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EVALUATION OF A CHEMOSENSOR FOR DETECTING DYNAMITE ABOARD AIRCRAFT

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16. Abstract

Tests were performed to determine acceptance and/or operational limitations of a laboratory device designed to detect dynamite by odor. The function of the machine is to combat bombing sabotage of aircraft by sampling air vapors within an aircraft prior to takeoff and signaling the presence of dynamite. The tests proved that the machine was very reliable in detecting exposed sticks of dynamite in an enclosed room, but detection was questionable when the dynamite was confined in a container. The conclusions indicate that the Chemosensor represents a substantial step in the direction of a workable production device, but considerable further research will still be required to attain that goal.

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INTRODUCTION

Purpose

The purpose of this project was to determine the operational feasibility and effectiveness of a laboratory device known as a chemosensor proposed to be used as an odor-detecting instrument for the detection of dynamite on board aircraft.

Background

The threat of in-flight bombing of a commercial aircraft has been a problem for a number of years and has created continuous motivation for investigation of means of bomb detection. The most promising of the many studies in which the Federal Aviation Administration (FAA) has been involved covers detection by a chromatographic method which involves chemical dissociation and detection of vapors.

Nitroglycerine is one of the principal components contained in commercial dynamites; however, some military dynamites are produced by use of trinitrotoluene (TNT) and contain no nitroglycerine. Dynamite generally contains from 10 to 20 percent nitroglycerine of which 40 to 80 percent is nitroglycol or ethylene glycol dinitrate (EGDN). It is the vapor of EGDN that is of particular interest since it serves as the functional component which the machine under evaluation was designed to detect. Also, because of its relatively high-vapor pressure, it is easy to detect this vapor directly in the air.

This project was originally referred to as "Hound Dog" because dogs have the ability to detect dynamite. Dogs have been trained for finding explosive mines, weapons, and hidden narcotics by operating principally on the basis of olfactory sense with possible assistance from other clues.

Because of the element of subjectivity in dealing with animals and the difficulties known to exist in maintaining continuous motivation of dogs to perform the search, this technique was not considered suitable for development for nationwide implementation. However, the principle of the objective olfactory bomb detection (chemosensing) method might be feasible providing instrumental techniques and sensors are capable of detecting extremely minute concentrations of characteristic vapors of explosives in air.

In December 1963, a contract was awarded to Illinois Institute of Technology Research Institute (IITRI) for an exploratory feasibility study on state-of-the-art instrumentation to detect certain explosive vapor trace concentrations in the atmosphere. This study provided a basis for developing an engineering model Chemosensor device. In April 1965, a contract was awarded to IITRI to continue its study, and develop an engineering model Chemosensor device. This was completed in August 1966. A subsequent contract was also awarded to IITRI to continue evaluation of the Chemosensor concept and to develop a second-generation model which resulted in a much more compact and efficient device. This unit was delivered to the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey, for evaluation on February 16, 1968.

Theory of Operation

The Chemosensor is a device built to monitor air for the presence of extremely small concentrations of vapor characteristics of certain materials. In order to match abilities of the olfactory organs of living beings and to be useful in various practical situations where the objective is to detect or identify certain vapor sources, the Chemosensor must reach sensitivities on the order of parts per billion in air and must be able to operate essentially automatically and for long periods of time without maintenance or replenishment. The Chemosensor, shown in Figure 1, was constructed to sample air and detect vapors of EGDN (characteristic of dynamites and technical nitroglycerine). The device uses reversible adsorptivity of the EGDN onto gold to concentrate the vapor to a degree where a short gas chromatographic partition column with an electron capture detector suffices to register the presence of EGDN and discriminate it from other vapors in a semiautomatic fashion.

All control valves and other nonadsorbent parts of the system, illustrated in Figure 2, which come in contact with the sampled gas are teflon coated since teflon is a relatively nonadsorbtive and noncatalytic material. Gold is used as the absorbent medium since it is the only oxide-free, solid metal having the necessary properties for absorbing the gas molecules. This adsorbent-desorbent medium must be carefully temperature controlled because of the inherent instability of the molecules of explosive materials. Zero Argon is the inert gas used for transferring vapor, and Regular Argon is used for purging. Nitrogen is used in the system for cooling.

Figure 3 is a schematic representation of the system. Vapor sampling begins with the primary adsorber. Approximately 12.5 cubic feet per minute of air is circulated by a blower for 40 seconds over

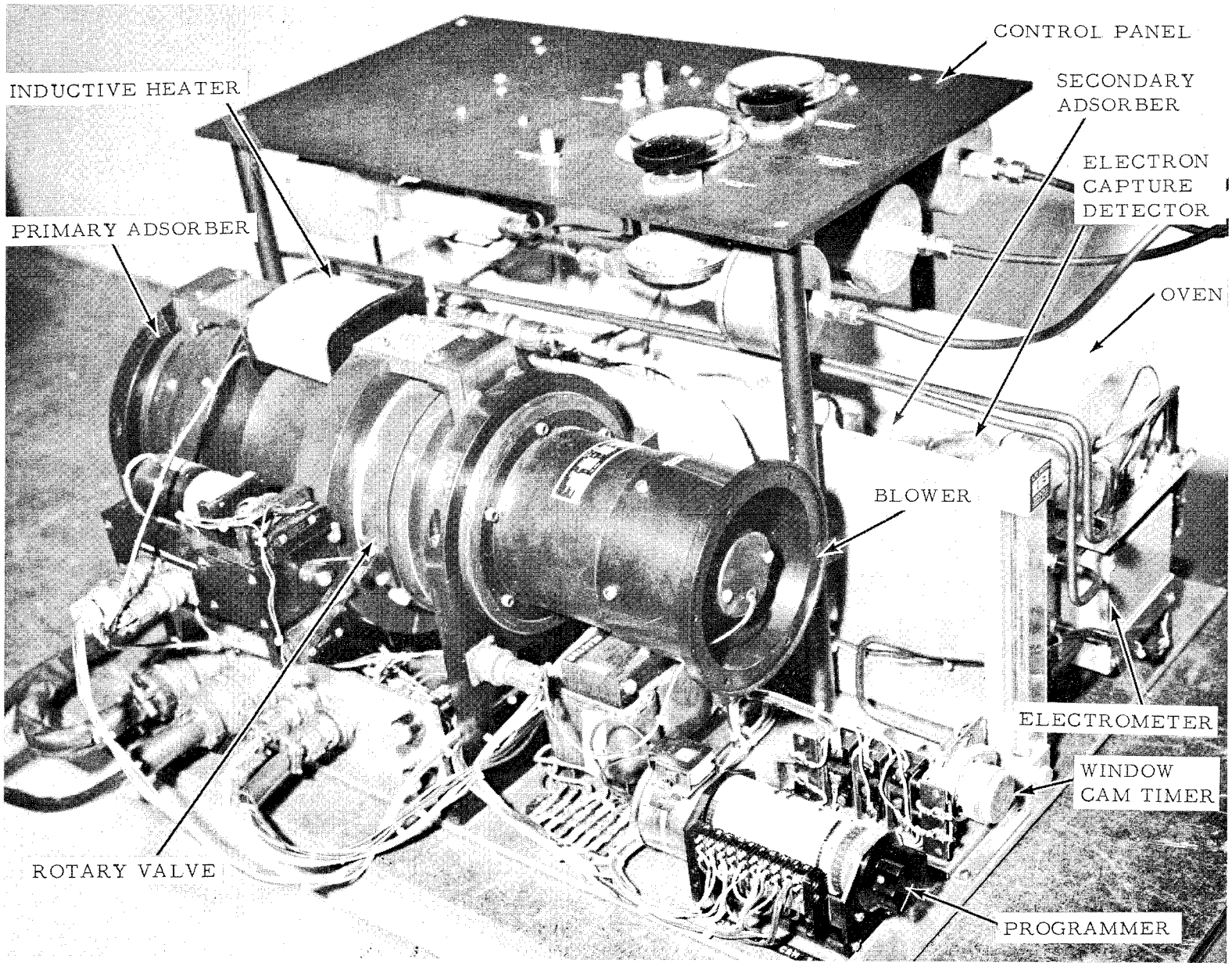

FIG. 1 CHEMOSENSOR

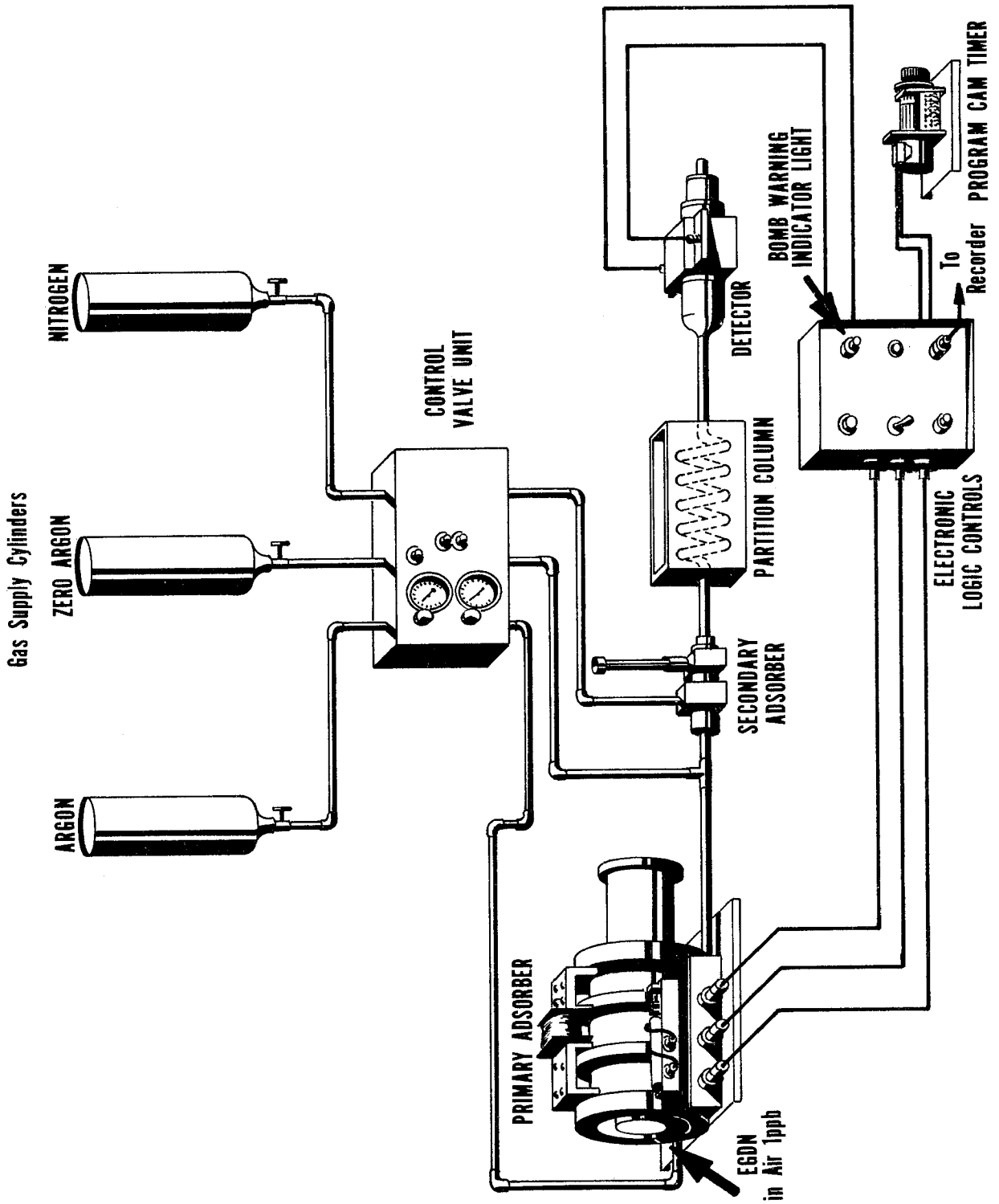

FIG. 2 DIAGRAM OF CHEMOSENSOR SYSTEM

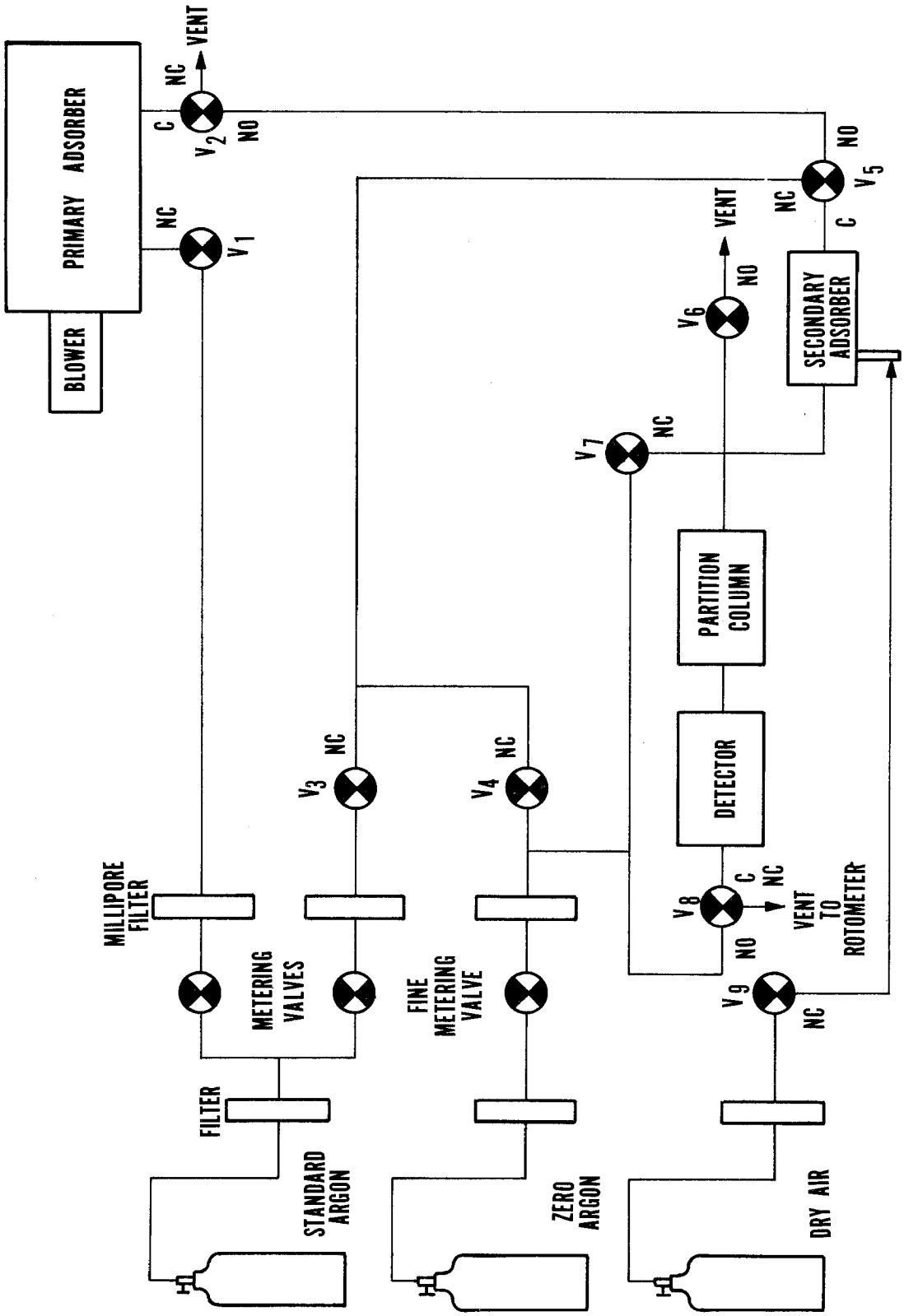

FIG. 3 SCHEMATIC REPRESENTATION OF CHEMOSENSOR SYSTEM

the gold adsorbing surfaces. The circulation of air through the primary adsorber initially cools the adsorbing surfaces for conditioning to collect any EGDN vapor (and other polar vapors) present in the air. At the end of the first 30 seconds, nitrogen begins flowing through a vortex tube cooling the secondary adsorber to $0^{o}C$ in preparation for receiving and adsorbing a sample of vapor from the primary. At the termination of the 40-second blower operation, a valve system isolates the primary adsorber from the ambient air, and the surface is inductively heated to desorb the collected vapors. Simultaneously with the operation of the valve and heating system, a stream of Zero (pure) Argon gas begins sweeping the vapors from the primary to the secondary at a flow rate of 1 liter per minute for 2 minutes where the vapors are again readsorbed.

At the termination of this 2-minute cycle, Zero Argon flow is now reversed. It then flows forward from the partition column through the detector at 50 cubic centimeters per minute for 40 seconds in order to clean and prepare the system for sample injection. In the meantime, the cooled secondary has been warmed up to $90^{o}C$ to desorb the vapors. The forward flow of Zero Argon is then allowed to pick up these desorbed vapors and pass them through the partition tube. The secondary has the effect of concentrating the vapors on a small surface, thus allowing very sharp injections of the vapors into the partition column. The partition column, which is packed with shredded teflon and apiezon-L grease, separates the vapors in the order of their pressures so that the flow to the electron-capture detector is scheduled by the degree of descending vapor pressures. The electron-capture detector is illustrated in Figure 4. This unit is essentially an ionization device in which vapors that have an affinity for electrons (polar vapors) decrease the electrical conductivity of gases. The passage of polar vapors such as EGDN is detected by a decrease in flow of ionic current. An electrical circuit transfers the change in electrical current from the detector to an electrometer where it is amplified and sent to a strip chart recorder which produces a conventional gas chromatographic presentation. A typical trace is shown in Figure 5.

Simultaneously, the signal from the electrometer is also fed into a differentiating amplifier which takes the first derivative of the output with respect to time and interprets it by an electronics logic circuit in a two-feature process. First, a positive slope must occur in a certain retention-time interval; second, a slope reversal (peak) must occur in a certain other-time interval. If both criteria are met, a multivibrator is actuated which flashes an optical signal on the electronics package panel denoting the presence of EGDN. The rate of passage of vapor through the partition tube is a function of the characteristic vapor pressure of the gas; hence, the machine can be time programmed to investigate any of the polar vapors. The first

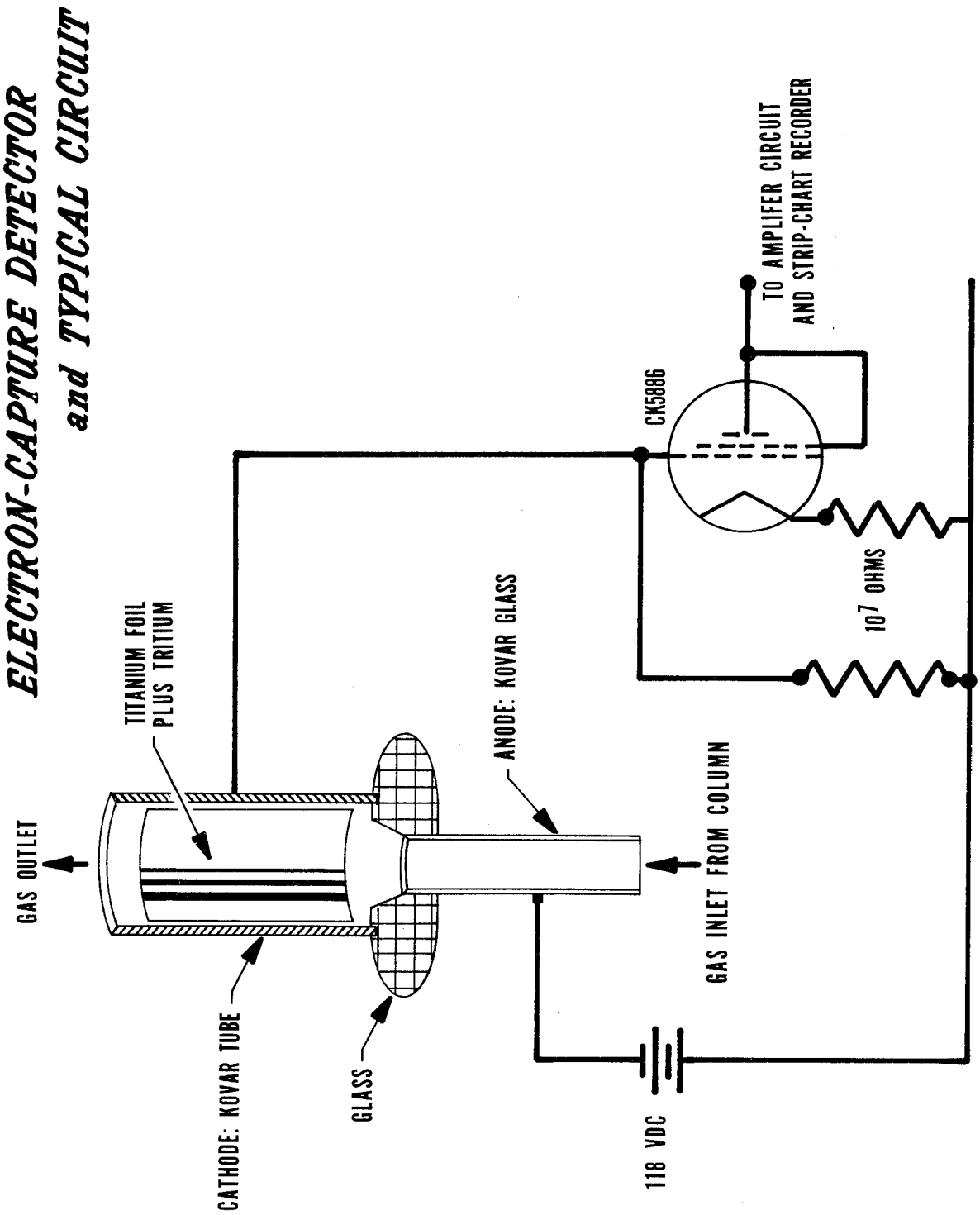

FIG. 4 ELECTRON-CAPTURE DETECTOR

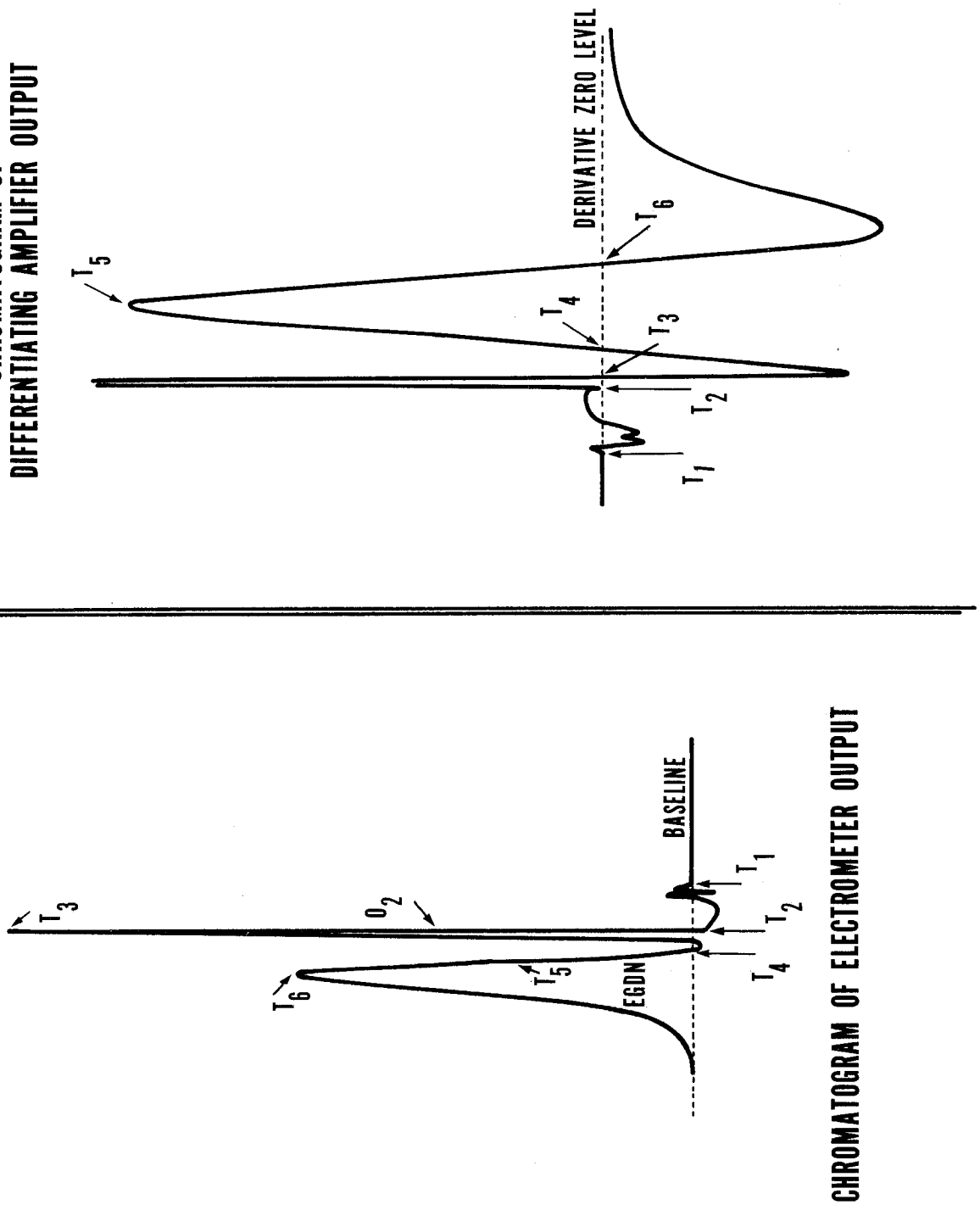

FIG. 5 CHART RECORDER CURVE

vapor to pass through the tube to the detector is oxygen followed by EGDN and then vapors of lesser pressure; however, with this device, the operation stops after the time sequencing for EGDN since detection of other vapors are of no concern in this investigation. The complete cycle takes 6 minutes.

Figure 6 illustrates a typical jet airliner nearing completion of loading. A bomb may be placed in baggage and loaded on aircraft in normal procedure or carried aboard by routine boarding of passengers. Perhaps the most dangerous type is the last minute passenger who gets on board in the nick of time carrying only an attache case.

Figure 7 depicts a concept of detecting EGDN from the flow pattern of the air-conditioning system in a typical aircraft. The detector could be located near the air outlet or several detectors could be spaced at different points in the airstream. The warning light would be in the pilot's cockpit.

In order for the machine to detect dynamite, vapors must be driven out of closed containers. This would be accomplished by cyclic pressurizing of the aircraft cabin, thus forcing the vapors out of containers by "induced breathing."

DISCUSSION

Test Procedure and Results

Systematic tests were planned to evaluate the operational feasibility and effectiveness of the Chemosensor. Evaluation began in a NAFEC laboratory with the easiest and least expensive tests followed by progressively more exhaustive tests. For the final test, it was planned to evaluate the machine aboard an airplane. By this procedure, testing could be stopped at any point along the progression at which the machine might fail to meet the required performance. Decision could then be made as to the best course of action at that point.

Contingent upon the successful completion of field tests and other aspects, it was also planned that development of an aircraft prototype could begin. This would be necessary since the second-generation engineering model Chemosensor device is a research device and not suitable for aircraft installation.

Test Area: The test area shown in Figure 8 is an insulated and air-conditioned room within a main test building. The size of the room is 14 feet by 16 feet 4 inches by 10 feet having a volume of 2,248 cubic feet. Figure 9 is an enlarged and cutaway illustration of a tank shown in the left-hand side of the room. This container is an aluminum aircraft fuel tank, elliptical in cross section, being

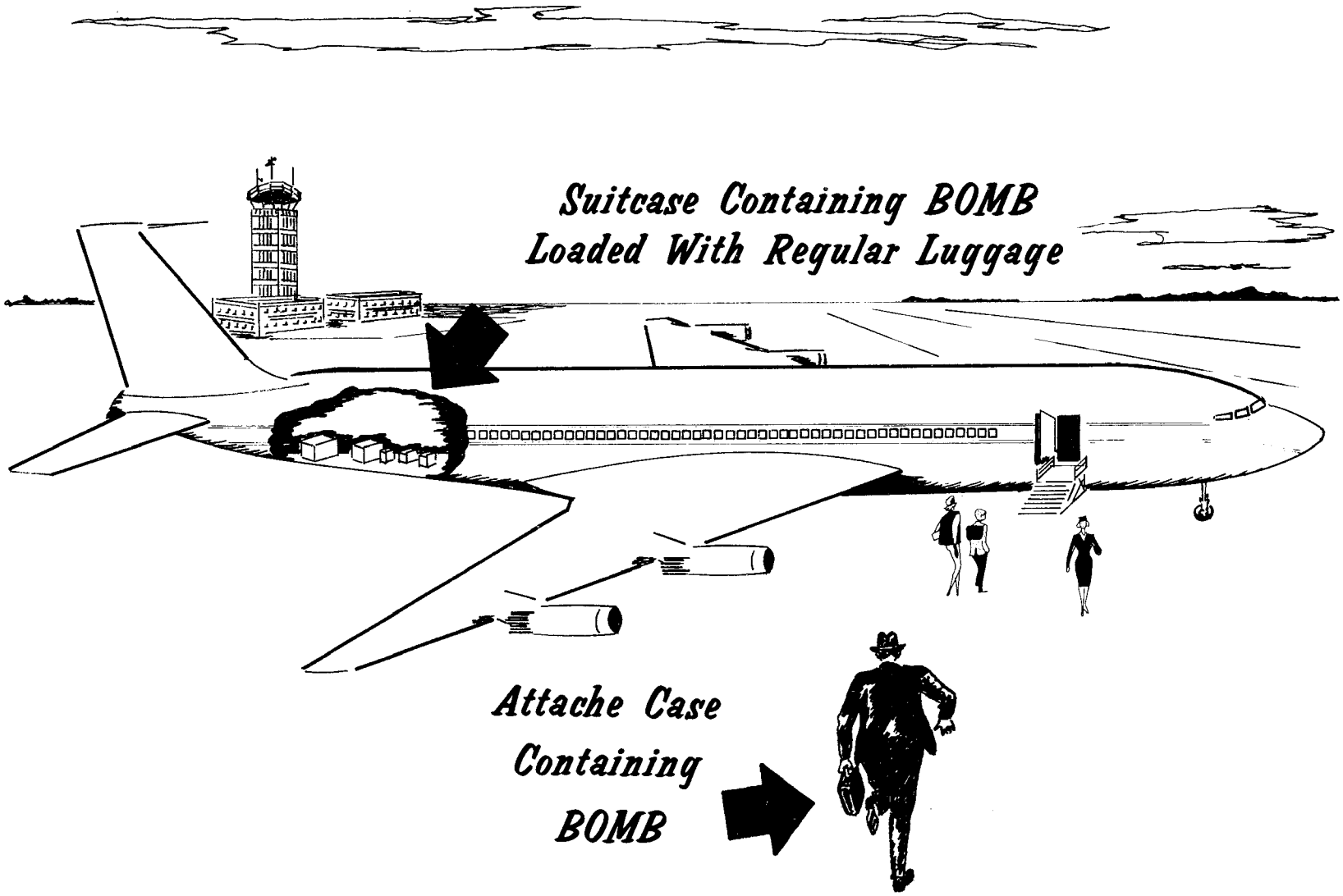

FIG. 6 AIRCRAFT ON GROUND BEING LOADED

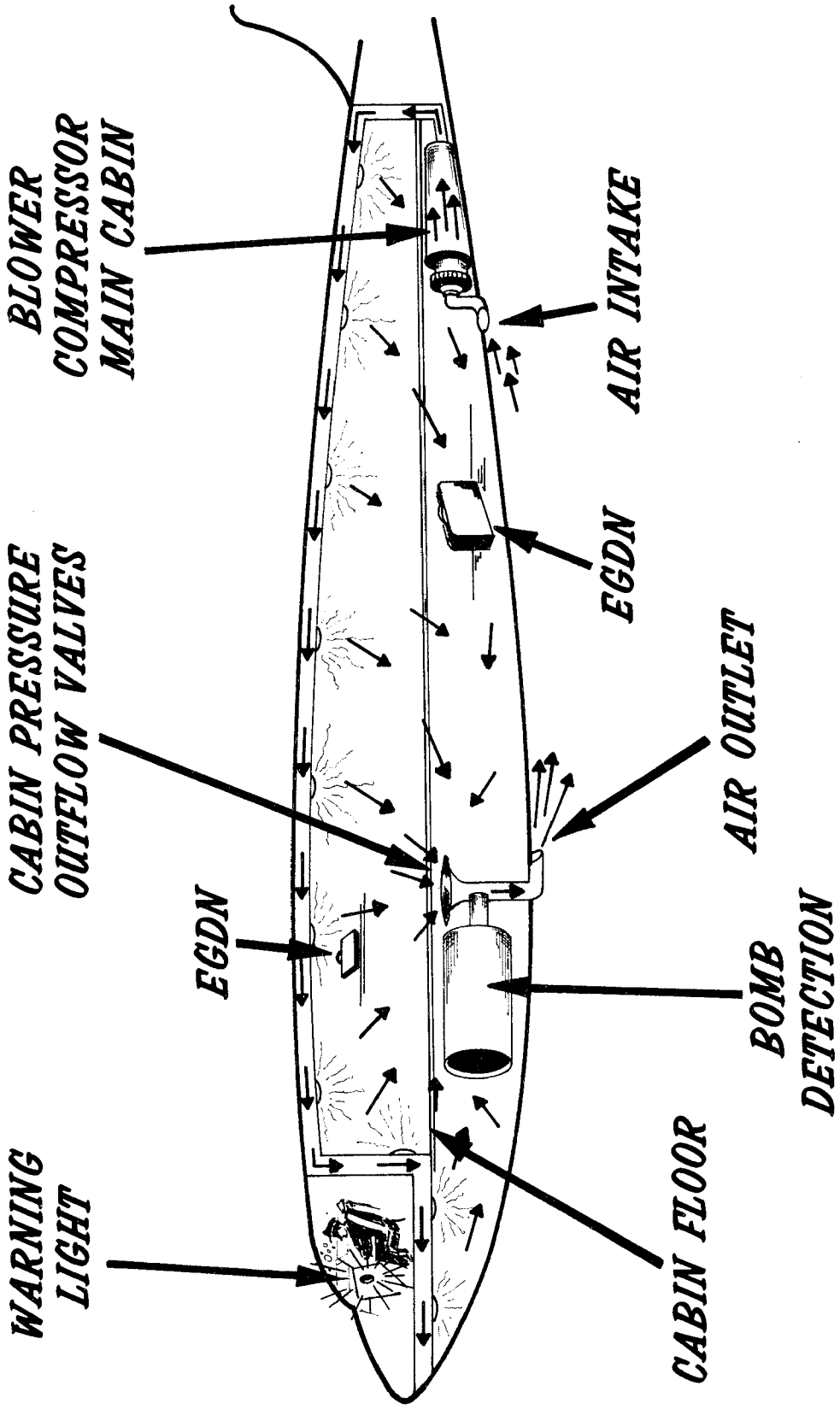

FIG. 7 VAPOR FLOW THROUGH AIR CONDITIONING SYSTEM

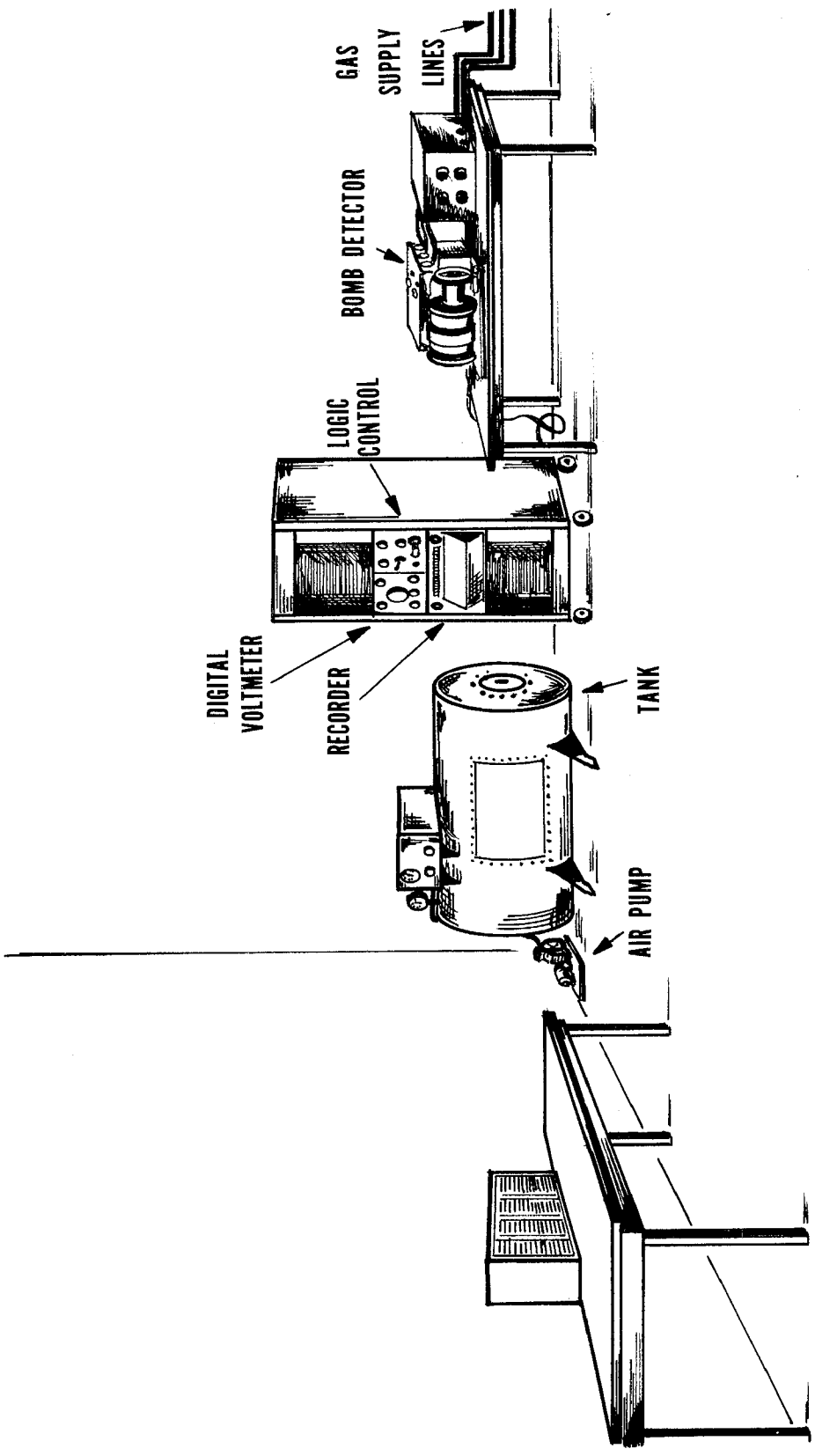

FIG. 8 TEST ROOM

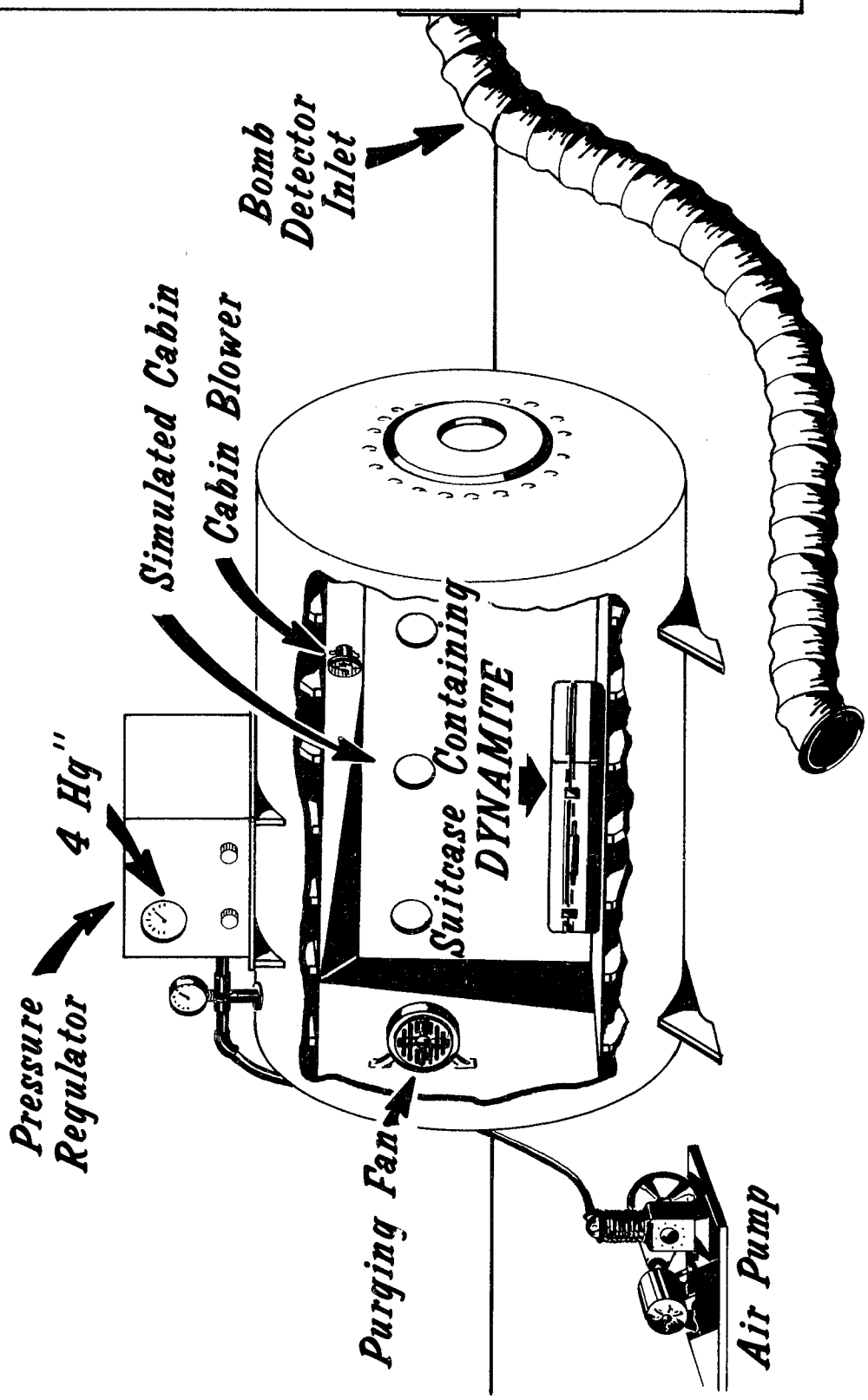

FIG. 9 SECTIONAL VIEW OF TEST TANK

4 feet high and approximately 8 feet long. The volume is approximately 50 cubic feet and was used to simulate induced breathing of luggage in a compartment of an aircraft by cyclic pressurizing of the tank which had a suitcase containing dynamite.

Dynamite Exposed in Room: Actual evaluation commenced with the simple test of determining the Chemosensor's ability to detect dynamite exposed in the test room. The test room and machine were purged and a dry run indicated no presence of EGDN. A stick of dynamite was then held 2 feet from the inlet of the machine, and detection was made. The test room and machine were again purged, and a dry run indicated complete purging. A stick of dynamite was then placed on a table 15 feet from the inlet and immediately the blower was actuated. After 40 seconds, which completed the sample time, the dynamite was removed from the room. Upon completion of the run, 6 minutes' processing time, no detection was made. The dynamite was then placed in the same location for 5 minutes before an air sample was taken. After processing the run, detection was positive. The runs proceeded in this manner by purging room and machine after each detection and insuring by dry runs that purging was complete before sampling for detection. After a number of test runs, it was determined that an exposed stick of dynamite placed in any location of the room could be detected; however, generally the time required for emplacement of dynamite before the machine could detect EGDN was in direct relation to distance of sample from machine. Air circulation in the room also has a direct influence on the time it takes for vapors to permeate throughout the room and to the machine; in fact, vapors were short circuited by exhaust fans out of a room and away from the machine so that detection was not made.

Dynamite Confined in Case: A stick of dynamite was placed in a polyethylene bag of about 2 millimeters' thickness. Care was taken not to contaminate the outside surface of the bag. The bag was sealed, brought into the room and held at the inlet of the Chemosensor during the sampling process. No signal was obtained.

Two sticks of dynamite were then placed in a leather travelling bag 6 by 12 by 18 inches. The bag was snapped closed and held at the inlet of the machine during air sampling. No signal was obtained. These tests were repeated intermittently for approximately 4 hours without obtaining any signals. The bag was then compressed several times, and still no signal was obtained. The bag was then held about 1 foot from the inlet and squeezed or pulsated violently which did produce a signal. In another series of tests, dynamite was left in the closed bag in the test room for 26 hours, and no signal was obtained. The seam of the bag was then held against the inlet nozzle of the machine so that a slight suction was produced during sampling. This time the machine did signal the presence of EGDN.

The dynamite was removed from the bag and the bag was placed opened outside of the test room to air out for 3 weeks. The opened bag was then held near the nozzle of the machine, and a signal was produced. This certainly indicates that EGDN vapors cling for long periods of time to a surface.

Simulated Compartment Test in Tank: The closed travelling bag containing two sticks of dynamite was placed in the tank as illustrated in Figure 9. The tank was then pressurized to 2 pounds per square inch by actuation of an air pump for 15 minutes. The plastic hose was then placed over the relief valve and the pressure was relieved creating a flow through the hose into the inlet of the machine for sampling, but no signal was present.

The tank was then cycled with pressure several times, and no signal was present. Another procedure was tried by passing a flow of air into one end of the tank and out the other and into the machine after again cycling pressure several times, but no signal resulted. The tank containing the bag was then sealed and left for 26 hours and again a sample was taken without producing a signal. The bag was opened in the tank and another sample was taken. This time a strong EGDN signal was produced. Possible deterrents that could have weakened the permeation of vapors to the machine were: (1) a faint mist of oil from the air pump suppressed the vapors; and (2) vapors became attached to plastic hose. However, in later tests, the tank outlet for the hose attachment was moved closer to the machine inlet so that a minimum length of hose was required, and still detection was not made.

Material Tested from an Attempted Sabotage: Material was received from an attempted sabotage in an American Airlines 707 aircraft. In this attempt, only the detonating cap exploded but did cause considerable disturbance in the luggage compartment of the aircraft during flight. Some of the debris from the explosion was sniffed by the machine some months after the incident and a positive signal indicated the presence of EGDN.

Maintenance of Chemosensor: A considerable amount of downtime resulted during use of the machine. That was to be expected since the machine was still an experimental vehicle. The main causes of the problems were vapor leaks in the teflon tubing joints, teflon-coated solenoid valves, and sticking of valves. The leaks were very minute and practically impossible to detect. The only solution was to replace the complete teflon piping assembly which was a very tedious and time-consuming task. Flow rates were extremely critical since any deviation from the scheduled pattern upset the very critical time programming, resulting in lost and odd-shaped signals on the recorder as shown in Figures 4 and 9, as well as negating the warning light controlled by the electronics package and timing window of the programmer.

A number of solenoid valves also required replacement as well as the electrometer and partition column. In the course of testing, cleansing of the unit was required. This was accomplished by purging the unit with anhydrous ether, a toxic and highly explosive compound requiring extreme caution in its use.

It was observed that extended periods of inactivity or movement of the Chemosensor between different environments were not conducive to good operation. It was very important to maintain a constant purging cycle at all times during periods when the machine was inactive.

Interference by Other Vapors: The IITRI ran extensive tests to determine the effect of other vapors on jamming the output; therefore, this type of test was not included in this evaluation program. The only vapor found that interfered with the machine was carbon tetrachloride. Shoe polish gave off nitrobenzine vapor which had retention characteristics similar to EGDN but, fortunately, did not transfer well from the primary adsorber to the secondary adsorber and finally to the analytical train. Only a very large concentration would interfere with the machine, and this would be easily detected by the human nose.

SUMMARY OF RESULTS

Demonstrations of the Chemosensor to groups of visitors from numerous agencies and companies resulted in producing very impressive displays. Visitors were generally impressed at the sophistication of the apparatus and its reliable detection of dynamite. However, testing was stopped when the equipment failed during a progression step of the test plan. The level at which the machine was unable to detect vapors was the placement of dynamite inside a standard travel bag which in turn was placed in a pressure chamber. The sample of air taken from the chamber simulates the cabin of an aircraft. Cyclic pressure of 2 pounds per square inch was applied to the chamber in an attempt to make the bag breathe, but it appeared that the dilution factor of the vapors in the air was too great for detection. An objective of the test plan was then met in which the capability limit of the machine was determined.

The sensitivity of the machine should be greatly increased for present-day aircraft, but on the basis of the trend for new aircraft to continually increase in size, the dilution factor alone could require such sensitivity that reliability would be impaired by false signals. A possible solution to this would be to provide an accumulator concentrator which would sound an alarm upon accumulating sufficient particles; however, generally baggage compartments will be loaded with modules having no circulation of air, thus making detection within the aircraft by the Chemosensor extremely difficult.

The time sequence of 6 minutes to process a sample of air must be shortened considerably in order to meet the need of airlines to speed up traffic for takeoff time from start of engines. The necessity to induce breathing by pressure fluctuation within an aircraft cockpit before takeoff imposes problems of passenger comfort as well as conflict of regulations prohibiting pressurization of cabin interior before takeoff.

The shipment of the machine from Chicago to NAFEC created serious maintenance problems and long delays in evaluation. Because the laboratory model was so sensitive to change in location and/or movement, the highest level of evaluation (aircraft installation) was not deemed appropriate for the laboratory model.