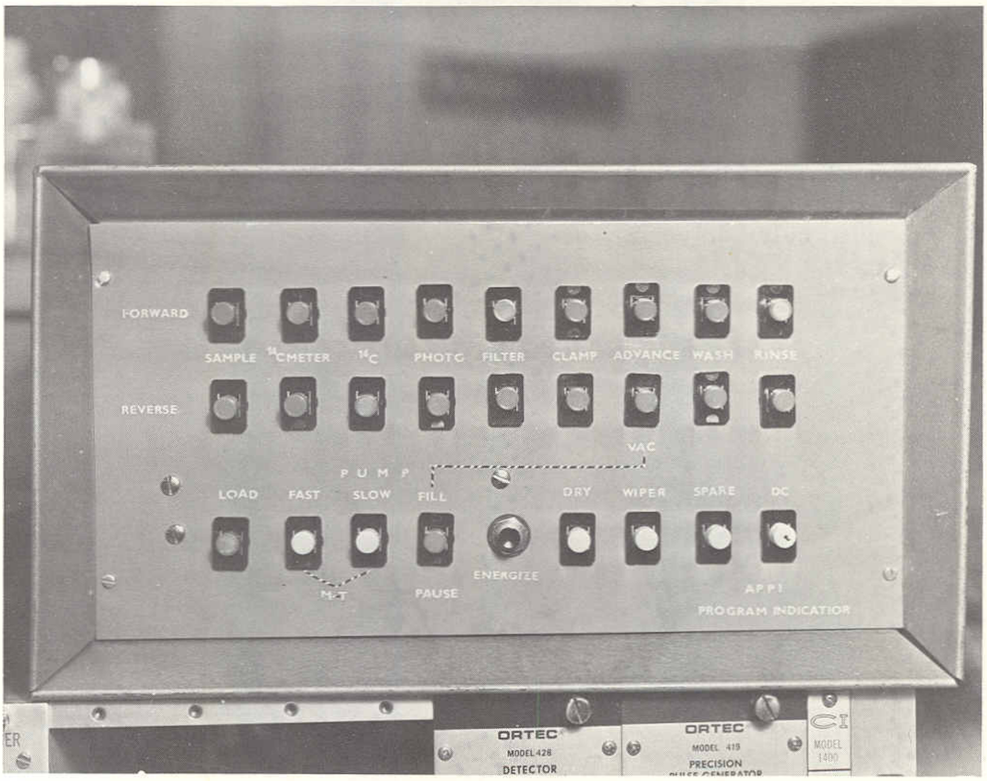

Figure 11. Program status indicator unit gives the operator verification of the APPI's operation.