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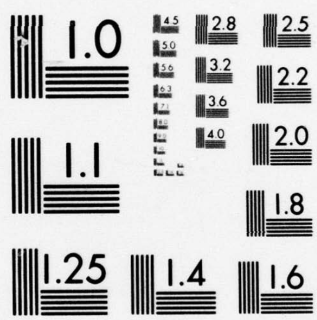

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NRL Memorandum Report 3680

Processor Aided Fire Detector

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Combustion and Fuels Branch
Chemistry Division

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A prototype multi-level blower assisted fire detection system has been developed. Specific principles of detection are adaptable to the detector housing depending on a particular need. The multi-level blower assisted feature increases the sensitivity above commercially available detectors. To reduce false alarms (especially during changing environmental conditions such as would be encountered with shipboard applications) a signal processor in the form of chip logic has been designed and adapted to the detector. The prototype system has been subjected to variety of small scale fire situations while being compared to other fire detectors.

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CONTENTS

PROCESSOR AIDED FIRE DETECTOR

INTRODUCTION

Research in early detection of hostile fires is an area of concern not only to the military but to the civil sector as well. If we compare the tremendous advances in other areas, such as digital electronics, microprocessors, and data processing, it becomes apparent that present techniques of fire detection can be greatly enhanced. Concern for fire safety among the general public seems to be analogous with other forms of destruction, in the view that it always happens to the other person. This general attitude, compounded with the small research effort, results in slow advances in the state of the art of fire detection. The fact is that 12,000 lives and approximately 11.4 billion dollars in destruction occur annually just in the U.S. alone (1). Much of this could be prevented if reliable methods of fire detection were available and were used.

Fire prevention and early detection are also important to the Navy. Each year many lives are lost and millions of dollars in property damage occur both at sea and ashore (2). In order to minimize the threat to life and property it is essential that early, reliable fire detection be achieved.

Many types of fire and smoke detectors are in current use (3). They are designed for a relatively constant environment. When these detectors are exposed to a different and changing environment, as encountered aboard ship, they can false alarm. Due to their false alarming

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characteristics, these detectors, in their present form, are not satisfactory for use aboard Naval vessels.

EXPERIMENTAL

The detector aboard ship encounters temperature, humidity and air flow extremes, depending on its location. In addition there are unique problems associated with machinery spaces, fuel and material storage areas which produce aerosols of their own that must be discriminated against, versus aerosols resulting from products of combustion. These aerosols, combined with dust particles, result in a contamination problem that will produce false alarms and degrade overall performance.

A mutli-head detector with a prototype processor has been designed and fabricated to counteract the problems described above. The use of more than one detector in the same head has a two-fold puspose. The first is the greater detection reliability obtained and the second is that the use of different types of detectors allow you to span a wide particle size range for detection of fires from different materials. Although the NRL detector presently uses two ionization type detectors for verification of this concept, eventually two different types of detectors will be used in the same head.

Detector

A major effort of this program has been to develop smoke/fire detectors which alarm when the fire is in the incipient stage. In general this requires sensitivity to sub-micron particles. The ionization detector demonstrates this sensitivity and therefore has been chosen for use in this new design.

The ionization detector (Figure 1) is basically a capacitor with a source of ionizing radiation. The geometry of the capacitor, placement of the radiation source, and the magnitude of applied electric potential determine its sensitivity. Gas molecules (oxygen, nitrogen) within the capacitor are ionized and thus subject to the influence of the electric field which establishes a current on the order of (10^{-11} amperes) (3). When smoke or other particles enter this space they act as condensation nuclei for the ionized gas molecules. Since these particles are far more massive, a resulting reduction in current occurs which may then be detected.

Two ionization detectors are employed in the experimental detector. The housing and mode of use of these detectors may be seen from Figure 2. Ambient air is drawn into cylinder (1), progresses to about the mid-point of the cylinder where it encounters the syphon tube (2) which samples a portion of the total flow into sampling chamber (3). Detectors 1 and 2 intercept air flow across the chamber, then exit tube (4) withdraws the sample which is united with the main air flow and the combined flow exits via the fan.

The sampling method employed provides for discrimination against dust particles and other large particles as these particles are unable to change direction easily due to their greater momentum. For this reason false alarms due to large particles are less likely. Buildup of contaminants over a period of time, which may provide a conducting path between plates and hence a loss in sensitivity, is also minimized.

The output signal from the detector is applied to a motor control circuit as well as to the input to the processor for the purpose of increasing fan speed when a detection is achieved. This serves to sample the environment more vigorously in the event of a real threat. Further, this procedure changes the chamber contents rapidly and reduces signals due to transitory causes such as cigarette smoke in the immediate vicinity of the detector.

Processor

The signal processor used in the NRL fire detection system is a specially designed, hard wired program, adapted to the two signal outputs of the NRL multi-detector sampling head.

The two signals received from the sampling head are detector # 1 and detector # 2 respectively, as referred to in the following text. This hard wired program processor function will, at a later date, be replaced by a microprocessor. The microprocessor will allow program changes from detector to detector, so they can be tailored to a particular application.

The processor shown in Figure 3 consists of a timing generator, two input analog to digital converts, a multiplexed averaging circuit, comparator circuit, short and long-term storage mediums, and output decoding circuitry. The timing generator operates from a 3 MHz D.I.P. mini-oscillator. It divides this 3 MHz osc down to 122 hz with four Binary counters. The timing generator also controls the sampling rate of the two A/D converters, the input multiplexer clock, the latch clocks of the averaging circuit, the strobes to the short and long-term storage mediums, and the strobe to the output.

The analog to digital converters sample the inputs alternately at a 0.5 sec rate for ten pulses per converter per 5-sec interval. Thus, the inputs are sampled 10 times each over a 5-sec internal. During these 10 samples per channel the input averaging circuit is adding the input of each channel to itself and keeps the two channels separate. At the end of the 10 samples per channel, the sum of the 10 samples is at the output. The accumulated average for detector # 1 is present on the output at the 19th pulse and the detector # 2 accumulated output is available on the output of the 20th pulse. The two detectors averaged signals are transferred to the short-term storage medium on the trailing edge of the 19th and 20th (5 sec's) register clock pulses, respectively, where they are stored for one 5-sec interval and then compared to the averages immediately available to the comparator from the present 5-sec average. Immediately, the previous average is compared to the present average by the comparators. If the previous and present averages are the same or if the present average is less than the previous average, a "0" is stored in the long-term storage medium for that channel by strobe from the timing generator. If the previous average is less than the present average, a "1" is stored in the long-term storage medium by a strobe from the timing generator. The long-term storage medium will store eight interval results for each channel at the same time. These results will later be decoded to determine what the two input signals were doing during previous intervals.

The output circuitry consists of the decoding logic, the interval magnitude logic, and the trend decision logic. The trend decision logic is a comparator controlled up-down counter which tells whether the two averages are increasing, decreasing, or remaining the same. The up-down counter will step up one count every time the present average exceeds the previous average on either channel until it reaches a maximum count of 15, where it will remain until it receives a down count from either channel — previous average exceeds the present average. It will count down every time the previous average on either channel exceeds the present average until it reaches the "0" state of the up-down counter, where it will remain until it receives another up strobe. If the counter has been going up at least one time and the comparator says the previous and present average are equal, the counter will count up one time for that equal. The previous up count must be from the same detector's average for this to be valid. If the counter has been going down in magnitude and the comparator says the previous and present average are equal, the counter will count down one time for an equal. The previous down count must be from the same detector's average for this to be valid. The trend decision logic up-down counter is decoded at the counter into four [4] outputs labeled R1, R2, R3 + R4 which are decoded as follows:

COUNTER STATE	DECODED OUTPUT
1	R1
2	R1
3	R1
4	R1 + R2
5	R1 + R2

6	R1 + R2
7	R1 + R2
8	R1 + R2
9	R1 + R2 + R3
10	R1 + R2 + R3
11	R1 + R2 + R3
12	R1 + R2 + R3 + R4
13	R1 + R2 + R3 + R4
14	R1 + R2 + R3 + R4
15	R1 + R2 + R3 + R4

Using these decoded outputs the range of excursion of detectors 1 and 2 are automatically fed into the output circuitry to enable fast, accurate detections.

Another part of the output circuitry is the interval magnitude logic. This circuit keeps track of the magnitude of the averages from detectors 1 and 2 and decodes its output circuitry. The decoded interval magnitude is decoded into four [4] outputs labeled as follows: L1, L2, L3 and L4.

DECODED OUTPUT	AVERAGE OUT	PERCENT OF TOTAL
L1 =	15	12%
L2 =	31	25%
L3 =	63	50%
L4 =	111	75%

The decoded output levels are used to set the output decoders so an alarm will occur at a predetermined set of parameters.

The output decoding logic consists of logic gates that look at: a. long-term storage results, b. magnitude decoder outputs, c. the trend decision logic, and d. quad latches with a four-output level light alarm system to determine the state of the fire situation.

The four levels of detection are as follows:

1. State # 1
2. State # 2
3. State # 3
4. State # 4

In a non-fire, normal situation "The Multiplexed Signal Averager" is sampling the inputs which are approximately 0. The A/D converters see no signal, and the averager's outputs are also 0. The long and short-term storage mediums, the trend monitor, magnitude logic and output also show no signal.

When a fire situation starts developing, the A/D's start seeing a rise in the analog signal and the averager starts sampling the new input data. After the first interval, the average has some number which is the total of the samples it took during the present interval. These results are compared with the previous average which was "0", and the present average is found to be greater than the previous average. At this time a "1" is stored in the long-term storage medium, the trend monitor up-down counter advances one step up, and the output alarm circuitry goes to the first state of alarm, *detection state* # 1, indicating a change in signal conditions has occurred. At this time the present average is stored in the short-term storage medium, and the previous average for detector 2 is pushed to the output of the short-term storage medium, ready for the comparison of the # 2 detector's present average. The # 2 detector's averaged output is present at the averager's output at the next (20th) strobe (5 sec) pulse, and an immediate comparison is made with the previous average. If it is found that the present average is greater than the previous average, and a "1" is stored in the #2 long-term storage medium, the trend monitor advances one more count up, and the output remains in *state* #1. If the fire situation being sampled continues to show a fire situation, the multiplexed signal averager will continue to store the results of the two detectors' analog outputs and advance the output circuitry of the averager, indicating the present level of the fire situation. If the fire situation reverses itself, the multiplexed signal averager will reset its output(s) after a downward trend is established. Only the output is reset, the results are retained.

If the fire situation continues to increase, the output logic monitors the magnitude, trend, and stored comparisons. Then an alarm indication is given when the decoder senses the present (by decoding scheme) level for a particular alarm level that has been exceeded. This massaging of the input signals will help detect fire situations with a minimum of false alarms, and allow monitoring of the progression or regression of the fire situation.

Environmental Test Chamber

Shown in Figure 4 is the environmental test chamber. Below the control panel is located the aerosol generation chamber. A sliding door is used to vary the flow of air (oxygen) to the fuel. A soldering iron is used to create smoldering combustion and is inserted through the side wall. The input fan whose speed is variable draws the aerosols into the chamber and directs the air flow to the variable speed circulation fan. The arrows indicate the general air flow within the chamber. At the rear is the fan for exhausting the chambers at the conclusion of a test run. Light attenuation (% obscuration) due to generated aerosols is measured using a 6 volt auto head-lamp mounted at one end of the chamber and a phototransistor detector at the opposite end. An air velocity meter manufactured by Hastings Raydist Corp. (Model AB-27) has its probe located at approximately the center of the chamber as viewed from the top. This probe may be adjusted vertically. Three thermo couples, positioned as shown in Figure 4, are inserted through the side to the center of the chamber. Percent relative humidity is measured by a Thunder Scientific Corp. Model PC2000 humidity sensor. Provision for changing the temperature/humidity is through the inlet port beside the light source.

Data Collection System

Data collection from the test chamber was achieved through a Hewlett Packard HP-3480B Data Logger Scanning Digital Voltmeter, with mass storage on paper tape. The scanning rate of the HP-3483 is limited to approximately 4 channels per second by the paper tape punch speed. After the completion of a "run" or fire test, which may last from 5 minutes up to several hours, the paper tape is processed by a Hewlett Packard, Model HP 9603A Measurement and Control System. The data are then presented in tabular form or selected data channels can be plotted versus time.

Test Criteria

Test chamber parameters for each run are outlined in Table 1. For each run indicated, a plot has been generated. These plots may be seen in the Appendix. Test runs 2 thru 6 include a logic-aided commercial prototype detector.

Each plot depicts the analog outputs from the detectors and percent obscuration versus time in minutes. The points indicated by small circles show at what point in time and at what detector analog level an alarm condition exists.

Four levels of output (Alarm states 1, 2, 3 and 4) were selected for the NRL detector. Although these levels are initiated by the processing of the analog signals resulting from each detector, one can see from the (above mentioned) plots that there is a direct relation between the analog signal magnitude and the level achieved. This correspondence is intended to convey to our observer that *State* # 1, for example, indicates an unusual environmental change, since this level takes place at an analog level not greatly removed from conditions attributed to environmental excursions. Therefore, *State* # 1 might be initiated by excessive non-fire related situations. However, this state does not imply cause for immediate alarm. *State* # 2 suggests that ordinary ambient changes have been well exceeded and that a check of the detector is in order. *State* # 3 asserts that conditions are clearly abnormal. Finally, the *State* # 4 indicates that immediate corrective actions should be initiated. The commercial detector is preset to alarm at about 0.8 volts. An alarm for the logic-aided commercial detector depends upon the exercise of logic on its analog signal.

RESULTS

Run # 4 has been selected as an example. This test run compares the results obtained from three detectors. The first is a commercially developed, residential ionization detector (X). The second is a commercially developed prototype logic-aided detector (Y). The third is the NRL developed processor aided detector (Z), which, because of multiple detectors, has two analog outputs. The three detectors for this run are found on plot # 4. The plot also includes the percent obscuration. The maximum obscuration reached during this run was 1/10 of 1%.

The fuel used in this run was a lighted cigarette placed in the aerosol generation section of the smoke box. At the start of the run, the commercial logic-aided detector's analog output starts to rise followed by the NRL # 1 analog some 10 second later. The NRL detector's 10 second lag is attributed to its exponential dilution method of sampling. With this method, incoming combustion products dilute the normal atmosphere in the detector head. This effectively smoothes the signal and averages the rate of rise of contaminants which may be in the sub micron particle range, and discourages fast ambient changes which may cause false alarms. The NRL # 2 analog's lag in response is due to its geometric location in the detector head. Its presence in the detector is to simulate a different type of sensor to evaluate the detection scheme. Approximately 20 seconds later (total time 35 seconds into the run) the NRL detector (2) has reached its *first* state of detection — State # 1 — indicating a possible fire situation. The percent of smoke obscuration at this point is less than 1/10 of 1%. At approximately 45 seconds into the test, the commercial logic-aided detector's analog is starting to level. Approximately 50 seconds into the test, the commercial detector and the NRL # 2 analog start to respond to the fire situation. At approximately 1 minute 40 seconds into the run the NRL detector (Z) goes into its *second* stage of alarm, indicating an increasing fire threat. The percent obscuration has increased very slightly to around 1/10 of 1%. At one minute 55 seconds the commercial detector (X) responds with its single alarm. At this time the fire situation is still increasing and the analog signals are responding to the threat. At approximately 2 minutes and 15 seconds the NRL detector (Z) goes into the *third* stage level — indicating the accelerating threat of the fire situation. At approximately 3 minutes and 15 seconds the commercial logic-aided detector goes into its single alarm.

At approximately 4 minutes 20 seconds into the run, the exhaust vent and fan in the environmental test chamber were turned on the fuel removed from the aerosol generator. All detectors responded to the decrease in combustion products. Note the NRL # 1 detector's analog signal remains longer because of the design of the sampling chamber in the detector head. The combustion products must be diluted with incoming normalizing environment before a complete decrease in response to the products of combustion will be accomplished. The NRL designed detector head dilutes exponentially with the fan speed controlling the dilution rate. This technique averages short term combustion products, i.e., lighting of cigarette, and allows the detector a much greater non-false-alarming potential than any of the other detectors.

At approximately 6 minutes the commercial (X) and commercial logic-aided (Y) detectors show no further response. At approximately 6 minutes 25 seconds NRL # 1 analog shows the environment to be normal.

SUMMARY AND CONCLUSIONS

More reliable detection of fire situations can best be achieved by the earliest possible indication of a threat with subsequent stages of detection indicating magnitude of threat.

Outlined below are a number of detection parameters thought to give the best early warning of a fire situation.

1. Fast, accurate Detection
   A. capable of indicating a true fire threat within a reasonably short time.
2. Convey Additional Information
   A. Immediate indication of a potential threat.
   B. Indications of increasing magnitude of threat.
3. Versatility
   A Processing to suit location.
   B. Increase Sampling rate when products of combustion are present.
4. Environmentally Adaptive.
   A. Integrate out "background noise."
   B. Smoothe rapid environmental changes.

It is felt that no detection system using one preset alarm or one predetermined set of detection parameters, for a single alarm, will give adequate early warning of all fire signatures.

The varied environmental conditions found aboard naval vessels pose the more difficult task for a detection system. These conditions can be related to "background noise levels" because of their effect on the detection process. No detection system with one preset detection level will operate optimally in every environmental location. Thru design, the NRL system has the versatility and flexibility to be adaptable to different anticipated "background noise levels."

This is accomplished by changing the processing parameters to suit the detector's location. This optimized system will take advantage of the advances made in data processing, digital electronics, and micro processing. The processor will be somewhat like the "chip" found in pocket calculators today. This chip will be inexpensive and perform operations not possible with previous fire detection systems. This system will show the progression of the fire situation thru its multi-stepped alarm output.

The present work shows that the NRL-developed fire detector does in fact give a very early indication of a possible fire threat. Furthermore, it also allows the monitoring of the progression or regression of the "fire situation". This markedly decreases the potential for false alarms inherent in many present-day fire detectors if they are pre-set to give an early alarm, because such detectors respond in a "go-no-go" mode. Thus, the ability to follow the cause of the fire threat by a Damage Control Center also permits better guidance and coordination in the fighting of a fire.

Compared to the above outline it is felt that the NRL detector meets most of the requirements stated, therefore, continued effort in this area is highly recommended. Although discrete false alarming parameters have not been set, a new series of environmental testing is in the planning stages. The *same three detectors* will be exposed to environmental extremes as well as rapid environmental changes including temperature, humidity, and air flow.

ACKNOWLEDGMENTS

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2. "Annual Federal Fire Council Reports on Fire Losses." National Fire Prevention and Control Associates, Washington, D.C. 1976.
3. R. L. P. Custer and R. G. Bright, "Fire Detection State-of-the-Art," National Burea of Standards report NBSIR 75-700.

APPENDIX

Fig. 1 — The Ion Chamber Schematic

Fig. 2 — NRL Multi Detector Sampling Head (NRLMSD)

Fig. 3 — NRL Processor

Fig. 4 — Environmental Test Chamber

Fig. 5 — Test Chamber Parameters

Fig. 6 — Test Run No. 1

Fig. 7 — Test Run No. 2

Fig. 8 — Test Run No. 3

Fig. 9 — Test Run No. 4

Fig. 10 — Test Run No. 5

Fig. 11 — Test Run No. 6

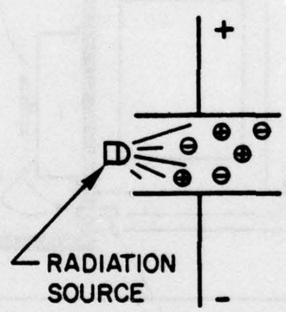


FIG. I ION CHAMBER

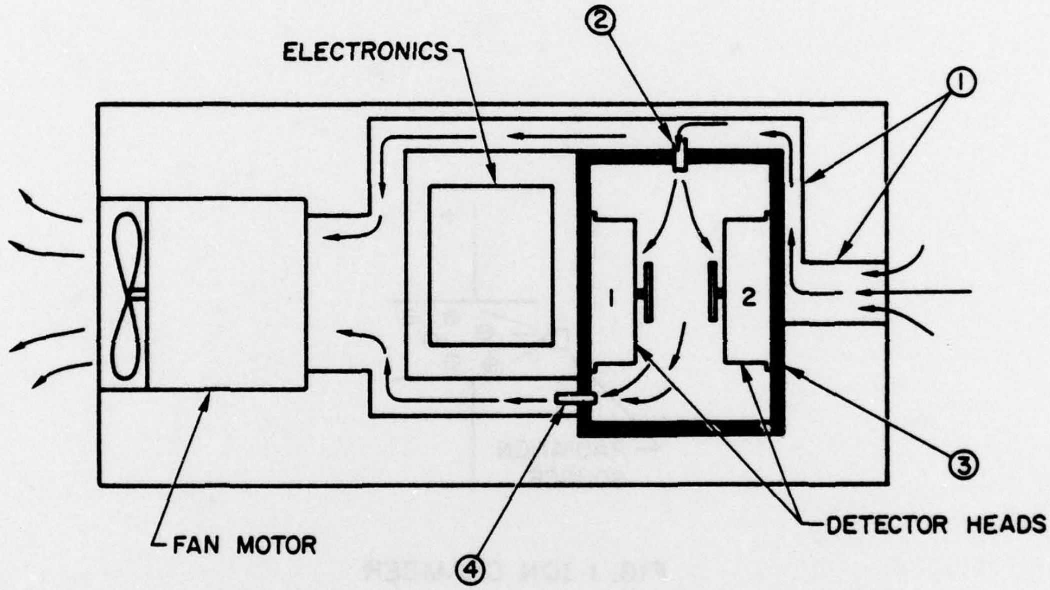
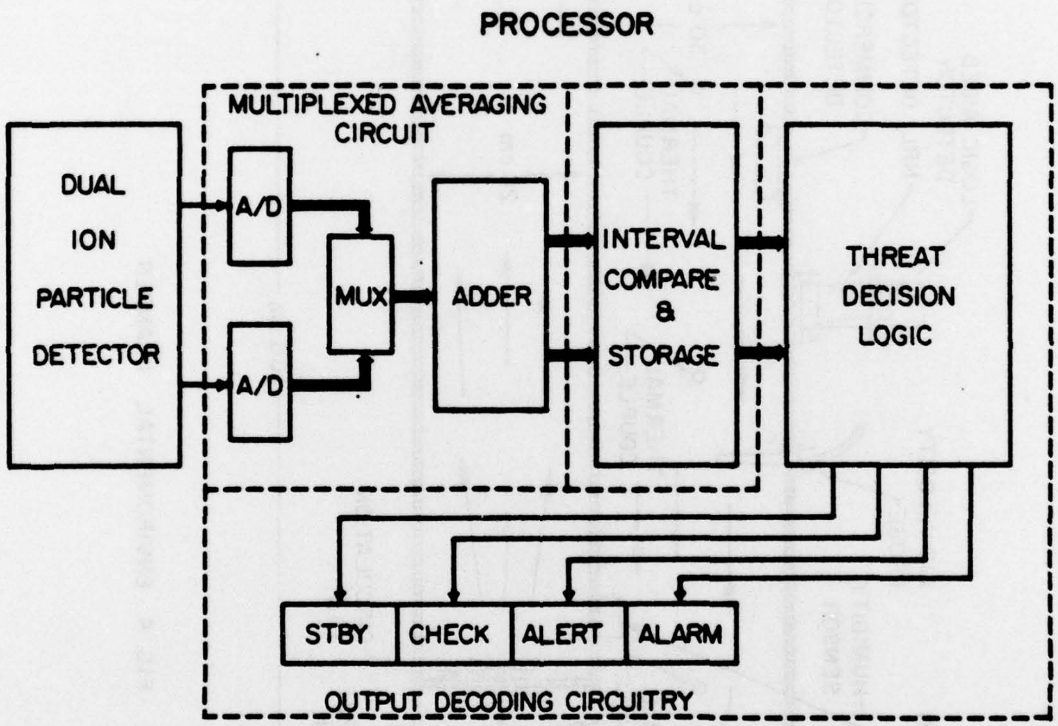


FIG. 2 MULTI DETECTOR SAMPLING HEAD (NRL MSD)


PROCESSOR
MULTIPLEXED AVERAGING CIRCUIT
DUAL ION PARTICLE DETECTOR
A/D
A/D
MUX
ADDER
INTERVAL COMPARE & STORAGE
THREAT DECISION LOGIC
STBY
CHECK
ALERT
ALARM
OUTPUT DECODING CIRCUITRY

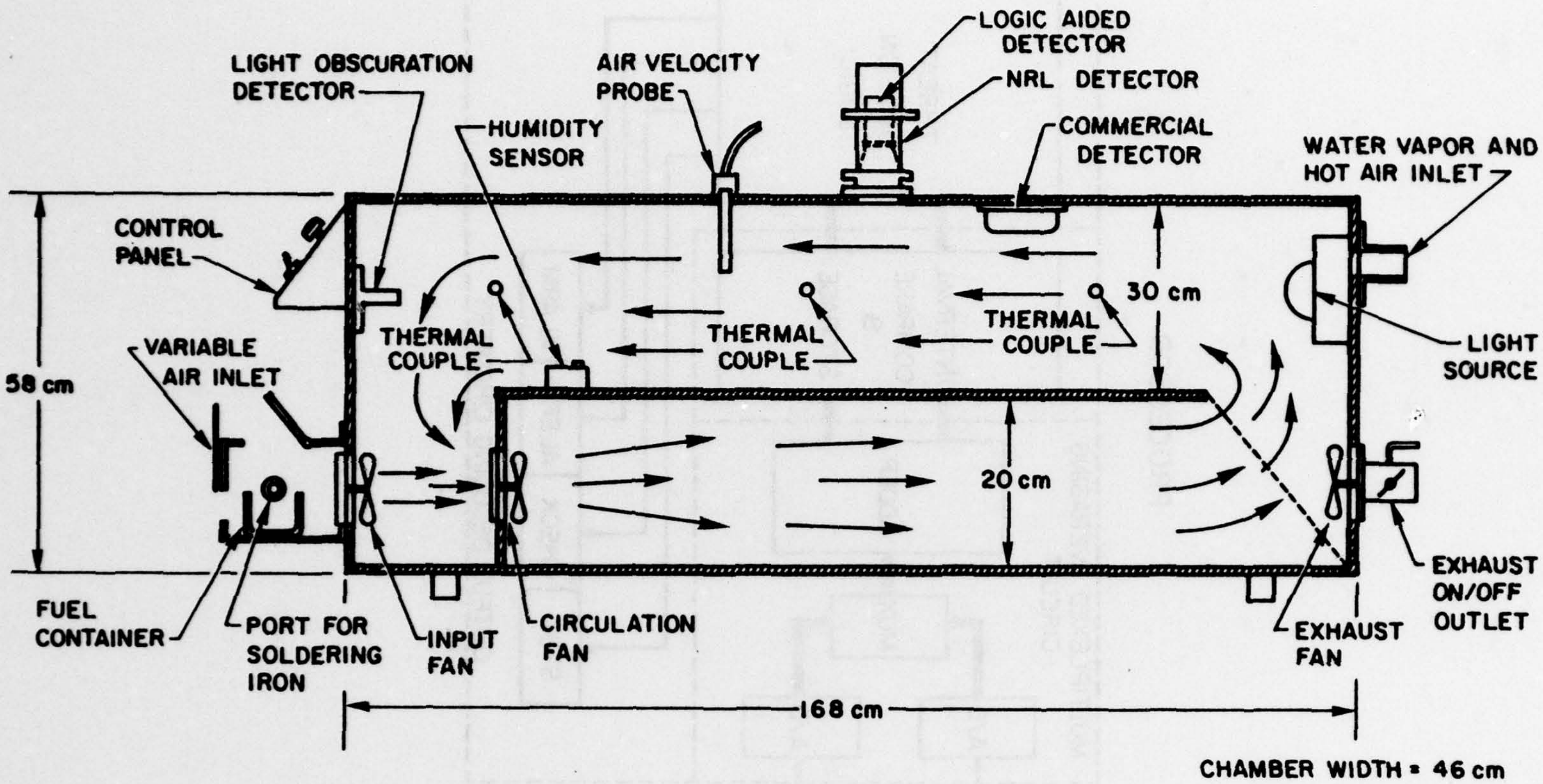


FIG. 4 ENVIROMENTAL CHAMBER

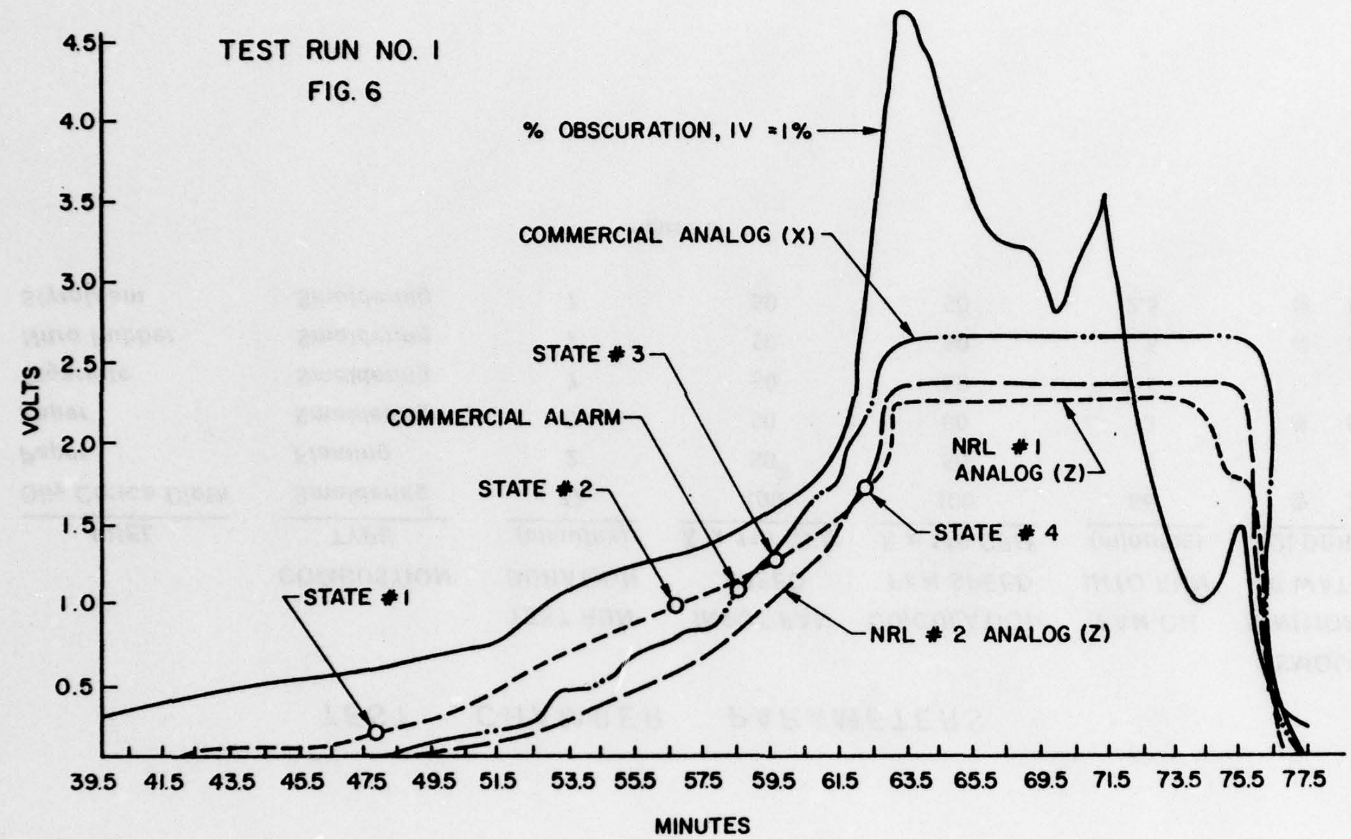
TEST CHAMBER PARAMETERS

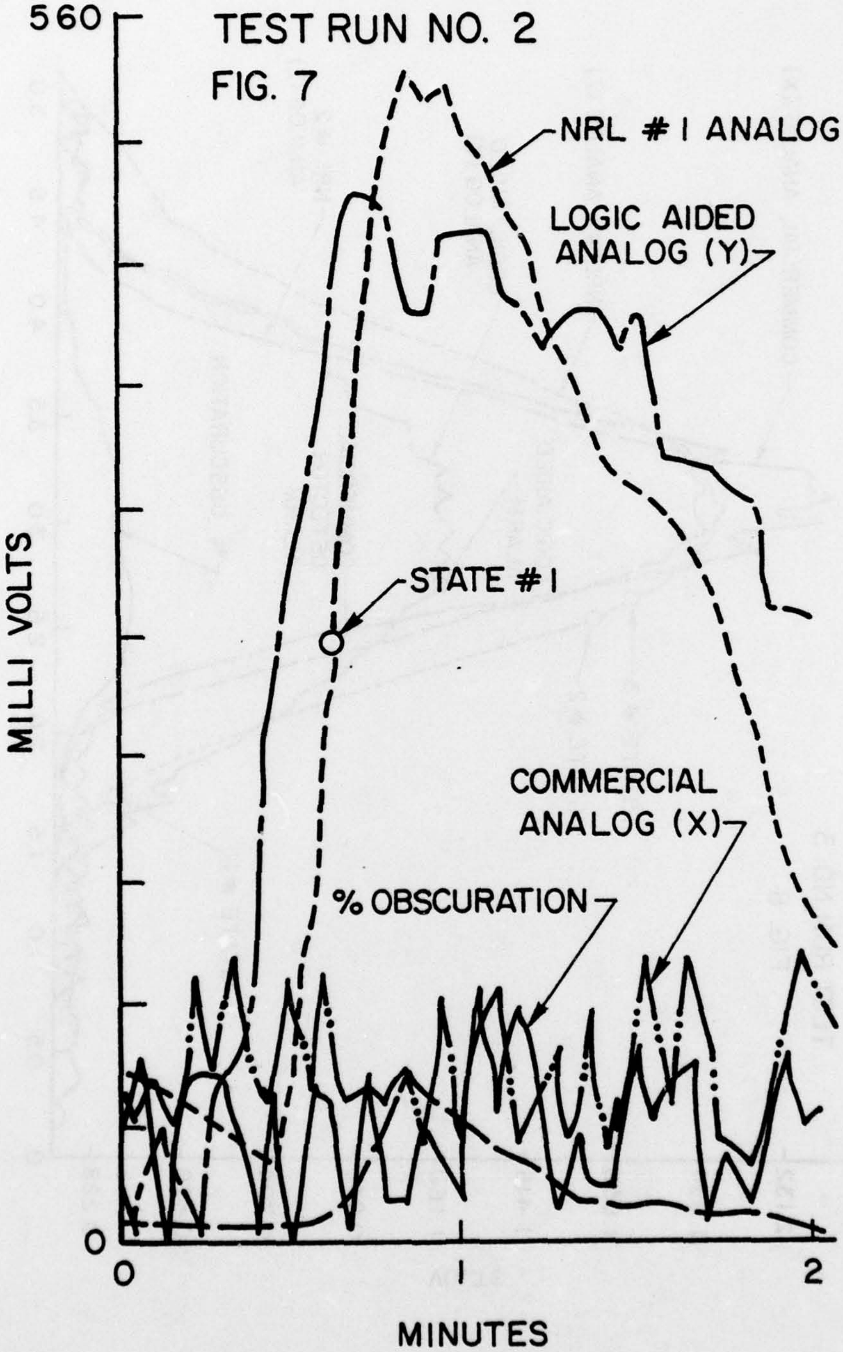
TEST	FUEL	COMBUSTION TYPE	TEST RUN DURATION (minutes)	INPUT FAN SPEED % x 110 CFM	CIRCULATION FAN SPEED % x 110 CFM	FAN ON INTO RUN (minutes)	SMOLDERING IGNITION SOURCE 50 WATT UNGAR SOLDERING IRON
1	Oily Cotton Cloth	Smoldering	77	100	100	66	@ 75 volts
2	Paper	Flaming	2	50	50	2	"
3	Paper	Smoldering	5	50	50	3	@ 90 volts
4	Cigarette	Smoldering	7	50	50	5	"
5	Nitro Rubber	Smoldering	7	50	50	5	@ 80 volts
6	Styrofoam	Smoldering	7	50	50	2.5	@ 90 volts

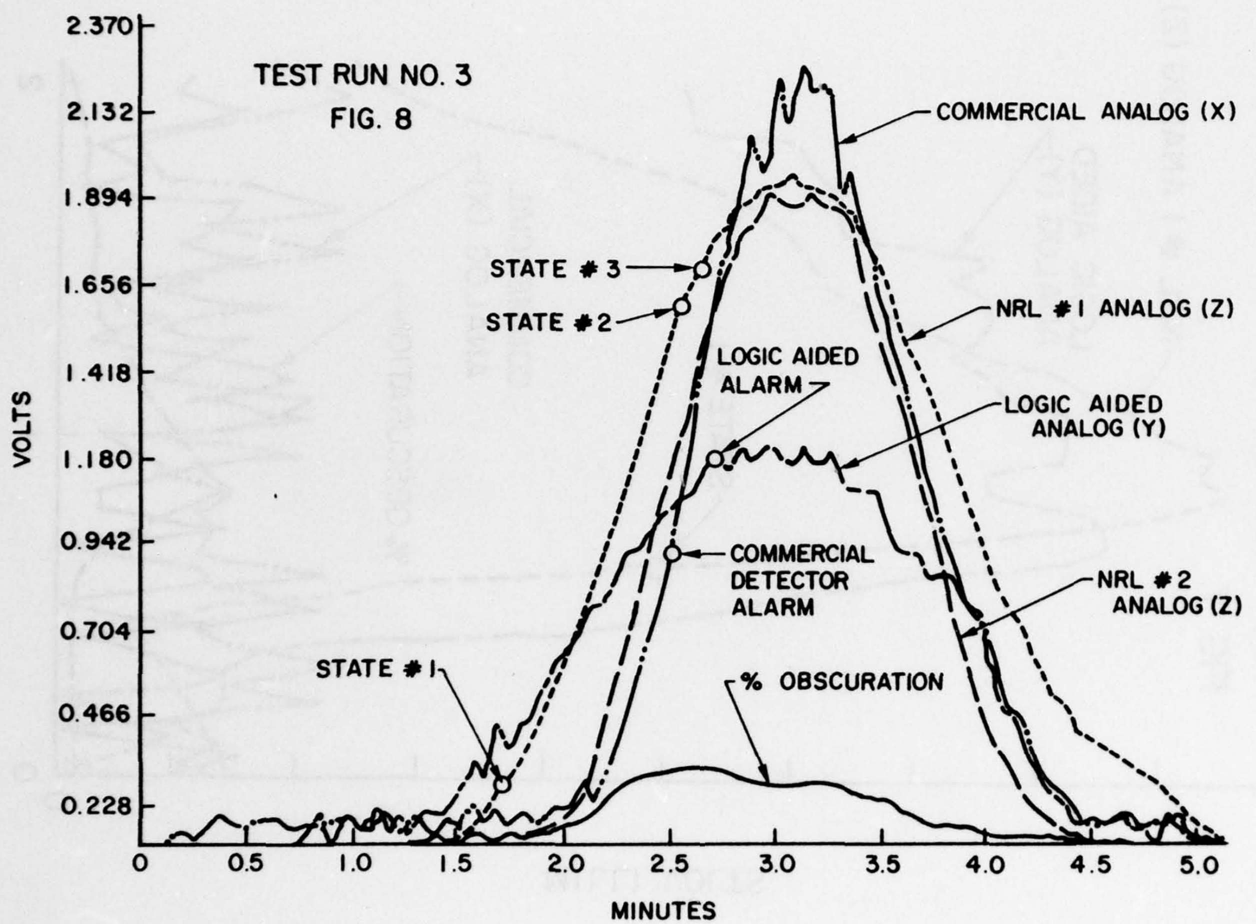
Figure 5

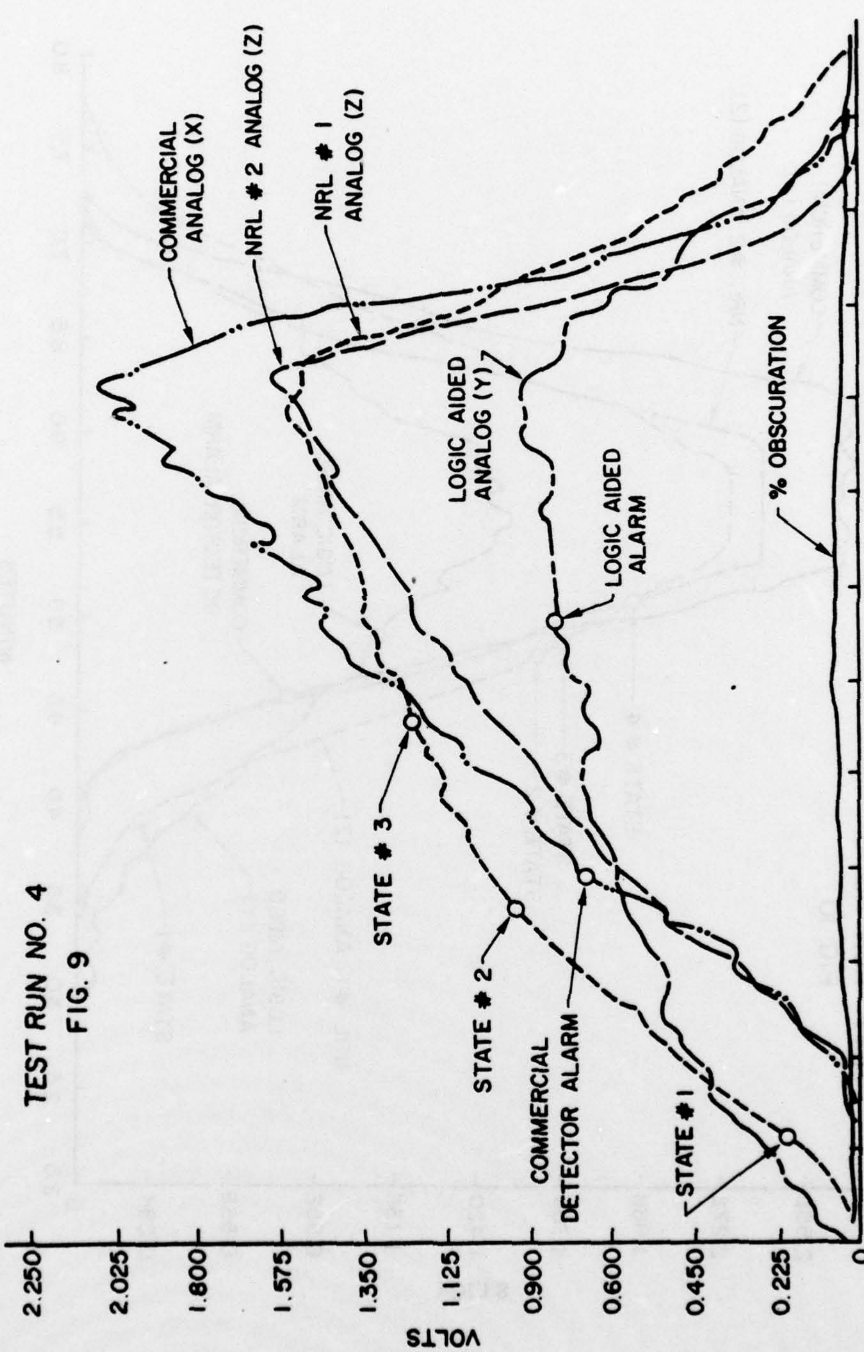
TEST RUN NO. 1

FIG. 6



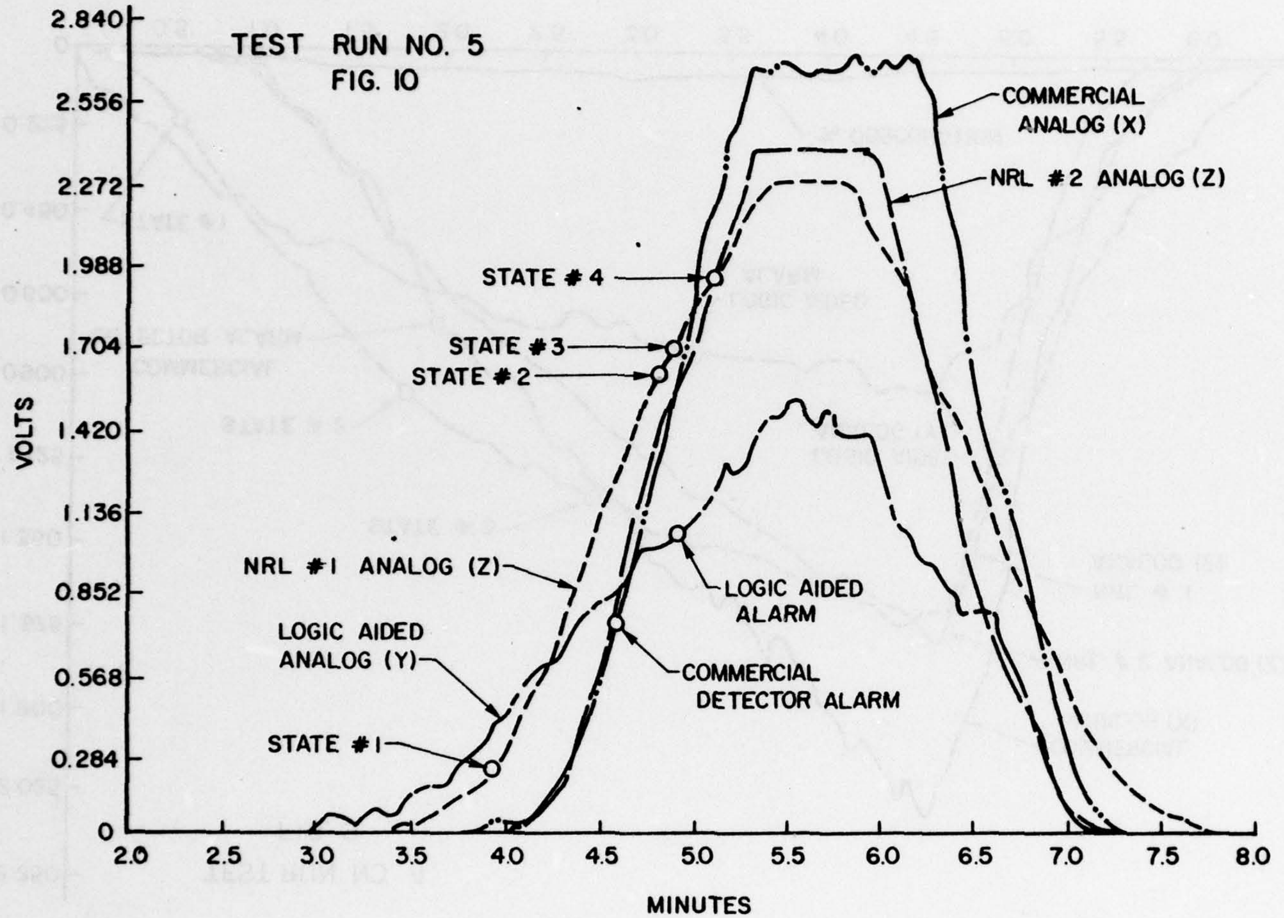

560
TEST RUN NO. 2
FIG. 7
NRL # I ANALOG (Z)
LOGIC AIDED
ANALOG (Y)
STATE # I
MILLI VOLTS
COMMERCIAL
ANALOG (X)
% OBSCURATION
0
0
I
2
MINUTES

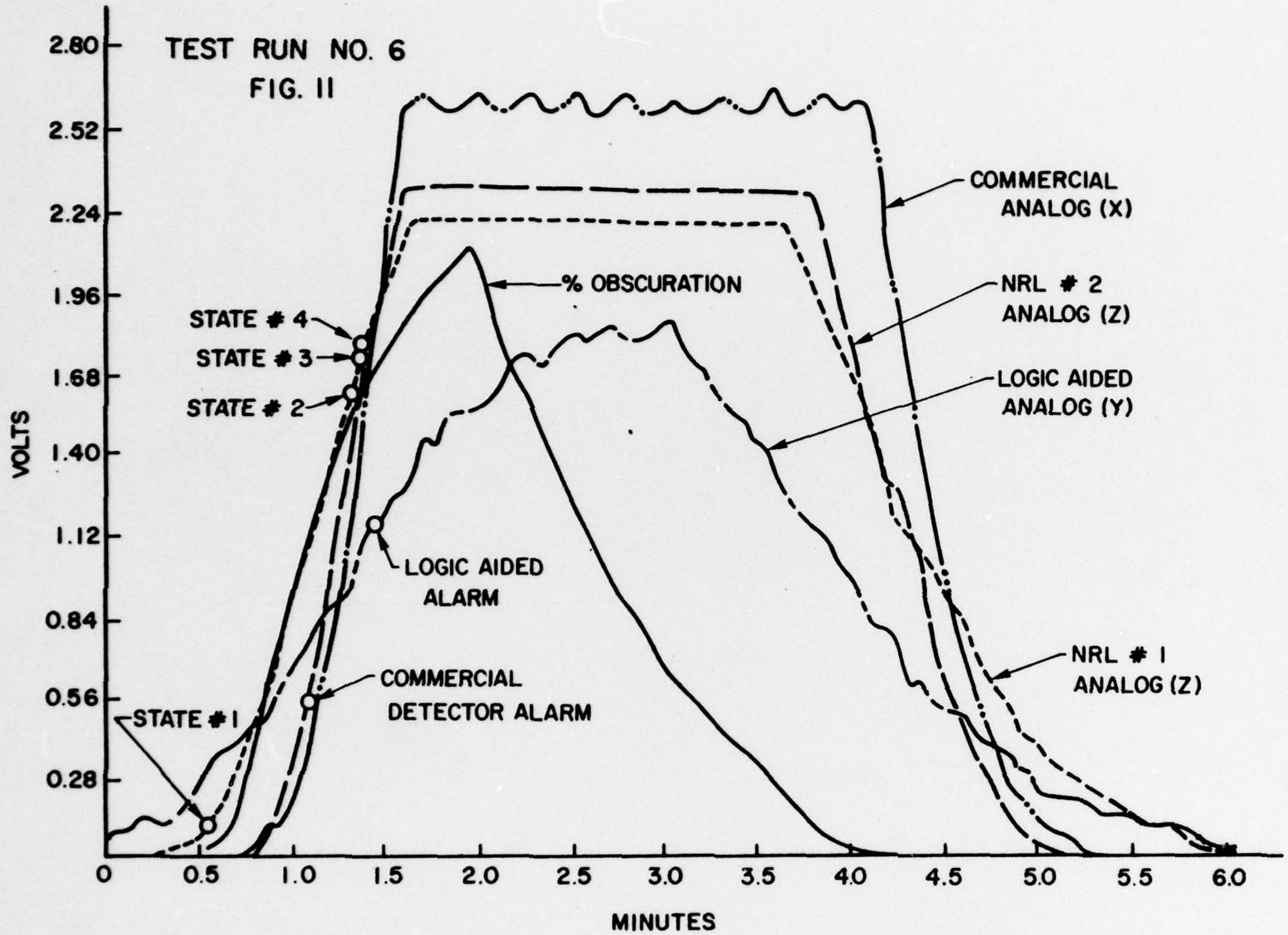

TEST RUN NO. 3
FIG. 8
VOLTS
2.370
2.132
1.894
1.656
1.418
1.180
0.942
0.704
0.466
0.228
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
MINUTES
COMMERCIAL ANALOG (X)
STATE # 3
STATE # 2
NRL # 1 ANALOG (Z)
LOGIC AIDED ALARM
LOGIC AIDED ANALOG (Y)
COMMERCIAL DETECTOR ALARM
NRL # 2 ANALOG (Z)
STATE # 1
% OBSCURATION



TEST RUN NO. 4
FIG. 9

TEST RUN NO. 5
FIG. 10




TEST RUN NO. 6
FIG. 11
VOLTS
2.80
2.52
2.24
1.96
1.68
1.40
1.12
0.84
0.56
0.28
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
MINUTES
COMMERCIAL ANALOG (X)
NRL # 2 ANALOG (Z)
LOGIC AIDED ANALOG (Y)
% OBSCURATION
NRL # 1 ANALOG (Z)
STATE # 4
STATE # 3
STATE # 2
STATE # 1
LOGIC AIDED ALARM
COMMERCIAL DETECTOR ALARM