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SYSTEM EVALUATION OF SOLID CHEMICAL  
OXYGEN GENERATORS

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March 1975

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Block 20 Abstract continued

This effort concerned the test and performance evaluation of two basic types of chlorate candle oxygen generators while operating in a laboratory system console. The two candle formulations were compared for oxygen producing capacity, flowrate, and ignitability. System data on candle generator temperature and accumulator pressure was also recorded.

The results of the effort established that sodium chlorate candle ignition and performance were more consistent and superior to lithium perchlorate candles.

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## FOREWORD

This technical report was prepared by the Air Force Flight Dynamics Laboratory (AFFDL), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. This effort was documented under Project No. 6146, Task No. 6146 01, Work Unit 6146 01 09 in the Environmental Control Branch of the Air Force Flight Dynamics Laboratory. Mr. Edward B. Thompson, Jr. was the principal investigator.

The subject report summarizes the results of an in-house program concerning the test and evaluation of oxygen generating chlorate candles operating in a total system configuration. The candles were evaluated on the basis of oxygen generation capacity, flowrate, and ignitability. Generator temperature and pressure data were also recorded.

The manuscript was released for publication by the author in January 1975.

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## SECTION I

### INTRODUCTION

LOX systems for supplying breathable oxygen to aircraft crews are gradually being replaced (in planning or practice) by alternative oxygen generating devices that are less dependent on re-supply and maintenance.

One such alternative system is the Solid Chemical Oxygen Generator (chlorate candle). This device has already been adopted for aircraft emergency oxygen application and is being developed for normal respiratory support on the C-5A and C-141 transports.

This gradual transition in applied technology has been implemented through costly and time consuming engineering development programs. All too frequently costly design changes arise during the development program which could have been averted if sufficient preliminary design data had been available prior to contract.

The subject program was undertaken with the dual objectives of (1) determining the capabilities of a laboratory breadboard model of a solid chemical oxygen generation system, and (2) evaluating the comparative performance between sodium chlorate and lithium perchlorate candles operating as part of a breadboard system configuration.



## SECTION II

### DISCUSSION OF THE PROBLEM

Solid chemical oxygen generation systems - hereafter referred to as "chlorate candles" are being increasingly accepted by aircraft subsystem designers and planners as a suitable replacement for LOX oxygen supply systems. Emergency oxygen systems have been moving towards adoption of chlorate candles as a LOX replacement - beginning with the C-5A transport several years ago. Other aircraft, military and commercial, have also adopted the candles. Normal oxygen supply systems utilizing chlorate candles are now in the pre-development stage. Normal systems will utilize the multi-candle/accumulator principle as opposed to the individual emergency oxygen units tailored to each passenger. The former approach (sometimes termed "central system") is more efficient and economical but is also more vulnerable to malfunction because of design complexities. Not only is the operation more complex but envelope sizing and hardware installation problems are more extensive. For example, replacement of a LOX palletized system with a chlorate candle unit would probably involve enlarging the storage compartment to accommodate the unit. The larger volume required by the candle system is due to the existence of the accumulator - a component not contained per se in the LOX system. Another design consideration for the candle system would be heat removal during operation. A typical sodium chlorate - iron powder formulation - liberates 0.8 BTU per gram of candle mix. A single candle having this

formulation and weighing 1,000 gms (e.g., C-5A unit) would produce 800 BTU during combustion. Heat removal problems with a multi-generator system would be considerable unless preliminary design data indicates that system cooling could be readily accomplished without alternation of the airframe structure.

Many of the problems encountered in designing a chlorate candle system for aircraft oxygen application can be directly related to the quantity of oxygen deliverable from the system commonly termed "oxygen capacity." This is directly related to the oxygen "bound" into each candle or the stoichiometric oxygen present in the candle formulation. A lithium perchlorate formulation candle for example contains approximately 50% more oxygen than a sodium chlorate candle of identical size. It logically follows that two systems identical in design except for candle formulation would differ markedly in potential performance. The lithium perchlorate candle system would be smaller for the same oxygen capacity or of the same size thereby having a larger life support capability. Unfortunately, lithium perchlorate burns somewhat erratically and requires a plenum for levelling the oxygen flowrate. An accumulator accomplishes this purpose as well as providing a storage/demand feature for the system.

SECTION III  
DESCRIPTION OF LABORATORY CONSOLE  
AND OXYGEN GENERATORS

The system console was designed for operational flexibility, simplicity, and minimal maintenance. The unit features remote and local ignition control of the system, automatic and manual operation modes, and six chlorate candles contained in individual rechargeable generators. The six generators each contain an integral filter for contaminant removal. A regenerable dryer using molecular sieves (Linde 13X) is provided for moisture control. A mass flowmeter monitors the oxygen generation rate. The generated oxygen is stored in a 500 cu. in. accumulator at less than 500 psig. An ignition control system using 28V DC power permits the generator activation sequence to be programmed for automatic operation. An override is included for manual operation. An automatic safety override is designed into the ignition control system which removes generator activation power and indicates when the system pressure exceeds 400 psig. Oxygen can be delivered from the system at a pressure of 2 to 100 psig through three constant flow stations or through one demand flow station. System diagnostic information includes 19 temperatures: 3 for each generator and one for the delivered oxygen, 6 oxygen generation flowrates and system pressure via continuous record transducer and gauge. The console dimensions are 84 in. long by 30 in. high by 28 in. wide.

See Figures 1 through 4 which depict the Laboratory console and candles.

Each of the console subsystems can be described as follows:

1. Ignition Control Subsystem

This subsystem automatically activates the candle ignition devices to maintain a pressure of at least 50 psig in the accumulator. A manual override is an integral function of this subsystem. The override is activated from a three position control module to activate one candle. Manual activation of additional candle ignition devices requires switching to the "OFF" position then back to the manual position. The third position of the control provides the automatic operation.

The sequential ignition control subsystem operates on 28V AC/DC.

The three position control module is connected to the remainder of the system by an electrical umbilical 10 feet long. The sequential ignition control subsystem is designed so that no candle is ignited when the accumulator pressure exceeds 400 psig.

2. Oxygen Generator Subsystem

This subsystem consists of six oxygen generators each of which contain a chlorate candle. Each generator is equipped with an electrical ignitor, internal/replaceable filter and means of indicating that the

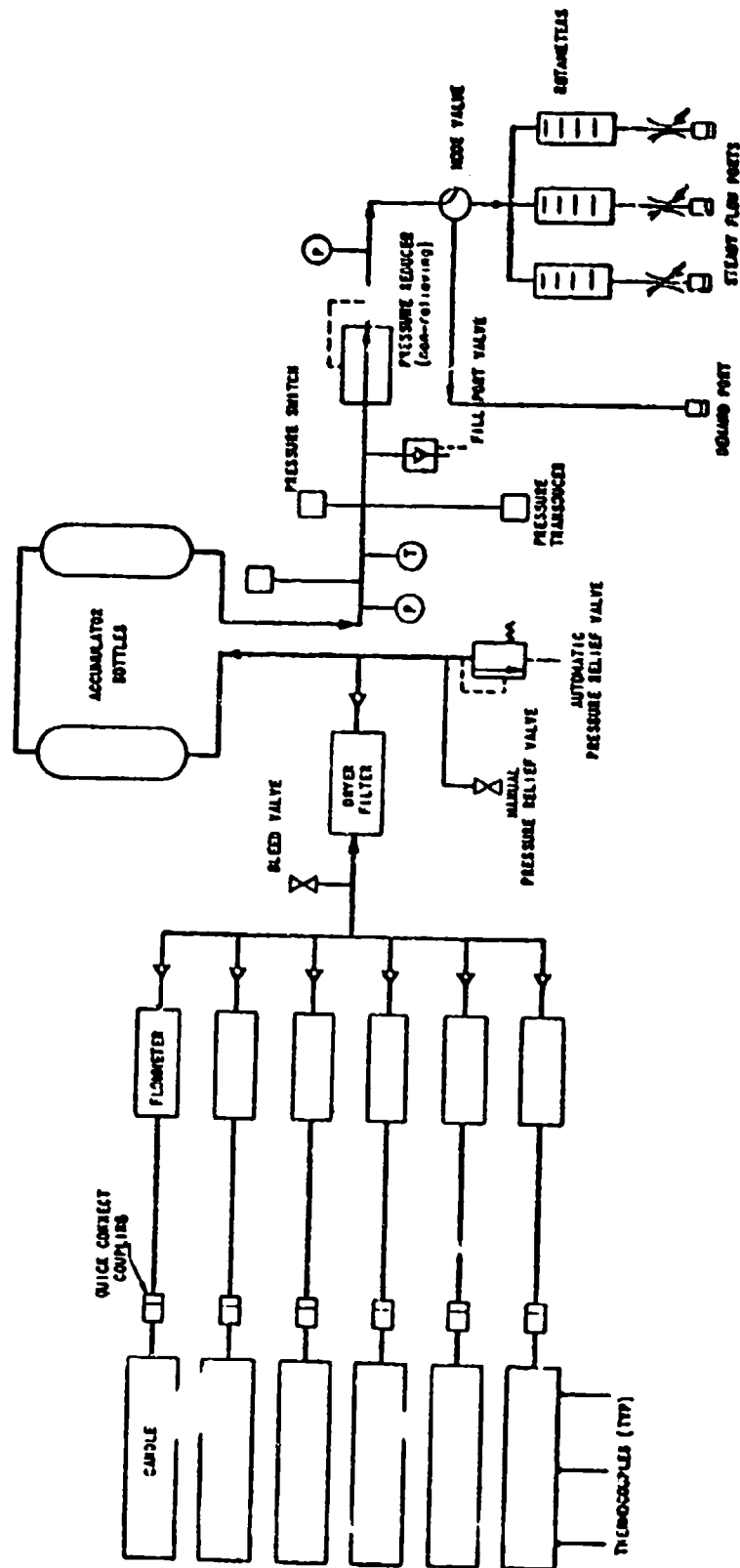


FIGURE 1 Schematic of Laboratory Oxygen Generation System Console

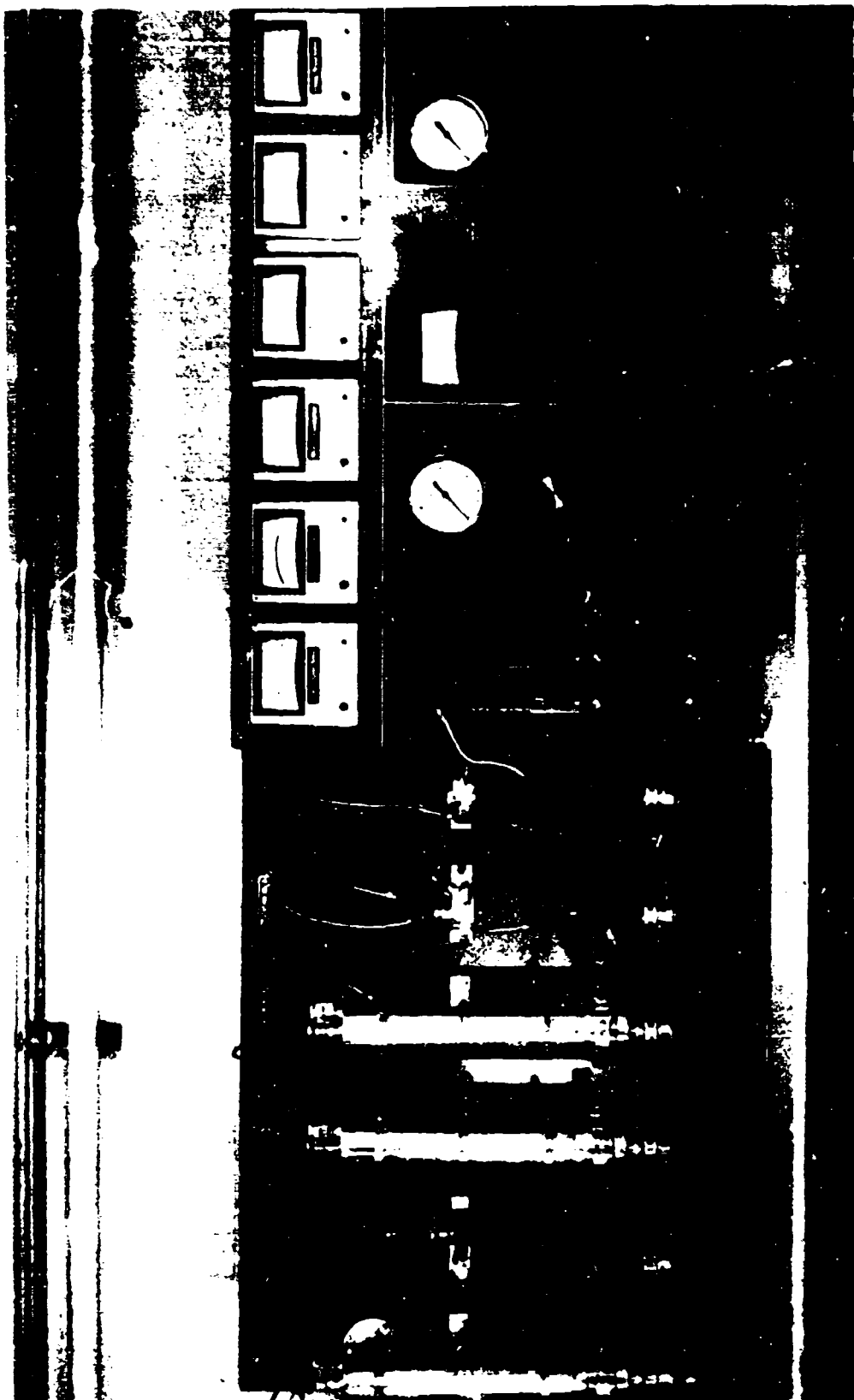


FIGURE 2 Photograph of Laboratory Oxygen Generation Console

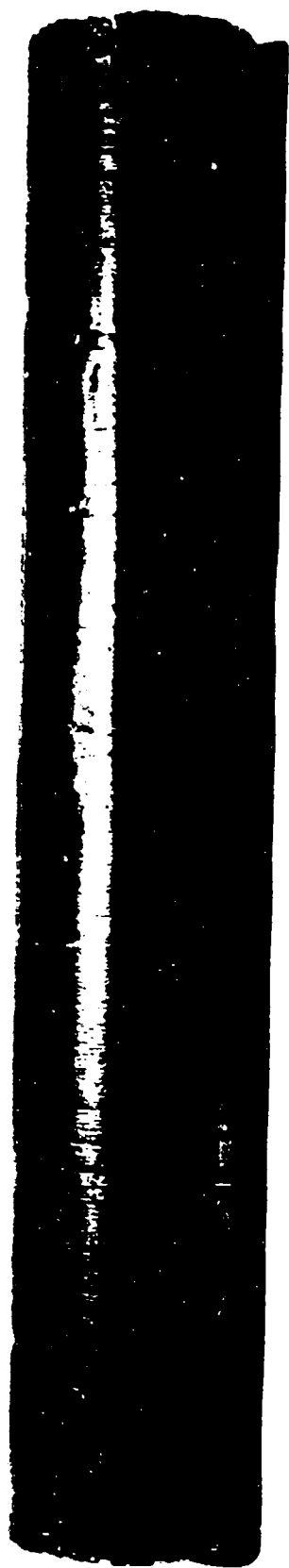


Figure 3. Chlorate Candle Prior to Installation in Generator Housing

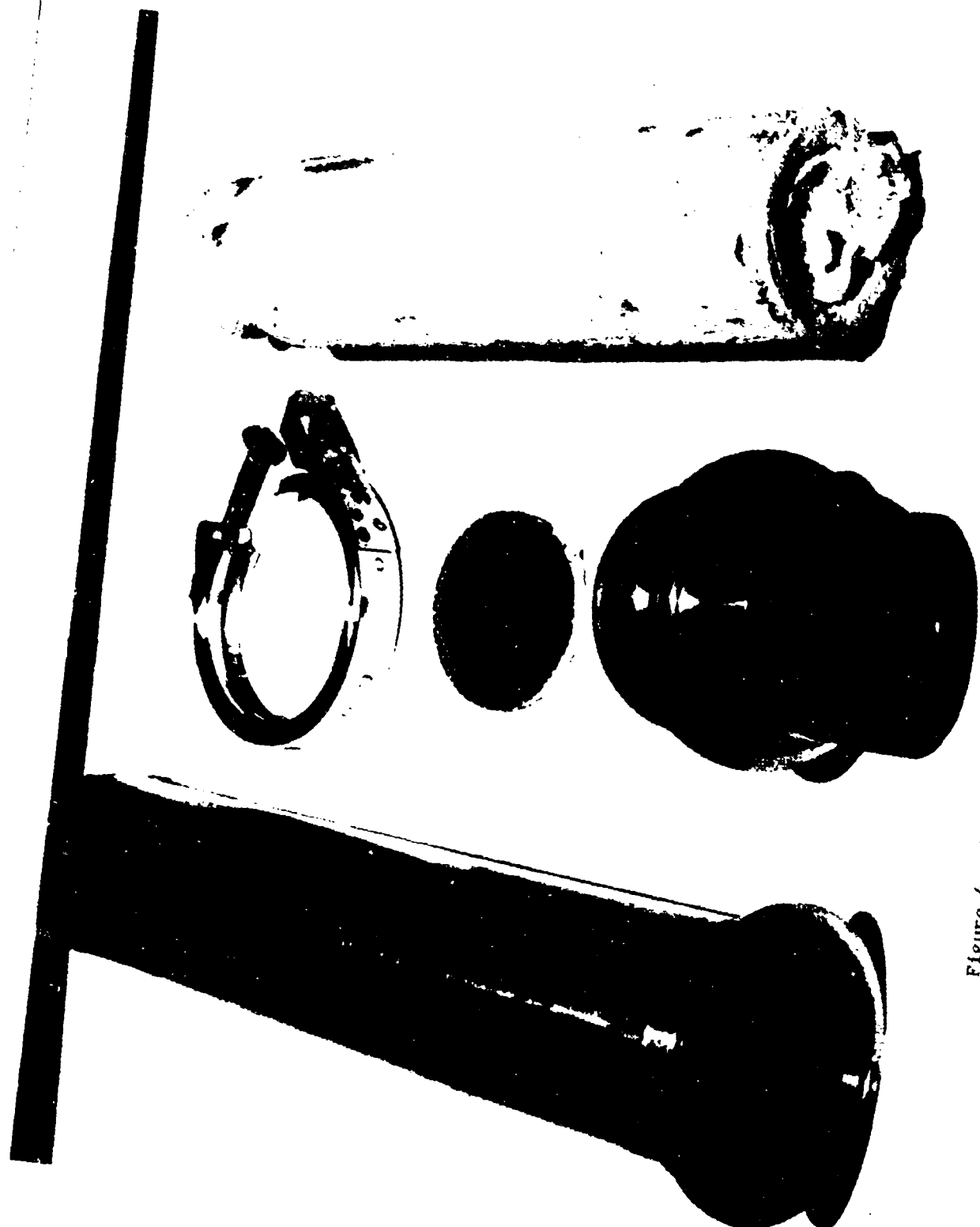


Figure 4. Oxygen Generator Components Before Assembly



candle is functioning or has been expended. Integral to each generator is a safety head with a rupture disk which relieves the internal pressure of the generator if the generator outlet becomes plugged.

The six generators are interconnected in parallel with the total oxygen flow directed to a manifold and accumulator.

The interconnecting flow lines between generators are equipped with check valves to permit ignition and operation of a particular candle. The generators are connected to the system with "quick" disconnects to enable removal of individual generators from the system without disrupting the system operation.

The surface of each generator is fitted with one fixed thermocouple and two adjustable thermocouples which move on a track. Each candle delivers 270 liters of oxygen at a nominal flowrate of 9 LPM measured at sea level pressure and 70°F temperature. (Sodium chlorate candles).

### 3. Accumulator Subsystem

The oxygen delivered by the generators goes to an accumulator. The accumulator possesses sufficient volume to contain the entire volume of oxygen produced by one candle at a pressure not to exceed 600 psig.

The accumulator is fitted with pressure and temperature gauges and a pressure relief device.

The delivery subsystem is fitted with three delivery stations each of which is capable of delivering at least 3 LPM of oxygen. Each delivery station includes a flow indicator and regulator.

SECTION IV  
PLANNING OF TEST PROGRAM

The test plan devised for the program was based on the principles discussed in Sections II and III of this report and the experience gained from chlorate candle evaluation programs previously completed.

It had been originally planned during this program to "test-evaluate" candles empirically to determine oxygen flowrate and thermal output data. The experimental procedure adopted in previous similar programs was decided upon for this effort. Candles of the pre-determined formulations were to be compounded and fabricated according to standard practice.

In order to evaluate the performance of the system console in alignment with the objectives of the program, it was planned to prepare two types of chlorate candles for testing. The candles were to have the following composition, size, and weight:

<u>Composition</u>	<u>Total Weight</u>	<u>Size</u>
89% $\text{NaClO}_3$ 6% FE 4% $\text{BaO}_2$ 1% Glass fibers	500 gms	10" long x 1 5/8" dia.
66% $\text{LiClO}_4$ 33% $\text{LiI}$ 1% Glass fibers	(500 gms)	10" long x 1 5/8" dia.

Six candles of each type would be fabricated by the hot press technique.

All ingredients were to be kept in sealed storage containers before and after candle preparation. After initial storage and drying in an oven at 250°F, the ingredients were blended in a rotational mixer for 30 minutes. Each candle formulation was then poured into a mold pre-heated to 250°F in the oven and stored there for 1 hour. Ram and mold were then placed in the press and pressing of each candle was accomplished at 10 tons per square inch. The cone mixtures were prepared separately and pressed into each candle at 4 tons per square inch.

Precautions were taken during the heating and pressing of lithium oxidant candles to keep the candles free of any organic material. The higher oxygen content of lithium perchlorate makes it all the more vulnerable when contaminated.

Two commercial "off-the-shelf" candles were installed in the console and ignited. General performance of these candles was used to re-check the console and determine that all components were functioning properly.

The following parametric data was to be gathered during the combustion/performance of each of the twelve candles:

- Generator temperature profile
- Oxygen flowrate
- Accumulator build-up rate
- Candle burning time
- Accumulator temperature

Qualitative information relevant to candle ignition characteristics was also to be noted.

## SECTION V

### TEST PROGRAM

The data recorded during the testing was divided into candle performance results. Tables I and II summarize the candle performance data. The tables also contain the console operating data.

The tests were divided into sodium chlorate candle and lithium perchlorate candle evaluation categories. All six generator positions were first filled with sodium chlorate candles. The candles were sequentially ignited according to the order and time intervals shown in Table I. The lithium perchlorate candles were then installed in the generator housings after the system had been flushed with nitrogen. The dryer cartridge was also changed. Test conditions for the lithium oxidant candles are depicted in Table II. Both tables include effects on console performance - specifically, the accumulator pressure build-up rate.

Prior to the test of the candles, sequential automatic ignition of the console was verified using only electrical igniters. Ignition of the candles during the generator tests was accomplished manually.

TABLE I  
SODIUM CHLORATE CANDLE/SYSTEM CONSOLE PERFORMANCE

Generator/ Candle Test Nr.	Generator Operating Time (Mins.)	Average Oxygen Flowrate (LPM)	Oxygen Flowrate Range (LPM)	Generator Housing Peak Temp. Range (°F)	Accumulator Pressure Range (PSI)	Time Between Candle Ignition (Mins.)	Remarks
2	38	11	6-17	405-470	0-205	N/A	Satisfactory ignition and candle performance gradual pressure build-up rate.
2	34	13	9-16	415-490	204-415	38	Satisfactory ignition and candle performance.
3	41	10	8-17	400-486	415-450	34	System vented at 450 psi - 3rd candle burned to extinguishment.
4	2	4	1-6	N/A	0-15	15	System completely vented candle extinguished prematurely. Limited data recorded.
5	35	11	8-13	395-480	15-242	2	Satisfactory ignition and candle performance.
6	40	12	11-14	408-491	242-435	35	Satisfactory ignition and candle performance.

TABLE II  
LITHIUM PERCHLORATE CANDLE/SYSTEM CONSOLE PERFORMANCE

Generator/ Candle Test Nr.	Generator Operating Time (Mins.)	Average Oxygen Flowrate (LPM)	Oxygen Flowrate Range (LPM)	Generator Housing Peak Temp. Range (°F)	Accumulator Pressure Range (PSI)	Time Between Candle Ignition (Mins.)	Remarks
1	1	N/A	0-16	N/A	N/A	N/A	Candle extinguished shortly after ignition.
2	32	15	11-24	325-375	0-265	1	Satisfactory ignition and candle performance, erratic oxygen flowrate.
3	3	5	4-9	346-365	265-280	32	Candle extinguished shortly after ignition.
4	24	17	14-24	338-370	280-450	3	Accumulator vented at 450 psi. Bleed down to 300 psi.
5	5	8	6-12	322-374	300-355	15	Candle extinguished shortly after ignition, erratic oxygen flowrate.
6	2	7	6-11	N/A	355-380	5	Candle extinguished shortly after ignition.

Table I data is depicted in Figure 5 and clearly shows that sodium chlorate candles performed consistently with one exception. The exception concerned candle #4 which cracked at the cone section upon ignition. The system accumulator pressurized as scheduled and leak checks were conducted. Generator #3 leaked slightly at the housing clamp. This was corrected by tightening the clamp. Recorded housing temperature data was consistent with that expected for sodium chlorate candles.

Table II data and Figure 6 confirm the unpredictability of lithium perchlorate candles. Two of the six candles tested burned to completion although with an erratic flowrate pattern. The four failures occurred within a few minutes of ignition. In each case, the candle had become a shapeless mass.



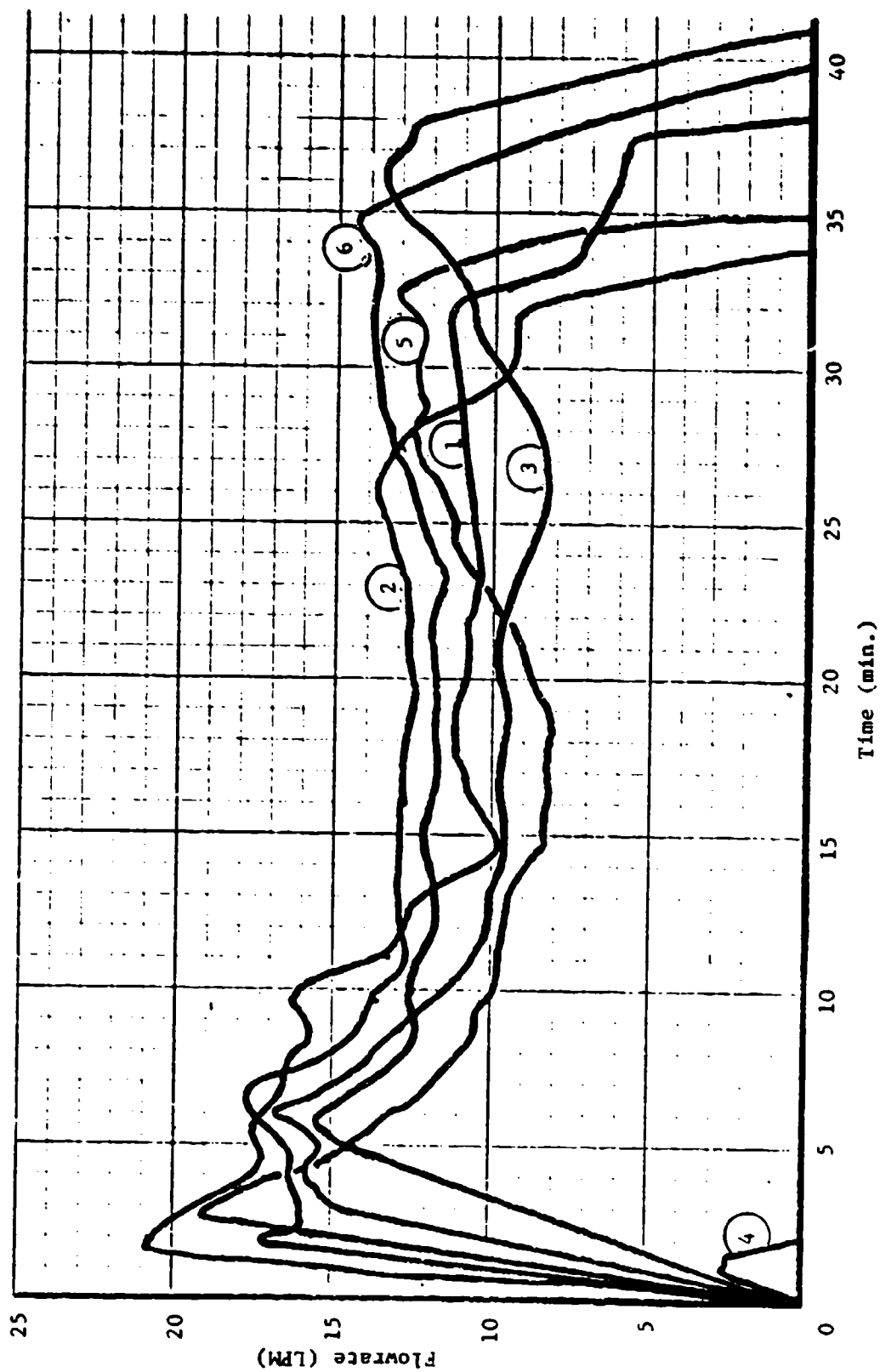


FIGURE 5 SODIUM CHLORATE CANDLE PERFORMANCE - TIME VS. FLOWRATE

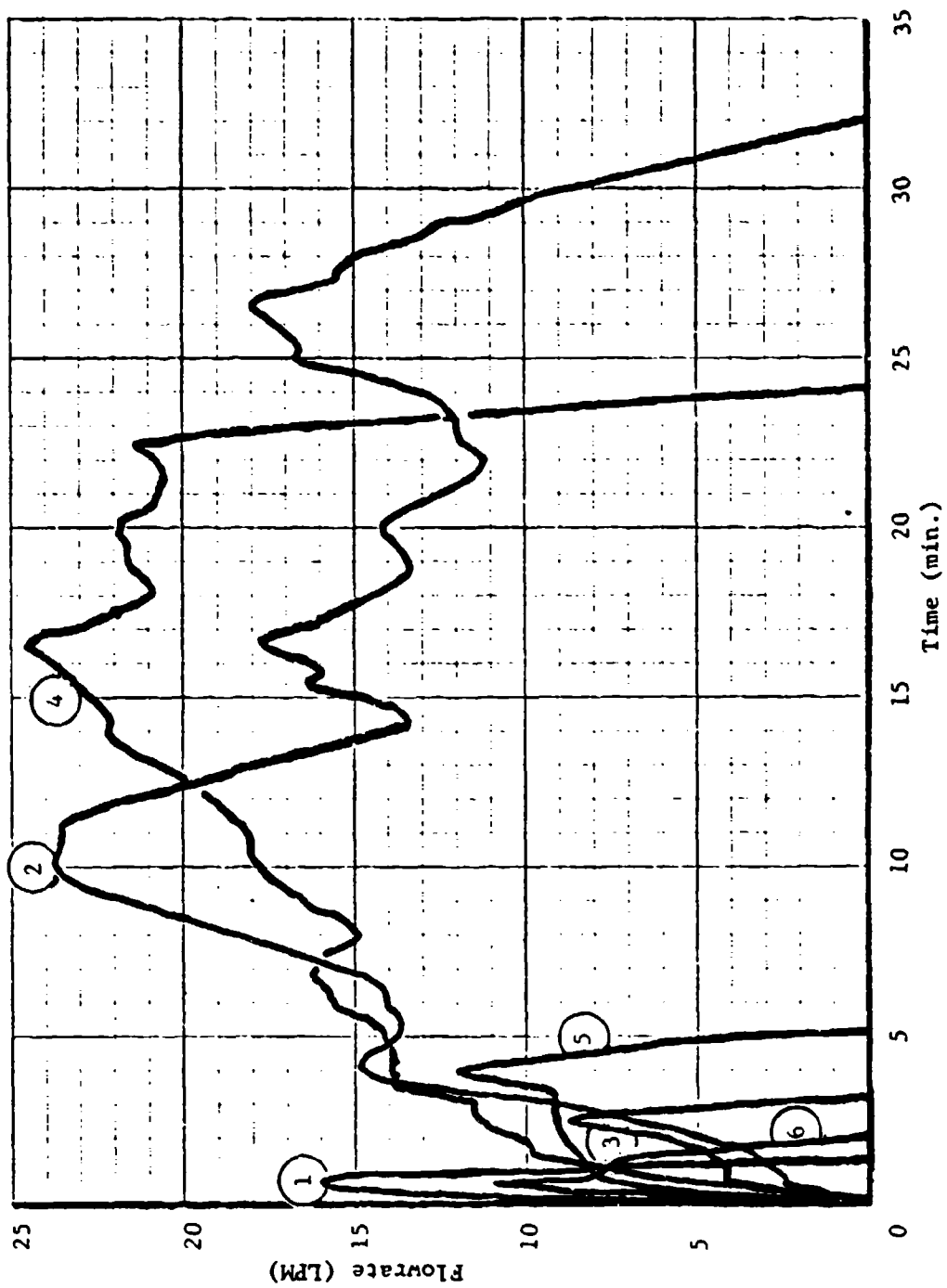


FIGURE 6 LITHIUM PERCHLORATE CANDLE PERFORMANCE - TIME VS. FLOWRATE

## SECTION VI

### CONCLUSIONS

The system console operated as designed throughout the testing - except for a minor leakage problem at the clamp of generator #3.

The results of the testing established conclusively that sodium chlorate candles are more reliable and consistent than lithium perchlorate candles while operating as part of a system configuration. Ignition of sodium chlorate candles was more readily accomplished and the oxygen flowrate profile is considerably more stable and predictable. The potentially greater amount of oxygen available from lithium perchlorate candles (same weight as sodium chlorate candles) does not offset the ignition difficulties and lack of consistent performance.

Future efforts in solid chemical oxygen generation should concentrate on the use of sodium chlorate candles in a demand system operating mode.

## SECTION VII

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