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INDEPENDENT RESPIRATORY SUPPORT SYSTEM

Hamilton Standard
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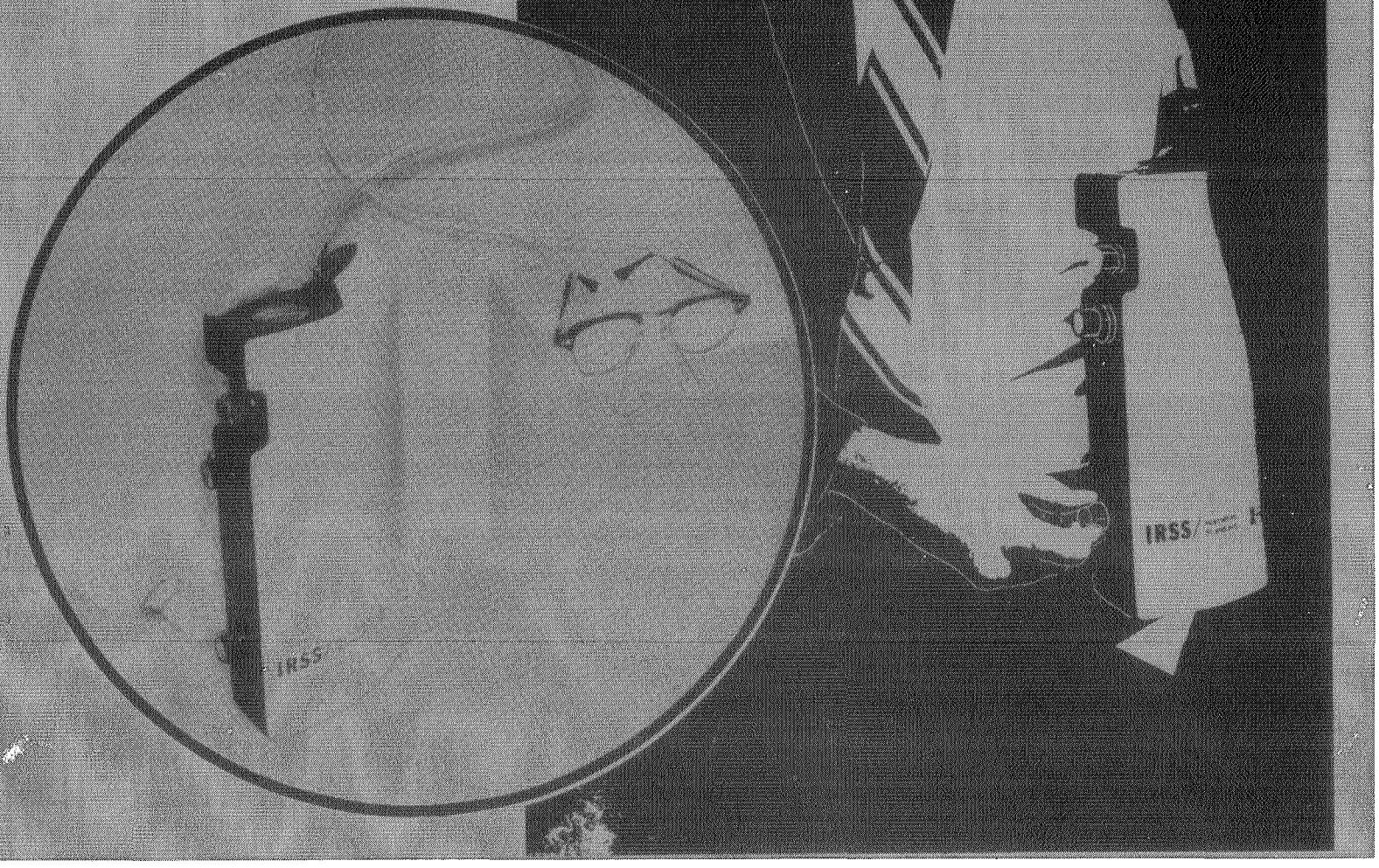

INDEPENDENT RESPIRATORY SUPPORT SYSTEM

Final Report

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FOREWARD

This program was conducted by Hamilton Standard, Division of United Aircraft Corporation, Windsor Locks, Connecticut 06096. The effort was performed under NASA Headquarters Contract No. NASW-1972, Control No. 10-7752. The program summarized herein was conducted during the period 2 September 1969 through 31 March 1970.

The principal investigator was Mr. Douglas C. Howard, Advanced Engineering, who was assisted by Mr. John Greene, Design Engineering. The contract technical monitor was Mr. William L. Smith, NASA Headquarters.

The basic objectives of the original IRSS was the development and delivery of a system which would have the following capabilities: (1) 2.5 lpm flow for a minimum of 30 minutes; (2) light weight, low volume high pressure O_2 system; and (3) nose catheter O_2 delivery system for crew operational non-interference.

The potential NASA applications of the IRSS included the following: (1) respiratory/pressurization support to bends treatment cells for incapacitated astronauts; (2) utilization in non-anthropomorphic space suit systems in conjunction with selective CO_2 membranes in emergency use; and (3) utilization in non-pressurized light aircraft operations where supplementary O_2 is required. During the course of the study it became clear that the IRSS could be utilized for supplementary respiratory support to ambulatory patients with emphysema, asthma, and other respiratory tract ailments. This contractor report explores this latter application.

ABSTRACT

Various forms of respiratory and circulatory disease produce chronic hypoxia at metabolic rates above resting. Short-term oxygen therapy will alleviate this condition for time periods up to two or three hours, depending on the severity of the ailment and the level of metabolic expenditure assumed. The objectives of this program were: (1) to define a "first-cut" system of low weight and volume satisfying a specific level of metabolic support; (2) fabricate three units as defined by the first objective; and (3) define an improved system based on user evaluation of the delivered units and detailed engineering studies. Three units were built having weights of 7.7 lbs and volumes of 210 cubic inches each. One such unit will provide 0.5 to 2.5 liters per minute of 100% oxygen to the nasal passages for durations of 2.5 to 0.5 hours, respectively. The operation of these units to date has been entirely satisfactory. Studies in support of the third objective indicate that optimized system weight and volume goals of 5 lbs and 165 cubic inches are not unreasonable. Additionally, a fluidics circuit would provide a demand capability permitting flows of 1 to 2 liters per minute for time periods up to four hours.

INTRODUCTION

There are physiological changes which occur in the human system which result in a pathological condition known as chronic hypoxia. This condition exists when the cellular oxygen tension or concentration is reduced below that required to maintain normal metabolic activity. There are four basic types of hypoxia:

- Ventilatory - whenever there is a reduction in alveolar oxygen partial pressure or there is an obstruction to oxygen transfer through the alveolar wall, ventilatory hypoxia exists.
- Hemic - Hemic hypoxia is the result of an inability of the hemoglobin to accept oxygen or a reduction in hemoglobin concentration.
- Circulatory - this type of hypoxia results from low blood flow, loss of blood volume, or obstruction of the vascular system.
- Histotoxic - the inability of the tissues to accept or use the oxygen is called histotoxic hypoxia.

Increased oxygen partial pressure in the respiratory gas mixture will relieve ventilatory hypoxia and some forms of circulatory hypoxia. This report documents the efforts of a program to develop a small, portable, inconspicuous oxygen delivery system for short term use.

SUMMARY

A six month program was conducted at Hamilton Standard to develop the Independent Respiratory Support System (IRSS). Each of three delivery end items consisted of a functional feasibility unit. These were delivered to NASA Headquarters, Washington D.C.

Preliminary concept studies were conducted to determine system configuration, suspension, operation, and mode of oxygen delivery. A weight and volume mockup with dummy controls was then evaluated. The ultimate result was definition of a system that will deliver oxygen at variable flow rates from 0.5 to 2.5 liters per minute for periods of time from 150 to 30 minutes, respectively. Delivery is accomplished via an inconspicuous tubing system that is integrated with eyeglass frames. System dry weight and volume were 7.7 lbs and 210 cubic inches. Additionally, system optimization studies were conducted which revealed that significant improvements could be made. These included changing the oxygen bottle material for weight savings, creating a demand rather than flush-flow system, and minor component redesign for volume reductions.

CONCLUSIONS

1. A low weight inconspicuous personal oxygen delivery system can be practicably fabricated and operated as a metabolic supplement.

2. Operational problems are primarily human engineering rather than system function oriented.

3. A system which would satisfy the majority of population need would provide 1-2 liters per minute for four hours.

4. System improvements can be made which will result in a substantially weight and volume optimized unit.

RECOMMENDATIONS

1. More use data on units now in the field should be obtained.

2. The improvements described in the System Optimization Study should be implemented.

3. A design study to generate a four-hour system should be initiated.

DISCUSSION

Configuration Study

A system configuration study was conducted to define the parameters listed in Table I. The ground rules dictated that the study consider only systems that would deliver oxygen at a maximum of 2.5 liters per minute for 30 minutes minimum. Furthermore, the system must be capable of recharge from a commercial 2000 psig source.

Oxygen Bottles

The total volume of stored oxygen is fixed by the recharge pressure of 2000 psig, the maximum flow rate of 2.5 liters per minute, and the minimum flow time of 30 minutes. All calculations were based on a bottle pressure of 1800 psig since this value represents that used by commercial bottle manufacturers.

$$W_{O_2} = V_{flow} \rho_{O_2} T_{flow}$$

$$= \frac{2.5 \text{ liters}}{\text{Minute}} \quad \frac{0.0828 \text{ lb}}{\text{ft}^3} \quad (30 \text{ Minutes}) \quad \frac{1 \text{ ft}^3}{28.3 \text{ Liters}}$$

$$= 0.22 \text{ lbs}$$

$$V_{O_2} = \frac{W_{O_2} R T}{P_{O_2}}$$

$$= \frac{(0.22 \text{ lbs}_m) \quad \frac{48.3 \text{ ft lb}_f}{\text{lbm } ^\circ\text{R}} \quad (500^\circ\text{R}) \quad \frac{12 \text{ in}}{\text{ft}}}{\frac{1800 \text{ lb}_f}{\text{in}^2}}$$

$$= 35.5 \text{ in}^3 = 583 \text{ cm}^3$$

To this volume must be added the ullage volume of six cubic centimeters since the pressure regulation is not accurate below 200 psig. Thus, the total oxygen storage volume is 590 cm^3. Commercial bottles designated as meeting U.S. Department of Transportation Title 49 requirements for a

TABLE I

IRSS CONFIGURATION STUDY PARAMETERS

- Number of oxygen bottles
- Package configuration
- Suspension
- Controls and displays
- Off-the-shelf components
- Oxygen delivery

3E-1800 oxygen storage vessel can be obtained in volumes of 600, 300, 150, 75, and 10 cm^3. Figures 1 and 2 show the effect of varying the number of oxygen bottles on system weight and thickness. The two bottle configuration was selected from this data.

System Definition

After defining the number of oxygen bottles, a system definition study was conducted. The objective was to define the external configuration suspension system, controls and displays, color scheme, off-the-shelf components, and mode of oxygen delivery.

Figures 3 through 7 show the concepts which represent maximum probability of translation into usable hardware. The other concepts studied would have required extensive development work to achieve safe working hardware. The concept shown in Figure 3 was selected for the IRSS feasibility units. The principal reason for this choice is due to the suspension system. The strap suspension is capable of many different arrangements, is simple to operate, has a very low weight, is inconspicuous, and is simplest to fabricate. The concepts shown in Figures 3, 4, and 5 are nearly equal with respect to configuration, controls, color, and components.

The concepts shown in Figures 6 and 7 were discarded due to the high system weight, inability to wear the system inconspicuously, and reduced safety due to the high pressure line used to connect the two tanks. Additionally, the Figure 7 concept cannot be worn in the sitting position due to the tanks riding up the chest to shoulder level.

Figures 8, 9, and 10 show the three oxygen delivery systems considered. These all adhere to the ground rule of oxygen delivery to the nasal passages so as not to interfere with the user's speech. Figure 8 was selected for the IRSS feasibility units. It provides the most inconspicuous method of delivery without interfering with the user's breathing as the concept shown in Figure 10 does. The system shown in Figure 9 does not interfere with user breathing, however, it is quite conspicuous.

Component Selection

Figure 11 is a system schematic based on a two oxygen bottle configuration. The components listed as off-the-shelf are described below:

- Fill Fitting - this is an oxygen clean charging valve manufactured by Scott Aviation, Company. It contains a particle filter and check valve to prevent back flow during the charging operation
- High Pressure Relief - This device is a 2400 psig blow-out disc. It also contains a fusible element that will relieve bottle pressure at temperatures in excess of 160°F. It is an integral part of the pressure regulator and supplied by Scott Aviation Company.
- Pressure Regulator - This is a single stage preset pressure regulation device. It will accept inlet pressures from 200 to 2000 psig and deliver approximately 50 psig at the low pressure port. It is manufactured by Scott Aviation Company. An oxygen shut-off valve is integral with the regulator.

- Pressure Gage - The pressure gage indicates the pressure in the oxygen storage tanks. It is graduated in 500 psig increments to 2000 psig. The mechanism will actually withstand 4000 psig, however, this is not indicated on the gage face. The back of the case is vented to relieve case pressure in the event of a bourdon tube failure or leak. The gage is supplied by Scott Aviation Company.
- Low Pressure Relief - This spring loaded 100 psig relief valve protects all components downstream of the pressure regulator. It is supplied by the Circle Seal Valve Company.
- Flow Control - Flow is controlled by a Whitey Valve Company micro-regulating valve. This valve will supply 0.5 to 2.5 liters per minute flow with a 180° rotation and approximately 50 psig at the inlet.

Fabrication and Test

Since the system is to be used with 100% oxygen, all off-the-shelf components were received as certified for 100% oxygen service. All other fittings, brackets, and components were cleaned for commercial oxygen use as a minimum. Additionally, Zyglo dye penetrant checks were made on all high pressure components to ensure structural integrity.

Assembly of each unit was carried out in an area of sufficient cleanliness to allow unhampered manipulation of all components without fear of contamination. After assembly of the high pressure sections of the system, a proof pressure of 2700 psig was imposed for fifteen minutes. Thereafter, a detailed visual inspection for evidence of

deformation was performed. Following proof pressure, a pressure leak test was performed. This consisted of pressurization to 1800 psig with helium and checking all joints with a special bubble solution called "SNOOP". The failure criteria was one visible bubble in one minute. If this occurred, the fitting was reworked until the bubbling disappeared.

Final assembly including the low pressure sections was accomplished after proof pressure and leakage testing. The completed unit was then inspected and pressurized to 1800 psig with oxygen and allowed to remain so for six to twelve hours. Evidence of pressure decay as denoted by the pressure gage was cause to repeat the helium leakage test until the observed pressure decay was undetectable.

Thereafter, a flow rate test was performed to verify flows of 0.5, 1.5, and 2.5 liters per minute as indicated by the flow control. The unit was then charged to 1800 psig and the capability to flow 2.5 liters per minute for 30 minutes minimum verified.

The final test conducted was an oxygen saturation test. A test subject donned the fully charged unit. With the oxygen distribution system in place and the flow set at 2.5 liters per minute, oxygen partial pressure measurements were made at various points on the subject. These points included the corners of the mouth, shoulders, throat, and chest areas. Measurements were made at the clothing level, 2 inches and 4 inches from the clothing. The only readings taken that registered more than the 145 to 150 mm Hg tare, were 190 mm Hg at the corners of the mouth. The test was repeated once to verify these readings. The unit was then bagged and tagged for shipment.

System Optimization Study

Following fabrication of the feasibility units, a study was conducted to determine which system improvements could be practicably incorporated. The result of the study was that there are three areas where significant changes may be accomplished which will result in weight and volume reductions to the system. These changes are: (1) addition of a fluidics circuit to change the current flush-flow system to a demand type; (2) changing the oxygen bottle material; and (3) minor component redesign. Finally, a survey of the number and types of disabilities requiring use of this system was performed.

Fluidics Circuit

The current system is flush-flow, that is, once placed in operation, oxygen continues to flow until the shut-off valve is closed or the stored oxygen depleted. The addition of a fluidic driven circuit such as that shown in Figure 11, will convert the system to a demand type. The pressure differential created during inhalation triggers the sensitivity control which opens the flow in leg "a" of the fluidic control module. This causes the flow entering d to switch from c to b. The positive pressure thus created opens the fluidic on-off valve allowing oxygen to flow to the user's nasal passages. The reverse procedure takes place during exhalation.

Since oxygen is used only during inhalation, flow is required at only those times. Inhalation occurs during 25 to 30% of the total respiratory cycle. The remainder is composed of exhalation and rest period. Therefore, the nominal oxygen storage requirement would be 25 to 30% of that for a flush flow system.

There is, however, a bleed flow required to run the fluidic circuit which averages one standard cubic foot per hour or approximately 15 standard liters for the 30 minutes use cycle. This bleed, when added to the usable oxygen storage required, results in a total oxygen requirement of approximately 50% of that required for the flush flow system. This change will produce system weight and volume savings of approximately one lb. and 8 cubic inches.

Oxygen Bottle Material

The oxygen bottles used in the present system are 1010 carbon steel. This could be replaced by a stainless steel such as 4130, having two and one-half times greater strength. Such a substitution would have two benefits. First, weight savings on the bottle of 20% or more may be achieved due to thinner walls. Secondly, safety and handling characteristics are improved because of the use of a more corrosion resistant material.

Redesign

A minor redesign effort which includes the packaging of the fluidics components would result in additional weight and volume savings of approximately 10% over those already described. Only those components requiring change due to the repackage effort would be redesigned. This includes bracketry, fittings, and perhaps the high pressure manifold.

Potential User Survey

The basic condition requiring the use of oxygen as a metabolic adjunct is known as hypoxia.

The two forms of hypoxia most often requiring supplemental oxygen are ventilatory and circulatory. These are manifested in the diseases described blow. Oxygen therapy is indicated for temporary relief of exacerbated symptoms and as a long term metabolic supplement.

1. Emphysema - A progressive disease of the air ways and alveoli resulting in inadequate gas exchange.
2. Pulmonary Fibrosis - Formation of fibroid tissue in the air ways forming a barrier to efficient gas exchange.
3. Bronchiectasis - Progressive dilation of the air ways, thus decreasing effective ventilation.
4. Chronic Bronchitis - Inflammation of the air ways due to foreign matter or other disease condition resulting in decreased ventilation.
5. Chronic Asthma - Spasm of the air ways with temporary loss of function.
6. Myocardial Disease - Any one of a combination of cardiovascular diseases which results in inadequate oxygenation of the heart muscle.

There are nearly fourteen million people who suffer from some form of diseases one through five and an additional four million who have heart disease of the type to benefit from oxygen therapy.

It should be mentioned that alveolar oxygen concentrations in excess of 40% are not achieveable using only a nasal catheter. Furthermore, long term dry oxygen therapy (in excess of eight hours) will result in necrosis of respiratory system tissue. With these restrictions in mind, what sort of benefits may be attained?

The average work-play activity cycle is about four hours. Furthermore, the oxygen flow required by those who could return to useful activity is one to two liters per minute. Therefore, a typical system would supply a maximum of two liters per minute on a demand basis for up to four hours before requiring recharge.

Such a system is well within the state-of-the-art today and would apparently be of benefit to approximately twenty million people.

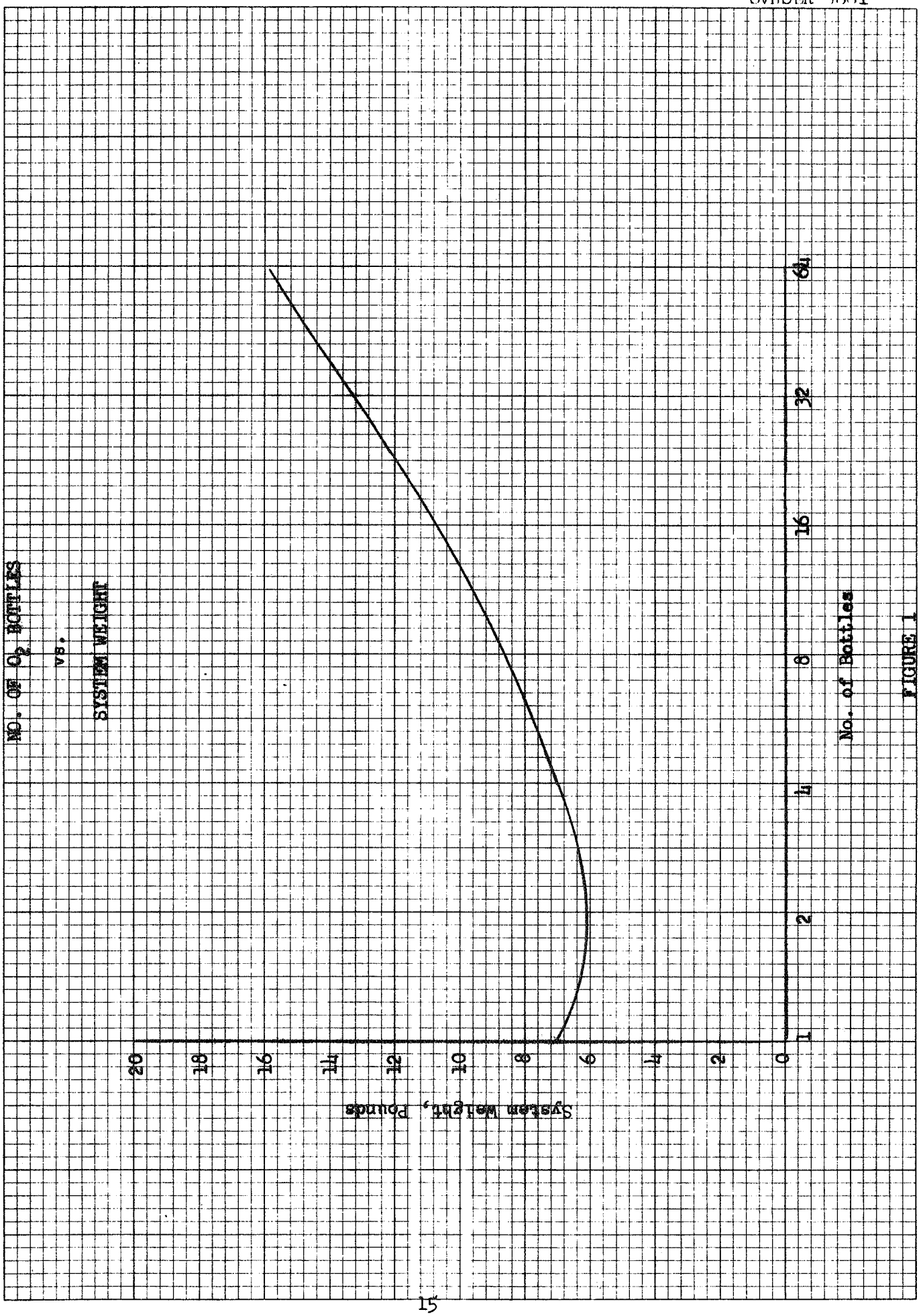


FIGURE 1

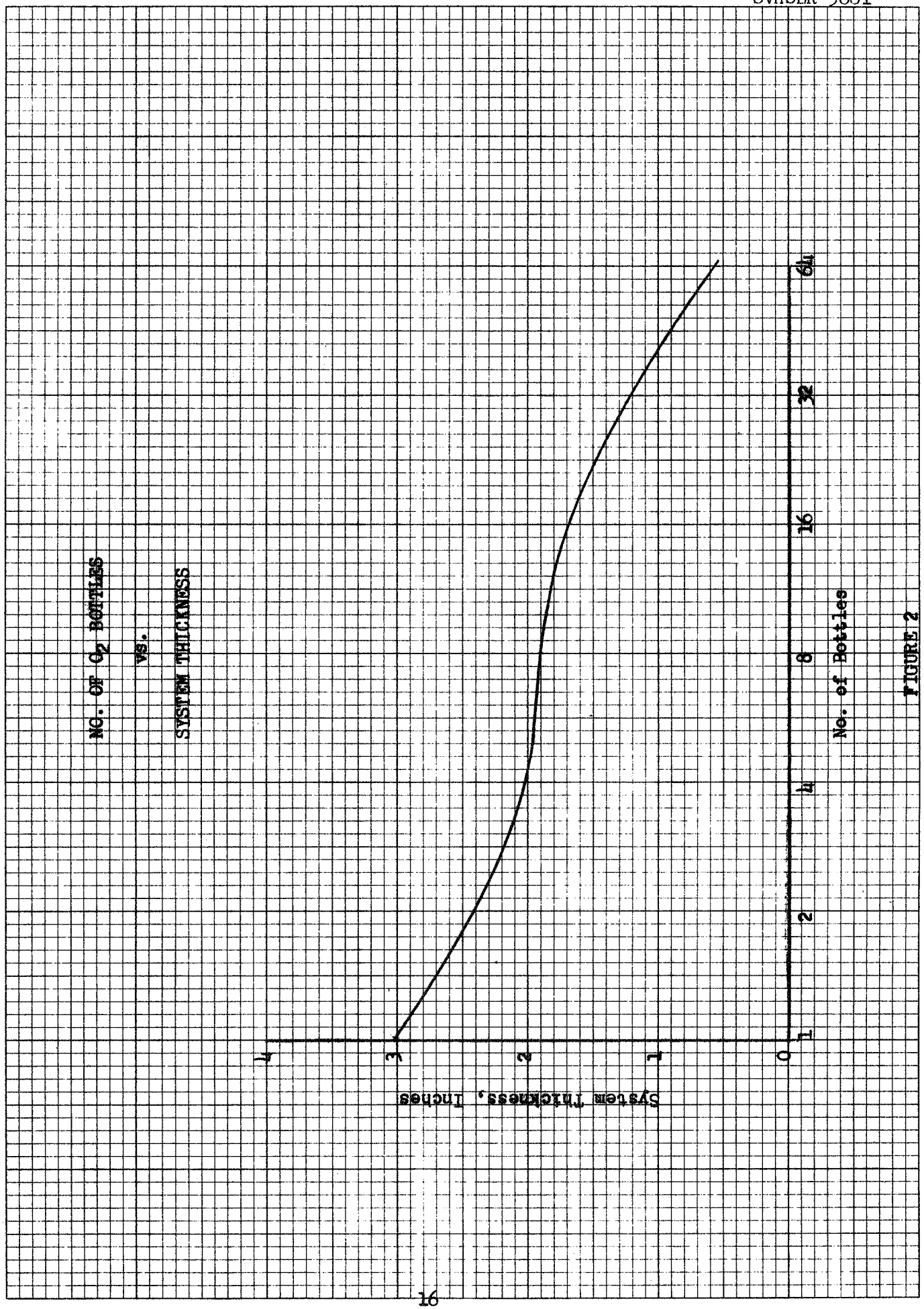


FIGURE 2

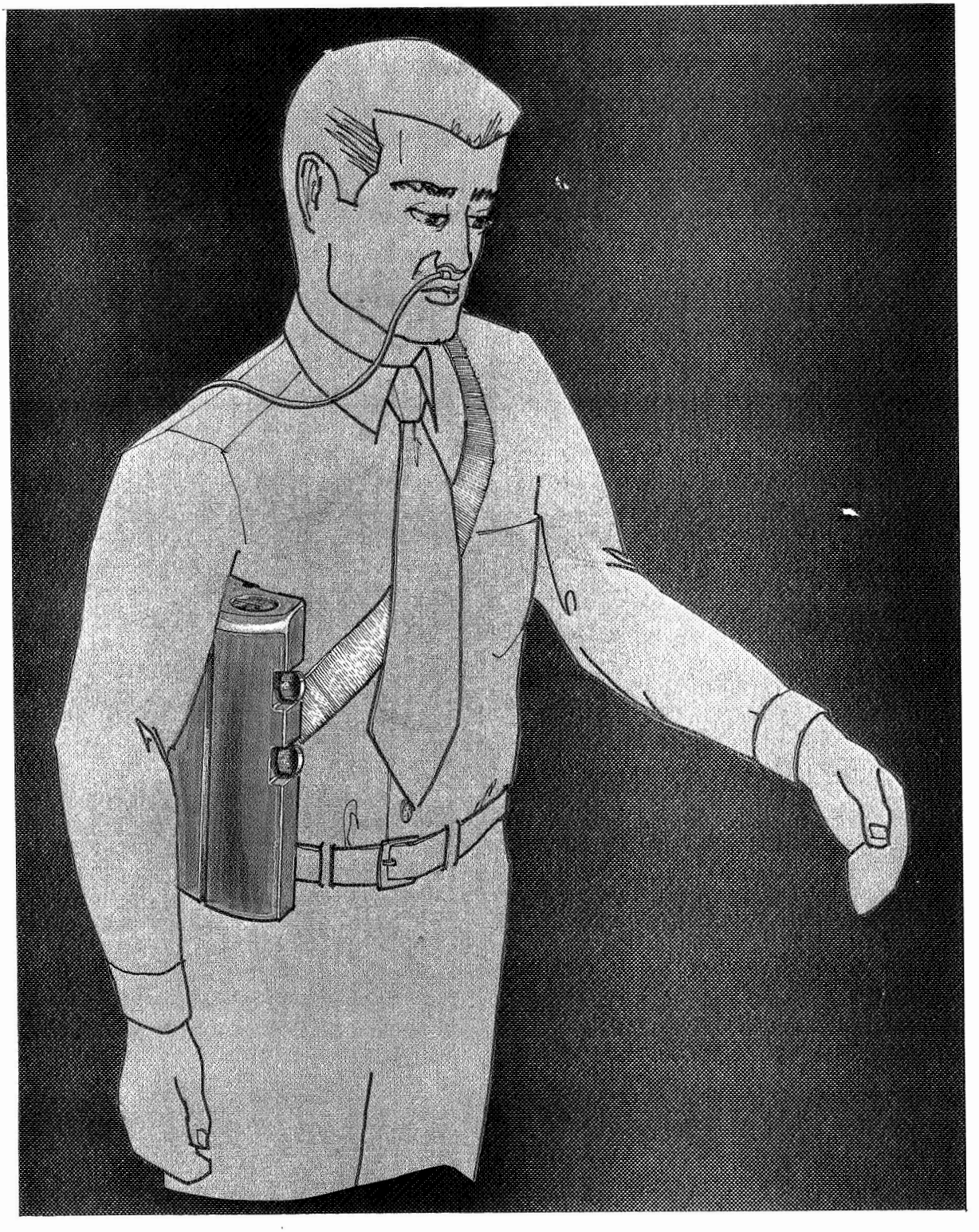


FIGURE 3. SELECTED IRSS FEASIBILITY UNIT CONCEPT

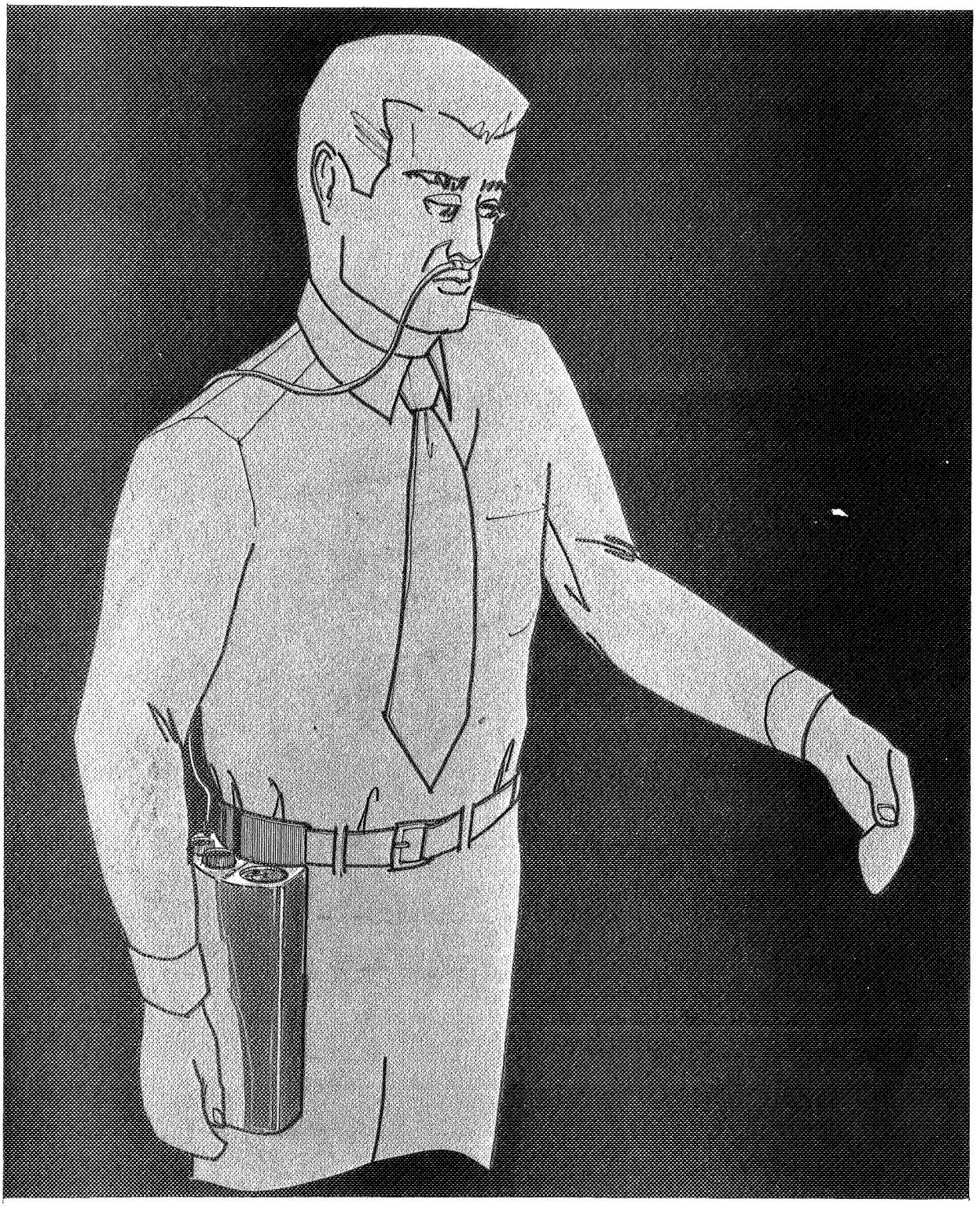


FIGURE 4. CANDIDATE CONCEPT NO. 2—IRRS FEASIBILITY UNIT

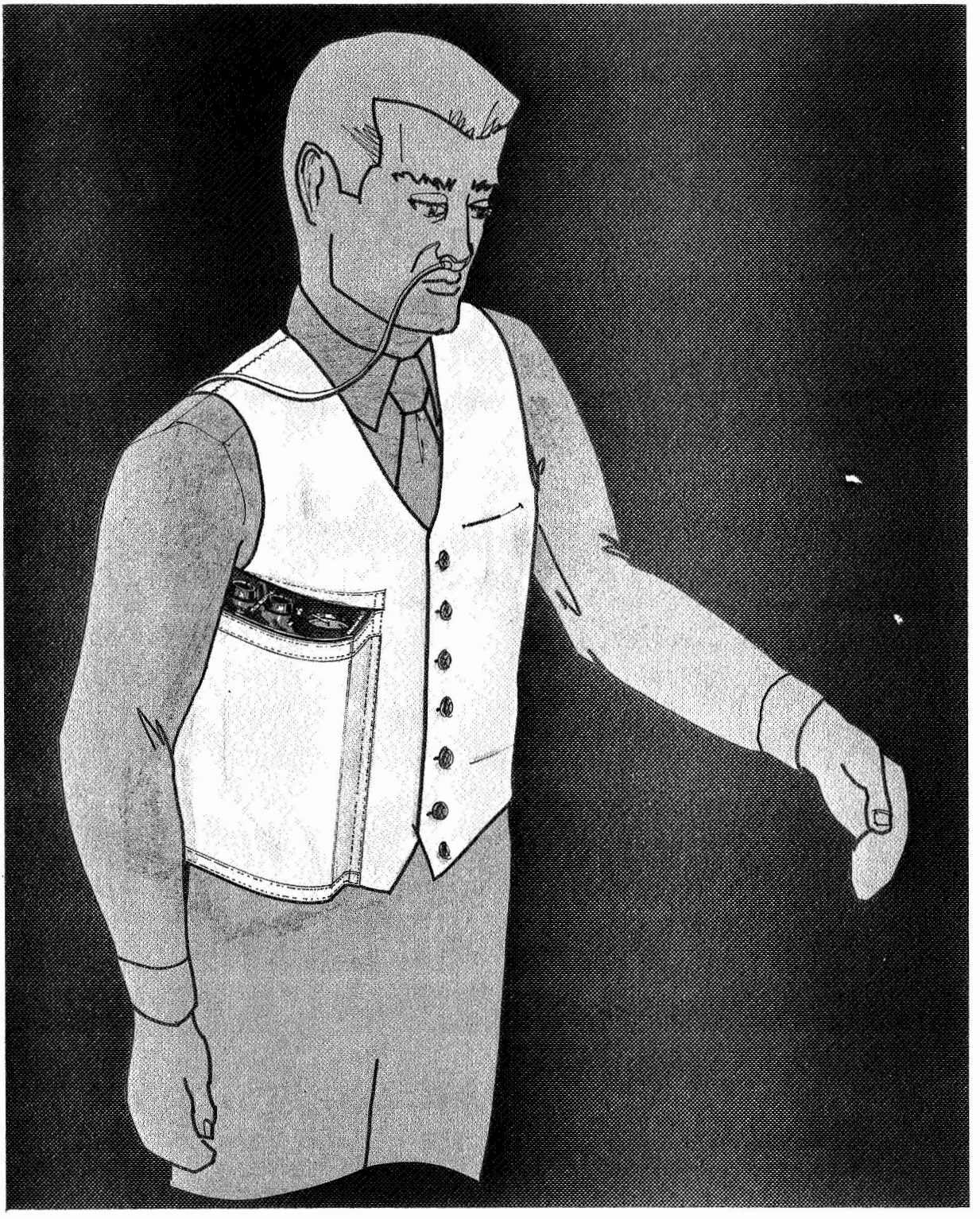


FIGURE 5. CANDIDATE CONCEPT NO. 3—IRSS FEASIBILITY UNIT

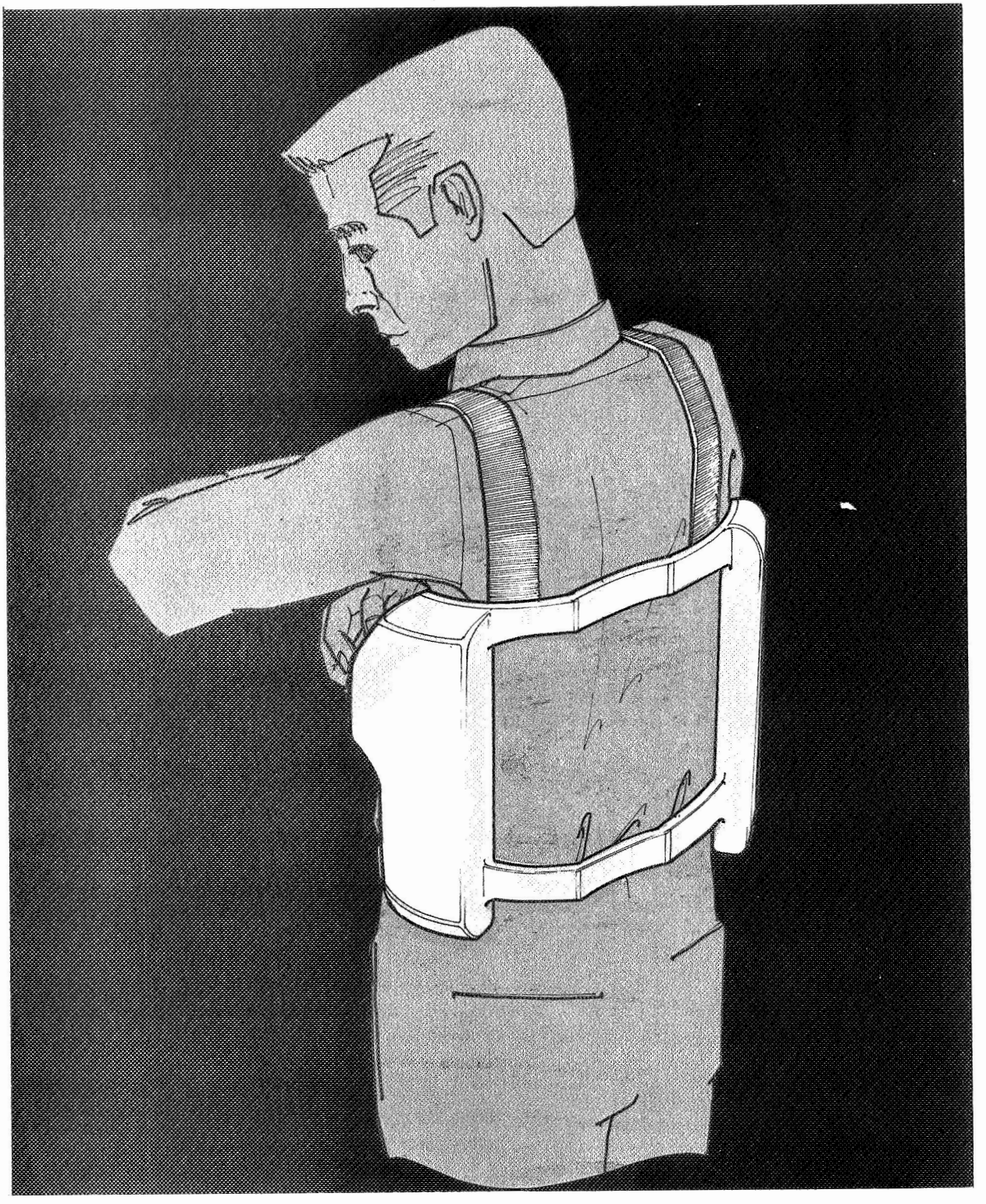


FIGURE 6. KIDNEY TANK CONCEPT

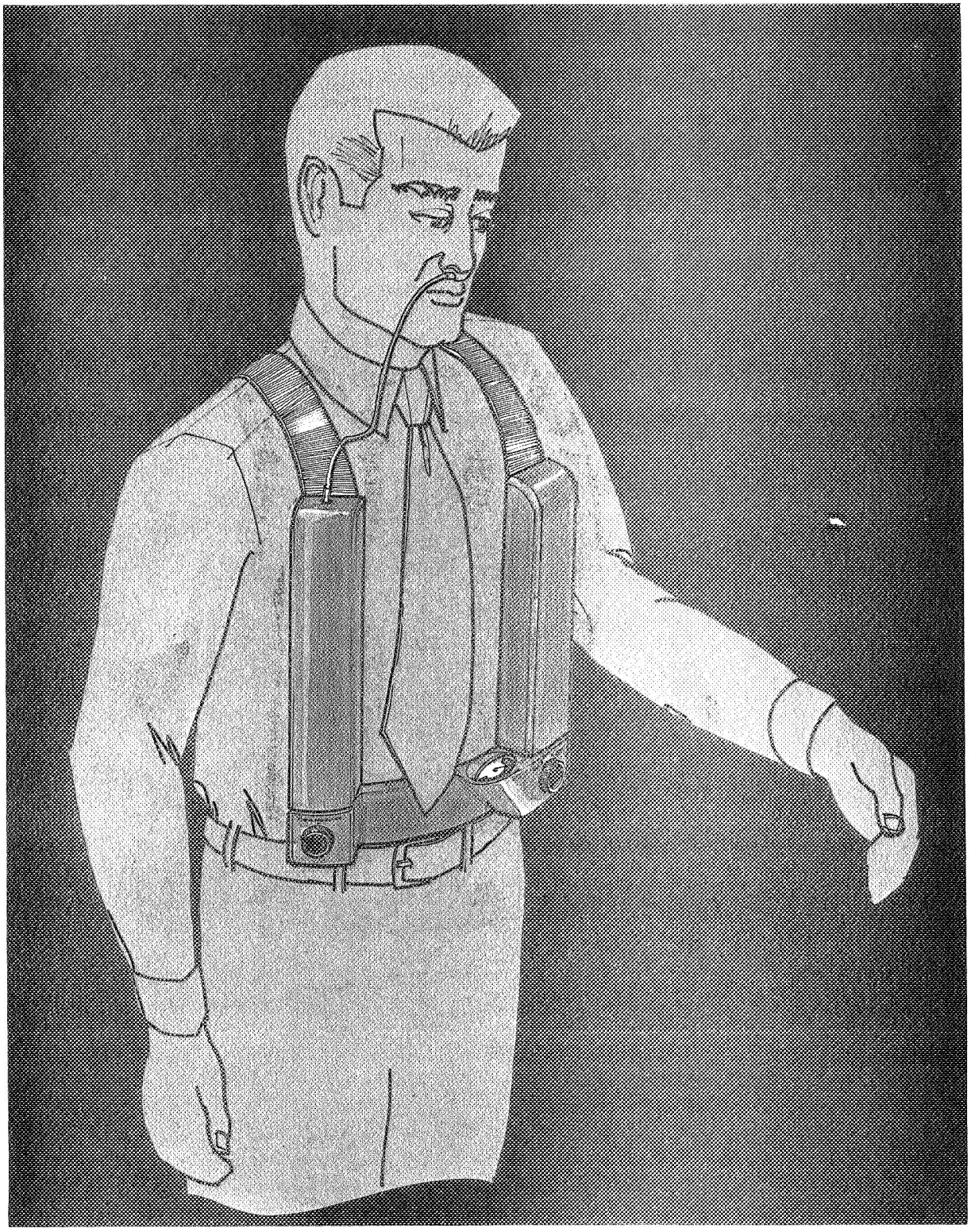


FIGURE 7. FRONT TANK CONCEPT

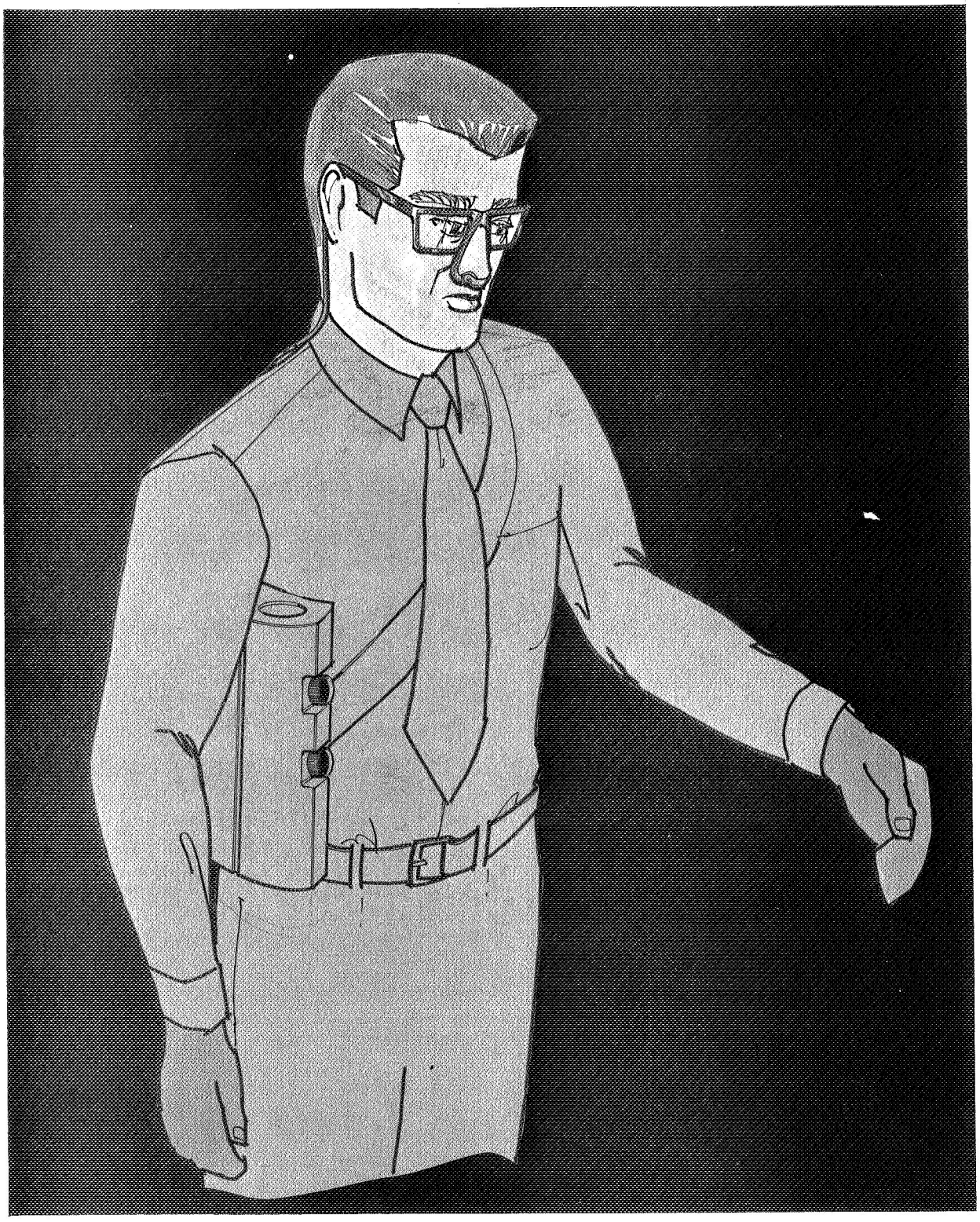


FIGURE 8. EYEGLASS O_2 DELIVERY SYSTEM

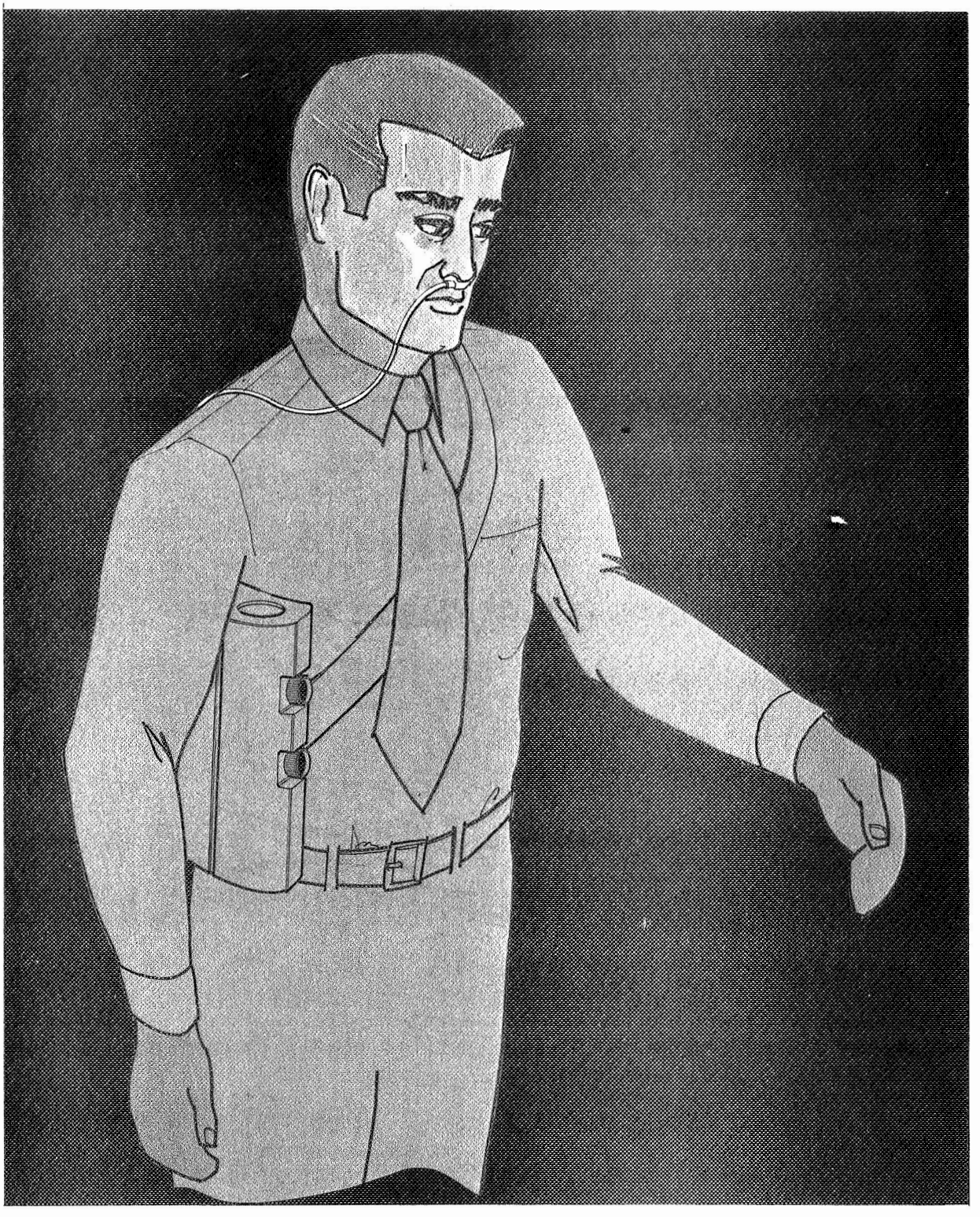


FIGURE 9. NOSE CLIP O_2 DELIVERY SYSTEM

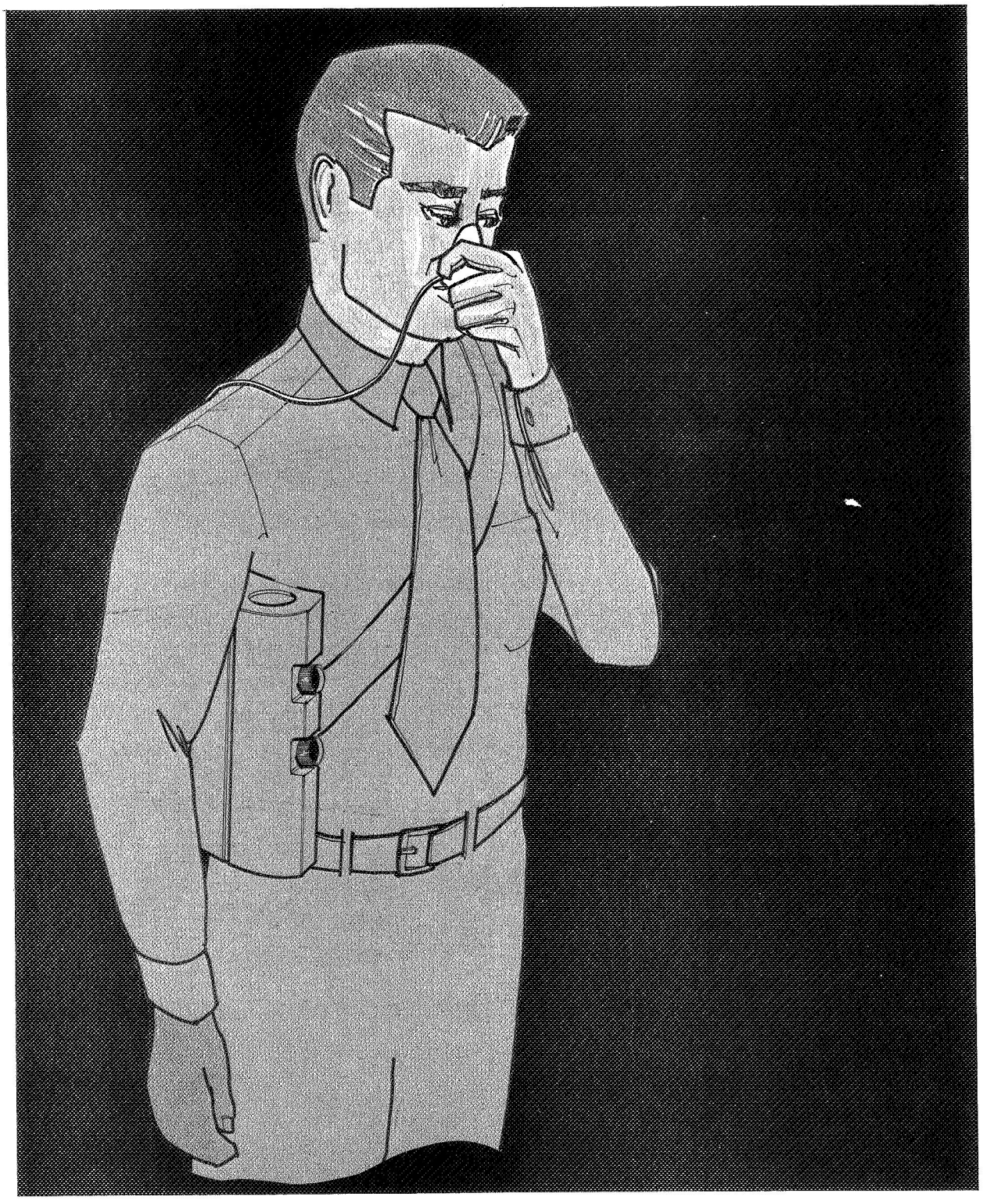
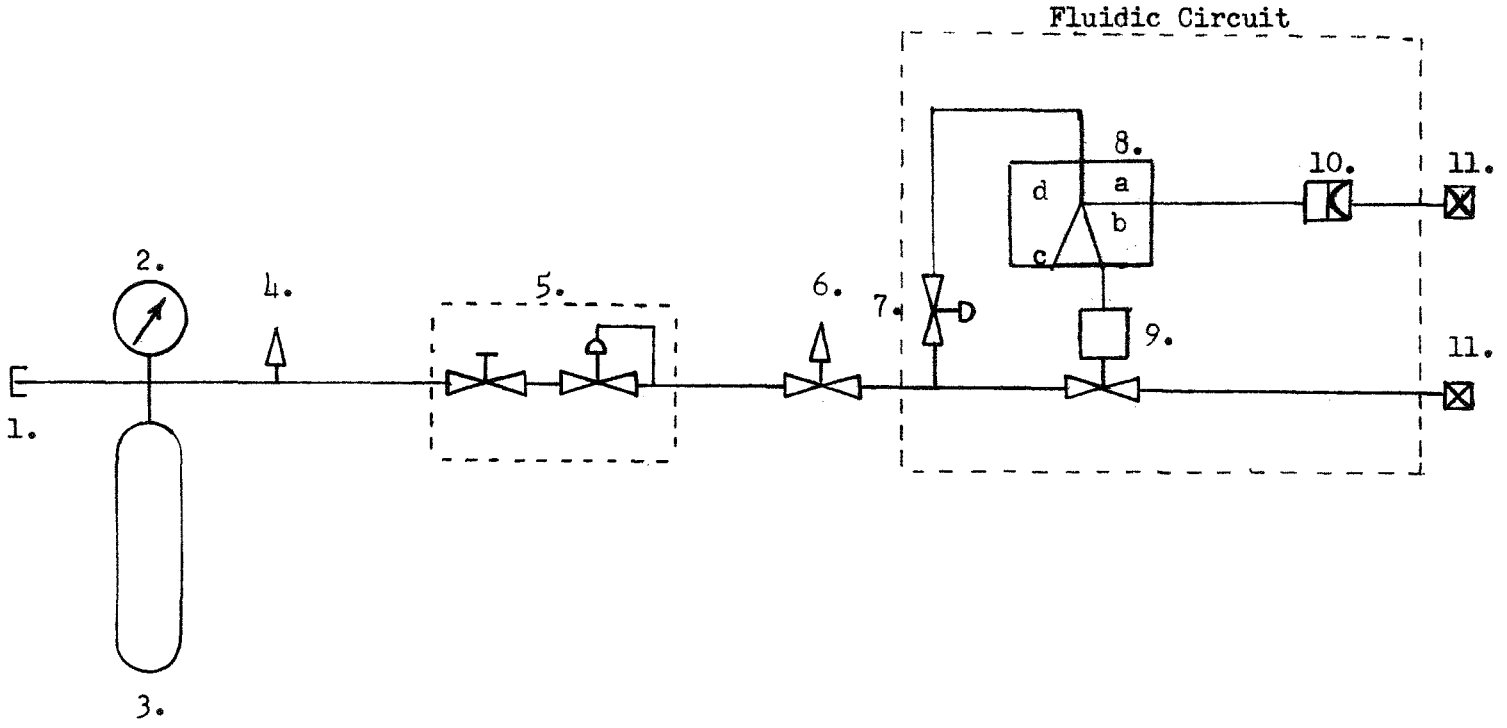


FIGURE 10. NOSE COVER O_2 DELIVERY SYSTEM



1. Fill Fitting
2. Pressure Gage
3. O_2 Storage
4. High Pressure Relief
5. Shut-Off Valve/Regulator
6. Flow Control
7. Fluidic Resistor
8. Fluidic Control Module
9. Fluidic On-Off Valve
10. Sensitivity Control
11. Disconnects

FIGURE 11. IRSS WITH FLUIDIC CIRCUIT