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DAMAGE CONTROL SUIT SYSTEM

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Natick, Massachusetts

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ADDENDA A

1. Page 4. In Table III, Q_D should read Q_T.

2. Page B-2. In the metabolic rate formula, the explanation of Q_S should read: Q_S is positive when body heat storage increases and is negative when body heat storage decreases.

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13. ABSTRACT

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The system was studied to ascertain its effectiveness in providing closed-system life support at various environmental temperatures and activity conditions. It was felt that the DCSS would be an improvement over current protective systems utilized aboard ships where whole body protection is required. It would be used for personnel who must: operate in engine spaces during closed-down conditions (high ambient temperatures and toxic environment); decontaminate spaces subject to mishaps like rocket-fuel spillages; and conduct search and rescue missions into toxic and oxygen-deficient spaces. (U)

Physiological and engineering tests of the system as well as proposed improvements to the current prototype indicate that: (a) the DCSS should provide life support to personnel required to work in hazard areas (duration would depend upon activity and temperature environment--2 hours of light work at 100°F; 1 hour of light work at 140°F--but can be extended by exchange of the expended life-support pack for a replenished one) (b) the profile of the proposed system should permit access to restrictive areas and provide good mobility; and, (c) the components utilized in the life-support pack should not impose any serious logistic burden on ship personnel. (U)

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NAVY CLOTHING AND TEXTILE RESEARCH UNIT
NATICK, MASSACHUSETTS

DAMAGE-CONTROL-SUIT SYSTEM

BY

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ABSTRACT

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DAMAGE-CONTROL-SUIT SYSTEM

INTRODUCTION

The Navy Clothing and Textile Research Unit (NCTRU) has been conducting feasibility and prototype development studies on personnel life-support clothing systems to improve the protection and human comfort presently provided by existing systems worn in corrosive and toxic environments with severe temperature and humidity extremes. NCTRU studied a prototype damage-control-suit system (DCSS) which could supply ship personnel with a closed, life-support system for protection in hazardous environments when performing such duties as: watchstanding in engine spaces during closed-down conditions; decontaminating spaces subject to mishaps like rocket-fuel spillages; and performing search-and-rescue missions into toxic and oxygen-deficient spaces. While conducting these types of missions, personnel can experience temperatures as high as 140°F with high humidity and may require protection against a combination of hazards occurring simultaneously (high concentration of corrosive liquids or vapors with inadequate oxygen supply).

In order for a given protective system to be suitable for shipboard use, it must provide the specific protection required for a suitable period of time, be logistically easy to support, and provide the mobility inherently required for any particular duty mission. In addition to these needs, the system must overcome certain physical restraints on ships, such as the size of hatch openings which must be entered and exited.

With certain modifications the DCSS prototype can meet shipboard protection, logistic, and mobility requirements for applications similar to those mentioned above.

This report describes the DCSS prototype, presents the performance data ascertained in physiological testing of the prototype, and discusses the modifications needed to make the system suitable for shipboard use.

DESCRIPTION OF DCSS

The DCSS is a closed, life-support system consisting of a life-support pack, impermeable suit, and communication headset. Figure 1 depicts schematically these system components. Figures 2, 3, and 4 are views of the pack and its components, the assembled DCSS, and the communication headset.

The life-support pack provides a breathable, conditioned, air supply to the wearer of the suit. The air delivered to the suit fulfills respiratory requirements and extracts and transfers metabolic and ambient heat loads from the suit to the pack. The suit provides total body cover to exclude toxic and corrosive elements and distributes the pack air supply. The headset permits communication between the suit wearer conducting a mission and control personnel.

Life-Support Pack

The pack utilizes wet ice as a refrigerant to dehumidify and cool the return air from the suit. Makeup oxygen and carbon dioxide scrubbing to support respiration is accomplished with a KO_2-LiOH chemical canister. The canister is equipped with a sodium-chlorate candle which serves as an emergency O_2 supply. A DC-motor, centrifugal blower unit circulates the air. A 12V, silver-zinc, battery pack provides electrical power for the DC-motor. For safety purposes, an O_2 sensing warning device is incorporated in the pack which provides a visual warning if O_2 concentration is low or high. If a low O_2 signal is observed, the emergency, sodium-chlorate candle can be fired which would provide 10 liters of O_2 to permit escape from the hazard location. The wet ice and the LiOH-KO_2 chemical elements were selected over the other means of life support to minimize the logistic and backup equipment problems encountered in maintaining the system. Table I gives a weight and size breakdown of the prototype pack and its components.

Table I - Weights and Dimensions of Prototype Pack and Components

Component	Weight (lbs)	Dimensions (in)
Silver-Zinc Battery Pack	4.95	12 x 10 1/8 x 1
Empty Refrigerant Containers	4.50	11 x 5 3/4 x 5
Refrigerant	12.00	-- -- -- --
O_2 Sensing Warning Device	1.00	5 1/8 x 5 x 1 1/4
Chemical Canister	4.75	3 5/8 x 10 x 5 3/4
Centrifugal Fan & Motor	1.00	3 7/8 X 5 3/4 x 6 1/4
Pack Shell and Hardware	11.00	28 1/4 x 14 1/8 x 7 1/2
TOTAL	39.20	

A more detailed description of the pack and its components and other engineering performance information can be found in references 1, 2, 3, and 4.

Damage-Control Suit

The impermeable suit consists of an outer shell, insulative liner, ventilation garment, and detachable dome-type helmet, boots, and gloves. The suit is also equipped with a backpack support frame and insulated pouch for mounting and protecting the pack from the external environment. Details of these components can be found in reference 1. The suit, besides isolating the wearer from a hazardous environment, distributes the pack air by way of a duct in the (dome) helmet and by means of a ventilation garment. Suit entry is through a pressure-sealing zipper. Table II lists the weights and materials selected for the suit components.

Table II - Weight and Materials Selected for Prototype Suit

Component	Weight (lbs)	Material
Helmet	3.75	Polycarbonate
Ventilation Garment	7.25	Composite *
Insulative Layer	4.00	Polyurethane Foam
Outer Shell	12.00	Butyl **
Gloves	1.00	Butyl **
Boots	3.00	Butyl **
Backpack Support	3.25	Aluminum Frame with Nylon Webbing Harness
TOTAL	34.25	

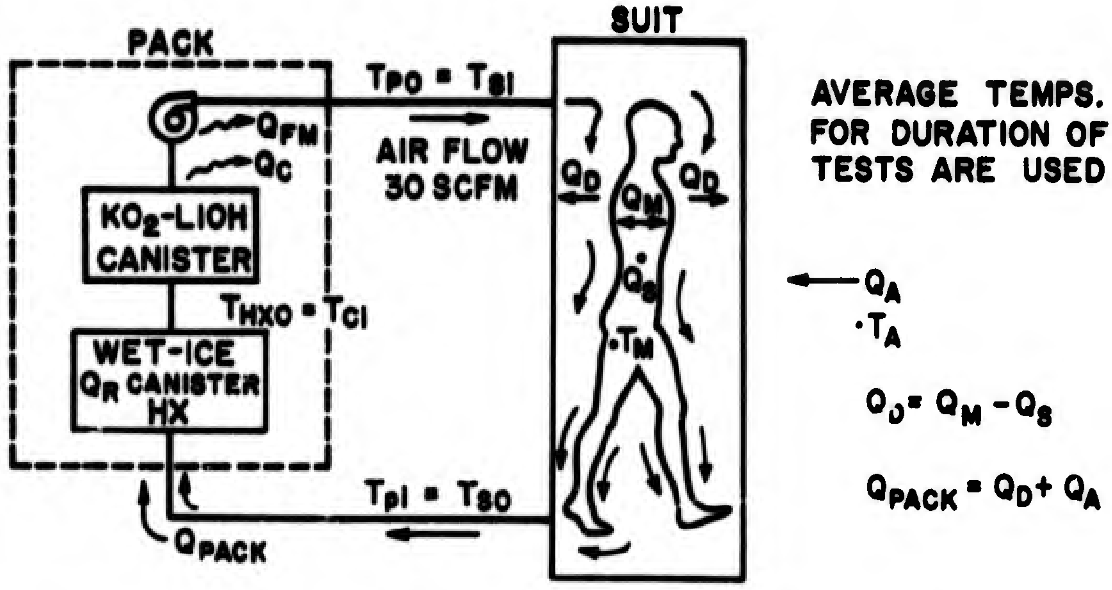
* Composite - Nomex, Trilok, Polyurethane, and Spandex.
** Outer material selection based upon specific hazard protection required.

Communication Headset

The headset was developed to be compatible with existing sound-powered communications gear aboard Navy ships. An inertial microphone mounted on the rear of the head for speech transmission precludes visual encumbrance in front of the face. Low-profile muffs are provided to attenuate background noise. Amplifiers are mounted in the headset to provide power sufficient to drive and to receive signals from sound-powered equipment. Complete details on the development and evaluation of the headset are given in reference 3.

PHYSIOLOGICAL EVALUATION

The DCSS prototype was evaluated to determine the amount of stress upon personnel wearing the suit system in temperatures of 70, 100, and 140°F and its effectiveness in supplying a viable environment to the wearer. Besides the measurement of physiological parameters, data were also collected to determine pack performance during man tests. In particular, the performance of the chemical canister in providing makeup O_2 and scrubbing CO_2 was of prime importance. Thirty-eight tests of the prototype were performed. Selected activities for tests were equal to watchstanding and light work levels (Standing and standing and walking at 1 1/2 MPH). Results from these tests indicated that the life-support system can adequately sustain a person doing light work for 2 hours at 70° and 100°F and for 1 hour at 140°F. Extrapolations of physiological test results and engineering data reported in references 1 and 4 indicate that the system should support moderate to heavy work for 1 hour at temperatures up to 100°F. Heavy work at 140°F would be possible for 30 to 40 minutes.



T_A (°F)	70		100		140	
ACTIVITY	STANDING	WALKING	STANDING	WALKING	STANDING	WALKING
DURATION (MIN)	120	120	120	103	60	60
T_M (°C)	37.3	37.3	38.0	37.9	37.7	38.0
T_{SID} (°F)	74	73	88	89	98	98
T_{SOD} (°F)	78	80	92	94	104	103
T_{HXOD} (°F)	52	50	61	62	67	68
Q_S (BTU)	-252	37	175	292	80	325
Q_T (BTU)	1179	1386	942	1330	421	754
Q_M (BTU)	927	1423	1117	1622	501	1079
Q_A (BTU)	−118	−137	208	143	488	488
Q_{PACK} (BTU)	1061	1249	1150	1473	909	1242
Q_{FM} (BTU)	220	220	220	189	110	110
Q_M (BTU/M)	463	712	559	945	501	1079
$Q_{R\,AVAIL}$ (BTU)	2360	2360	2360	2360	2360	2360
$Q_{C\,AVAIL}$ (BTU)	1079	891	990	680	1341	1008

TABLE III AVERAGE SYSTEM TEMPERATURES AND HEAT-LOAD-BALANCE DATA FOR ALL AMBIENT TEMPERATURES AND ACTIVITY CONDITIONS.

For these tests, projected tolerance times were not calculated because the amount of time personnel could remain in the suit is limited by the amount of cooling available from the ice containers and the O_2 producing and CO_2 scrubbing capacity of the chemical canister in the backpack.

Appendix A details the physiological test methods; Appendix B presents several formulas used to compute various parameters listed in Appendix A.

Results

<u>Ambient Heat Effects</u>. The influence of ambient heat loads on system performance can be seen in Table III and Figure 5. The ambient heat loads (Q_A) went from -118 BTU for the 70°F standing condition to 488 BTU for the 140°F standing and walking activities. This increase in system heat load with higher ambient temperature created a progressive increase in the average internal-suit temperature. For the 70°F test conditions the maximum internal-suit temperature was 80°F but reached 111°F at the end of the 140°F walking condition. The ambient heat load at 140°F accounted for 20% of the available system-cooling capacity. The ambient heat load levels were computed from suit overall thermal conductance values determined from reference 4 data and given in Table IV.

Table IV. Suit Overall Thermal Conductance Value

Ambient Temp. (°F)	AVG Suit Internal Temp (°F)	Suit Overall Thermal Conductance BTU/HR/°F*
72	60	9.8
120	78	10.4
139	84	12.5

* Includes conductive, convective, radiation and suit heat storage effects. The airflow external to the suit was 120 ft/min.

<u>Metabolic Load Levels</u>. The computed metabolic load levels (Q_M) are given in Table III. These levels ranged from essentially a basal condition for the 70°F standing tests, light activity at the 100 and 140°F standing condition, and light work for the walking regimens at 70, 100 and 140°F. Metabolic energy expenditure for the walking activities was approximately 50, 70, and 100% greater than the standing levels for the 70, 100 and 140°F test temperatures, respectively. For an individual with normal clothing, a 50% increase in metabolic rate would be expected between activities of standing and walking at 1 1/2 MPH in a cool, dry, ambient temperature (5 and 6). Since the walking rate occurred for only one half the period of the motion activity, a 25% increase in metabolic activity over the just standing condition could be estimated. Comparing this to the metabolic increase observed at 70°F of 50%, it would indicate that, for this type of motion, the suit imposes an additional 25% increase in energy expenditures. The greater increases in metabolic expenditures observed for the 100 and 140°F tests for and between the two activities can be attributed to the higher temperature environment within the suit (Figure 5).

Table V. Summary of Physiological Data

Amb Temp (^{o}F)	70		100		140	
Activity	Standing	Walking	Standing	Walking	Standing	Walking
Avg Test Duration (min)	120	120	120	103*	60	60
Mean Body Temp (^{o}C)						
Initial	37.8 ± .69	37.24 ± .38	37.7 ± .3	37.4 ± .17	37.58 ± .2	37.48 ± .31
Final	36.8 ± .62	37.39 ± .33	38.38 ± .3	38.5 ± .17	37.89 ± .6	38.72 ± .27
Diff	-1.0	+.15	+.68	+1.1	+.31	+1.24
Mean Rectal Temp (^{o}C)						
Initial	38.9 ± .9	38.02 ± .33	38.3 ± .32	38.34 ± .36	38.32 ± .2	38.12 ± .37
Final	37.76 ± .7	38.36 ± .26	39.05 ± .04	39.23 ± .18	38.08 ± .7	38.98 ± .33
Diff	-1.14	+.34	+.75	+.89	-.24	+.86
Mean Heat Storage						
k cal	-63.5	9.3	44	73.5	20.2	81.7
BTU	-252	37	175	292	80	325
Mean Respiration (Breaths/min)						
Initial	17 ± 1.1	17.5 ± 1.3	20.25 ± 1.4	18 ± .6	17.8 ± 1.6	16.8 ± .8
Final	16 ± .7	21 ± .8	16.75 ± .63	21 ± .3	17.4 ± .7	21 ± 2
Mean Heart Rate Beats/min						
Initial	94 ± 2.5	91.5 ± 2.9	98 ± 2	97.5 ± 5	91 ± 5	94 ± 4
Final	79 ± 4.8	112.8 ± 5.8	102.5 ± 4	147 ± 5	127 ± 4	151 ± 3
Mean Subject Wt (kg)	76.5	75	78	80	78.5	79.5
Mean Total Wt Loss (g)	310 (4) **	535 (4)	513 (3)	1060 (6)	787 (3)	1148 (3)
Mean Body Wt Deficit (%)	.405	.713	.66	1.33	1.00	1.44
Mean Evap Wt Loss (g)	240 (1)	348 (3)	390 (3)	521 (6)	314 (2)	470 (3)
Mean Evap Ratio (%)	82.5 (1)	65.7 (3)	76 (3)	49.2 (6)	41 (2)	41 (3)
Q_{MR} (BTU/hr) ***	463	712	559	945	501	1079

* Mean length of time before tests were halted; rectal temperatures had reached predetermined cutoff values.

** Numbers in ( ) represent number of observations from which means for the parameter were computed.

*** Q_{MR} = Metabolic Rate (see formula in Appendix B).

Body Temperatures. Mean body temperatures of the test subjects decreased in the 70°F tests during the standing activity and showed a slight increase (.15°C) while the subjects were walking. For the walking activity mean-body-temperature increases of 1.1 and 1.24°C were measured for the 100 and 140°F ambient conditions, respectively. Rectal temperatures showed the same general trend as body temperatures with no statistically significant difference between the 100 and 140°F tests. For the 70°F tests standing the temperature drop of 1.14°C was significant (Table IV).

Internal Pack Loads. The maximum refrigeration capacity of the pack (2360 BTU) is not totally available for dissipating man- and ambient-heat loads, because the circulating fan motor and chemical canister are heat-producing elements. Table III indicates the motor heat load (Q_{FM}) and the available cooling capacity for dissipating the chemical-canister heat loads (Q_{CAVAIL}). There appears to be sufficient system capacity to overcome these internal loads for the temperature-activity-duration conditions shown. For the 100°F walking condition, where the least amount of available cooling capacity exists for the dissipation of chemical canister heat, it is still sufficient. A simulator test of the final chemical canister (7) shows that only 300 BTU/hr of heat energy is produced by the canister when supporting a 1000 BTU/hr metabolic activity. Thus, for the 103-minute walking activity at 100°F, a Q_{CAVAIL} of 515 BTU would be required to overcome the chemical canister heat load. Table III indicates that Q_{CAVAIL} for this activity is 689 BTU.

Heart Rate. In these tests heart rate seemed a more sensitive indicator of stress than rectal or mean body temperature and the heart-rate responses were very consistent with a maximum standard error of 6 beats/min (Table V). Heart rates during the final few minutes of the 140°F walking condition were high enough to produce the 151 ± 3 mean beats/min seen in Table V, but the 150 beats/min point was never reached early enough in these tests to warrant stopping them on this account.

Respiration. Respiration rate changes were nearly constant for all three tests (Table V). Maximum changes in these parameters occurred during periods of exercise and tended toward normal during periods of rest.

Figures 6, 7 and 8 show the O_2 and CO_2 concentration patterns for the six test conditions studied. The production of O_2 by the chemical canister increased with ambient temperature and metabolic requirement but was still controlled within rather narrow limits. The lowest O_2 concentration measured was 16% which occurred after 100 minutes of the 70°F walking condition. For the other tests the O_2 concentration was never below 20%. The maximum measured O_2 concentration was less than 25% and occurred during the 140°F standing condition. CO_2 concentrations were never more than 1.5% for any test condition.

System Airflow and Pressure Drops. Figure 9 shows the system-airflow and pressure-drop characteristics for 2 hours of system operation (standing and walking). The maximum system pressure drop was 2.4 in H_2O with most of the loss occurring within the suit (1.8 in H_2O). The pack pressure drop was only 0.6 in H_2O. The resultant airflow was 30 scfm.

Remarks

The data indicate that this system with its current capacity can adequately support personnel performing light work for up to 2 hours at 100°F and for 1 hour at 140°F. Only at the 140°F walking condition was the subject undergoing any appreciable stress. In all other cases, heat storage, body temperatures, and respiration and heart rates stayed within acceptable limits.

The chemical canister had sufficient sensitivity to respond to metabolic rates from near basal levels to the upper limit of what is considered light work and the canister tended to show more response as temperature and metabolic activity increased. Thus, good response to even greater activity would also be expected. The relatively low range of excursions in O_2 concentrations from normal levels over the range of metabolic levels indicated some demand-type reaction to metabolic requirements (Figure 6, 7 and 8 and Table III).

Metabolic activity data show that the suit permits 25% less mobility than normal clothing while walking at 1 1/2 MPH. Consequently, some reduction in energy expenditure can be obtained with a better fitting suit.

To significantly improve mission time for any of the test conditions would require additional cooling and chemical capacity. The current pack weight and size is such that any further increase of refrigerant and chemical to extend duration would make the DCSS too cumbersome. If mission time were sacrificed, the system should be able to support higher work levels than those tested. For instance, it is estimated that the current system could support moderate to heavy work activities for 1 hour at ambient temperatures of 100°F and between 30 and 40 minutes at a 140°F ambient.

NECESSARY SYSTEM MODIFICATIONS

User requirements and test data demonstrate that the DCSS must be changed to improve mobility and reduce bulk. These changes will not appreciably increase the mission times. As was stated in reference 1, to improve mobility and reduce bulk, the pack would be mounted outside of the suit and would interface to the suit with special connectors, thus simplifying the suit construction and reducing the volume occupied by the pack and the pouch. This would also allow the pack to be: (a) exchanged in a hazard environment to extend mission time; or, (b) discarded when quick escape is desired. A short-duration, back-up respirator would be used to supply makeup O_2 and CO_2 removal during this escape. The shape of the pack would also be changed from that of a rectangular box to that of a torso configuration as shown in Figure 10. This shape should permit personnel to enter and exit hatch openings more easily and would also locate the pack CG closer to the man, thus permitting better mobility. The better weight and bulk distribution provided by this pack design would especially improve the wearer's ability to climb ladders and stairways.

The suit, being independent of the pack, can be designed for better fit and to reduce somewhat the additional 25% energy expenditure that occurred during the walking phase with the prototype. For better performance at all ambient conditions, the amount of insulation could be varied. For instance, the inflation of impermeable membranes with low-thermal-conductivity CO_2 or Freon gas charges could increase insulation as required rather than building in a fixed quantity of bulk insulation. For those situations in which ambient temperatures are normal and insulation is not required, the suit could remain deflated. To provide universal protection against all hazards, the suit would have to be supplied with several overgarments for protection against any specific hazard. The basic garment shell would be made of a material which provides the best overall protection of those currently available.

If the current system were repackaged with a torso-shape pack which interfaces with the suit by special connectors and if insulation selection were provided, a system could be achieved which has better mobility and less bulk than the prototype discussed in the report. The ability to exchange packs by using this type of system configuration could extend mission times far beyond those shown during physiological testing. The continued use of such life-support elements as wet ice, KO_2-LiOH, sodium-chlorate candles, and battery-operated air circulators should not impose any severe logistic burdens on shipboard personnel. Existing food refrigerators, small freezers at damage-control stations, or both could be used to maintain the wet ice in a frozen state. Since current chemical OBA's utilize KO_2 canisters with sodium-chlorate candles, the ability to maintain, use, and dispose of these types of products or similar ones is already available. The equipment required for recharging the batteries in the life-support pack is small, inexpensive and readily available.

CONCLUSIONS

It is thus concluded that: (a) the modified DCSS as proposed should provide life support to personnel required to work in high-hazard areas (duration would depend upon activity and temperature environment--2 hours of light work at 100°F; 1 hour of light work at 140°F--but can be extended by exchange of the expended life-support pack for a replenished one); (b) the profile of the proposed system should permit access to restrictive areas and provide good mobility; and, (c) the components utilized in the life-support pack should not impose any serious logistic burden on ship personnel.

APPENDIX A. PHYSIOLOGICAL TEST METHODS

The DCSS was worn at 70, 100, and 140°F under each of the following conditions:

a. Standing but moving occasionally to simulate watchstanding conditions.

b. Walking 10 of every 20 minutes at a rate of 1-1/2 mph to simulate the amount of energy expended for light work.

Each of the above levels of activity was conducted at least five times at 70° and 140°F but only four tests were conducted at 100°F at each level because of the shortage of chemical canisters. For all of these tests the pack was instrumented with copper-constantan thermocouples to monitor the air temperatures at the pack inlet, and refrigerant canister, chemical canister, and pack outlets. Attempts to measure relative humidity at pack inlet and outlet proved inaccurate and data were discarded. Pack pressure drop and flow rate were also monitored.

Prior to the test, the following procedures were carried out:

a. Test subjects reported to the NCTRU physiology laboratory and rested at least 15 minutes before the basal metabolic rate (BMR) was determined.

b. A urine sample was taken for determination of specific gravity and protein content.

c. Test subjects stripped and were weighed on a Toledo scale accurate to ± 10 gms.

d. Rectal temperature was measured with a clinical thermometer.

e. Copper-constantan thermocouples were applied to the skin at the following ten locations:

1. instep
2. calf
3. lateral thigh
4. medial thigh
5. back
6. chest
7. upper arm
8. lower arm
9. middle fingertip
10. cheek

f. A copper-constantan thermocouple covered with a No. 16 French rubber catheter was inserted approximately 15 cm into the rectum.

g. Two Telectrode, disposable, band-aid-type electrodes were attached to the side of the test subject to record respiration rate.

h. Three, Telectrode, disposable, band-aid-type electrodes were attached over the sternum in a vertical line between the fourth and sixth ribs. The area of electrode placement was washed with a 70-percent alcohol solution and the epidermis scratched lightly (without drawing blood or producing an erythema) to reduce skin resistance (8).

i. Cotton boxer shorts, cotton T-shirt, and cushion-soled socks were donned under the experimental suit.

j. Weight of the fully clothed test subject without pack and helmet was obtained on a Toledo scale accurate to ± 10 gms.

Upon completion of the above procedures, the pack was donned, and subjects entered the ante-chamber and attached physiological and pack harness leads to extensions which led to recorders. Harness leads and gas sampler and pressure tubes exited the suit through a special fitting with rubber stoppers at the left-hand side of the waist. After the connections and the system were checked, the helmet was sealed into place and the beginning parameter recorded.

Heart and respiration rates, EKG, and skin, rectal, and pack temperatures were monitored continuously. The physiological data were displayed on an expanded scale each 10 minutes on a Beckman, Type-R, rectilinear, oscillographic recorder, as necessary, to insure continuous monitoring of test subject. Subject temperatures were recorded each 30 seconds on an Esterline Angus, 48-point, programable recorder. Pack temperature data were recorded on a Honeywell, 24-point, temperature recorder. Ten-minute intervals were marked on each recorder to coincide with the expanded-scale recordings of the Beckman Dynograph Recorder.

In addition to the parameters described, CO_2 and O_2 suit concentrations were measured. A gas sample was drawn from the helmet of the suit with a Beckman Micro Catheter Sampling Pump and directed to a Beckman LB1 infrared analyzer and a Beckman polarographic oxygen probe and returned to the suit. The output of the infrared analyzer was fed to a Beckman CO_2 coupler and read on the Dynograph recorder. The recorder output was calibrated so that 4 percent CO_2 from a certified standard gas source caused a 4 cm deflection of the oscillograph pen. The output of the polarographic output sensor was conditioned to a Beckman Field Lab O_2 meter, standardized with room air to show 0 percent deviation, calibrated with a certified gas sample so that the pen deflection of the Beckman recorder was 1 cm for each percent of O_2 deviation from normal room air concentration, and coupled to the recorder through a Beckman DC coupler. Both O_2 and CO_2 sensors were linear over the range used and standardization was checked each 10 minutes while tests were in progress.

After the test was completed:

a. The helmet and pack were removed from the ensemble and clothed weight was obtained.
b. Pack shell weight and refrigerant and chemical canister weight were also obtained.
c. A final nude weight was obtained.
d. BMR, heart rate, and blood pressure were taken.
e. The test subject was allowed to shower, dress, and rest for 30 minutes before being dismissed.

Besides the above parameters, the following information was calculated.*

a. Mean skin temperature
b. Mean body temperature
c. Total weight loss
d. Evaporative weight loss
e. Evaporative ratio
f. Body weight deficit
g. Body heat storage (Q_S)
h. Ambient heat load (Q_A)
i. Heat transferred to suit from man (Q_T)
j. Metabolic rate (Q_M)
k. External heat loads dissipated by pack (Q_{PACK})
l. Internal pack heat load from fan motor (Q_{FM})
m. Heat-load-dissipation capacity available for chemical canisters (Q_{CAVAIL})

* Formulas used to compute these items are given in Appendix B.

APPENDIX B. PHYSIOLOGICAL FORMULAS

This appendix contains formulas used to compute physiological test parameters.

MEAN SKIN TEMPERATURE (T_S)

Computed each 10 minutes as the weighed mean of the outputs from the 10 skin thermocouples according to the formula described by Hardy & Dubois (9).

MEAN BODY TEMPERATURE (T_B)

Computed each 10 minutes as

$T_B = 0.8\ T_R + 0.2\ T_S$

T_R = Rectal temperature

TOTAL WEIGHT LOSS

Difference between initial and final nude weights expressed in grams.

EVAPORATIVE WEIGHT LOSS

Difference between initial and final clothed weights expressed in grams.

EVAPORATIVE RATIO

Evaporative weight loss divided by the total weight loss expressed as a percentage.

BODY WEIGHT DEFICIT

Body nude weights before and after tests.

BODY HEAT STORAGE (Q_S)

$Q_S = W(0.83)\ \Delta T_B$

Q_S = Body Heat Storage (kg Cal)

W = Weight of test subject (kg)

0.83 = Specific heat of body (kg Cal/kg ^oC)

ΔT_B = Change in mean body temperature (^oC)

AMBIENT HEAT LOAD (Q_A)

$Q_A = K\Delta T_{AMB}\ \theta$

Q_A = Ambient heat load (BTU)

k = suit overall thermal conductivity (BTU/hr ^oF)

$\Delta T_{AMB} = T_{AMB} - T_{AVGSi}$

ΔT_{AMB} = differance in temperature between ambient and average suit internal temperature (^oF)

T_{AMB} = ambient temperature (^oF)

T_{AVGSi} = average suit internal temperature (^oF)

θ = test time (hr)

HEAT TRANSFERRED TO SUIT FROM MAN (Q_T)

$Q_T = h_L W_E + MC\Delta T_A \quad \theta + Q_A + Q_S$
Q_T = heat transferred to suit from man (BTU)
h_L = latent heat of evaporation for water (BTU/lb)
W_E = weight of water evaporated (lbs)
M = mass of air circulating in suit (lbs/hr)
C = specific heat of air (BTU/lb°F)
$\Delta T_A = T_{SO} - T_{Si}$
ΔT_A = differance in suit air temperature from inlet to outlet
T_{SO} = suit outlet temperature (°F)
T_{Si} = suit inlet temperature (°F)
Q_A is positive when heat is transferred to the environment and negative when heat is added from the environment.
Q_S is positive when there is a loss in body heat storage and zero when there is an increase in body heat storage.

METABOLIC RATE (Q_M)

$$Q_M = \frac{Q_T + Q_S}{\theta}$$

Q_M = Metabolic Rate (BTU/hr)
Q_S is negative when heat is transferred to the environment and positive when it is added from the environment.

EXTERNAL HEAT LOADS DISSIPATED IN PACK (Q_{PACK})

$Q_{PACK} = Q_T + Q_A$ (BTU)
Q_A is negative when heat is transferred to the environment and positive when it is added from the environment.

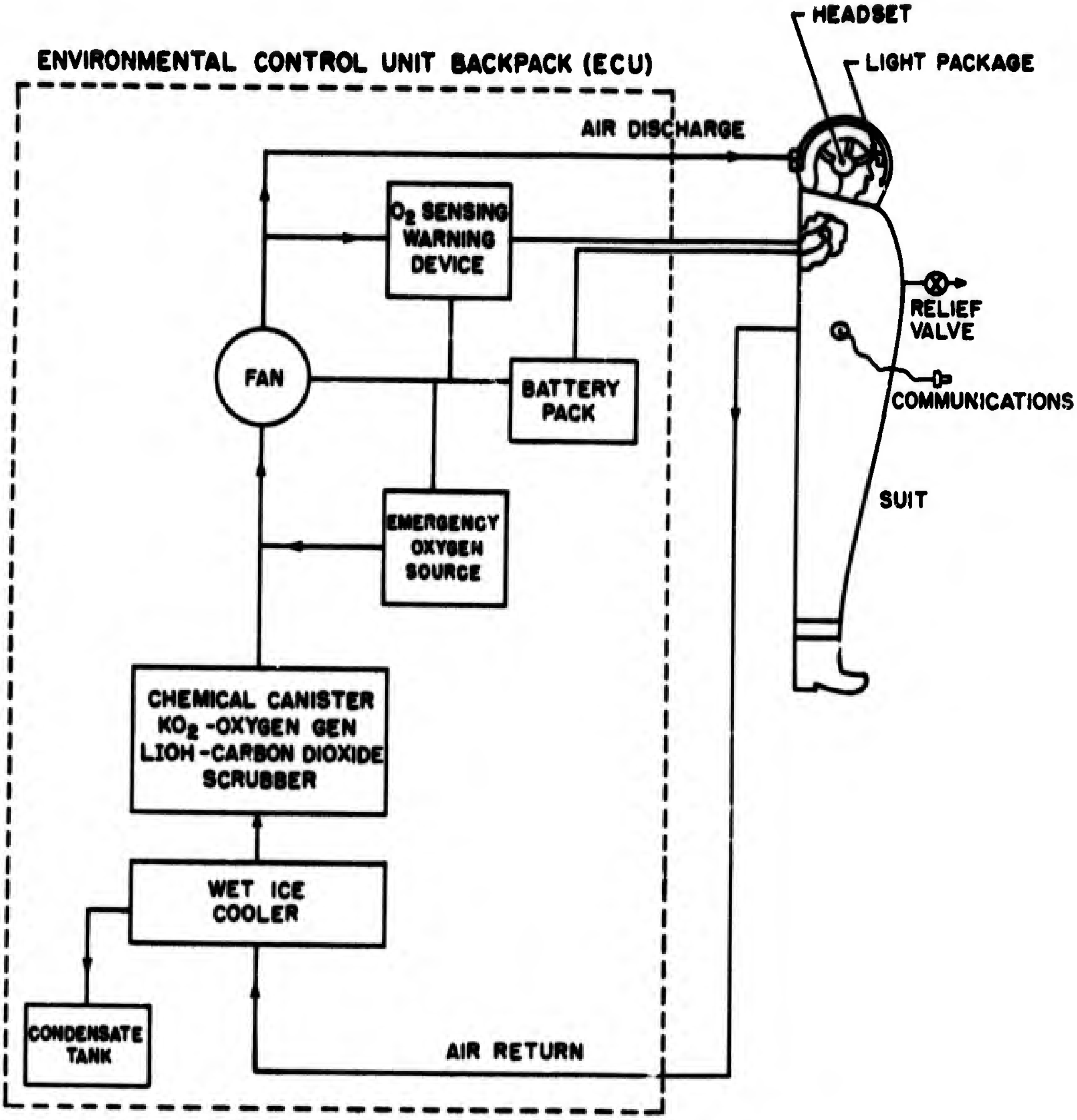
INTERNAL PACK HEAT LOAD FROM FAN MOTOR (Q_{FM})

$Q_{FM} = 3.4\ EI\theta$ (BTU)
3.4 = conversion of watt-hrs to BTU
E = Voltage input to motor (V)
I = Current input to motor (amps)

HEAT-LOAD DISSIPATION CAPACITY AVAILABLE FOR CHEMICAL CANISTER (Q_{CAVAIL})

$Q_{CAVAIL} = Q_R - Q_{PACK} - Q_{FM}$
Q_R = AVAIL refrigerant capacity = 2360 BTU

APPENDIX C. ILLUSTRATIONS



MODEL II

FIGURE I. DAMAGE CONTROL SUIT SYSTEM (DCSS)

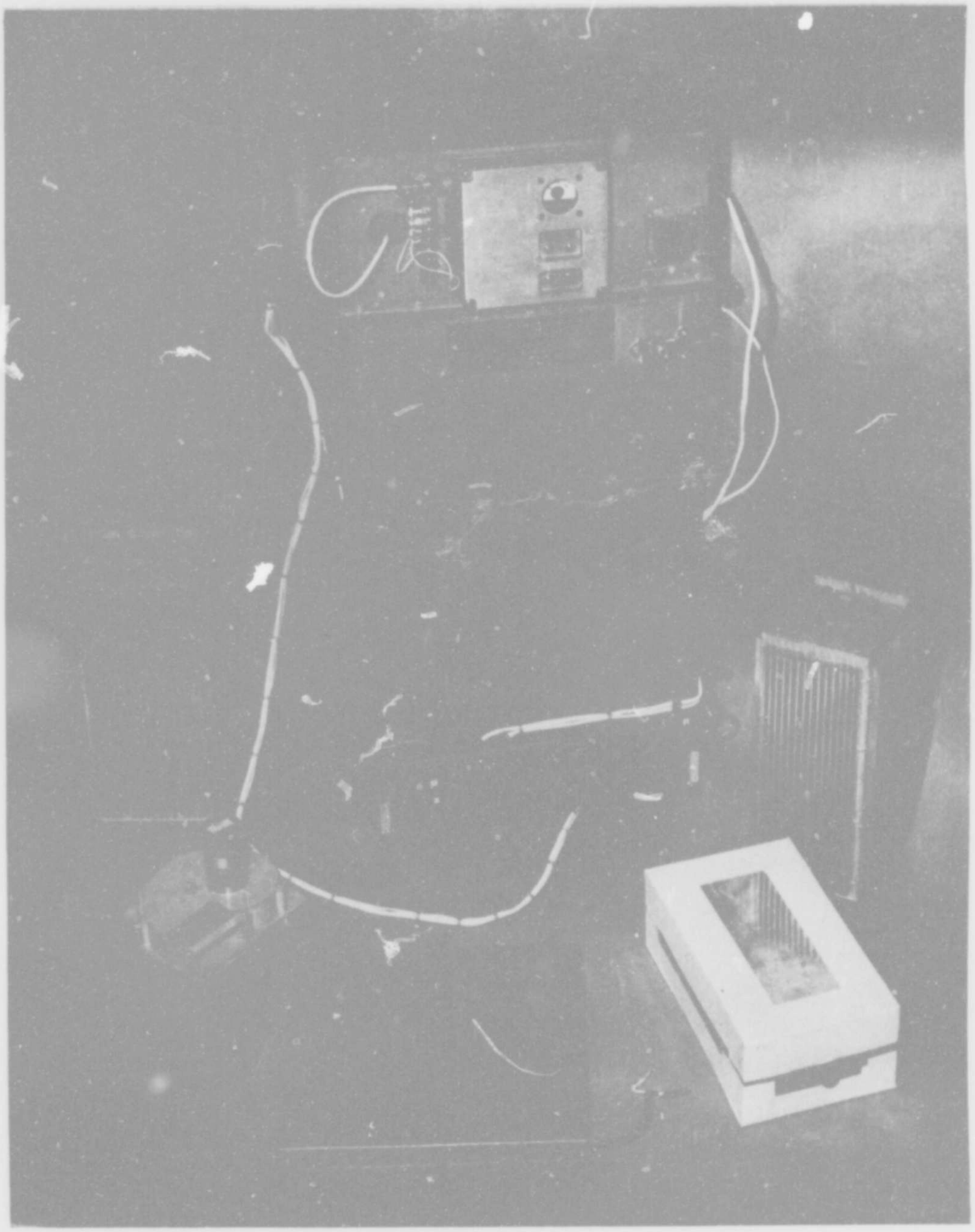


Figure 2 Environmental Control Unit Backpack (ECU) with the O_2 Sensing Warning Device attached. Other components shown are (reading clockwise): a Wet-Ice Refrigerant Canister, Chemical Canister, Silver-Zinc Battery Pack, Silver-Zinc Battery Cell, Centrifugal Fan and Motor Assembly, and another Wet-Ice Refrigerant Canister.

Figure 3   Side View of Model II Prototype DCSS.

Figure 4   Front view of Communication Headset: light package for O_2 Sensing-Warning System is shown at left; strap across forehead includes sweatband.

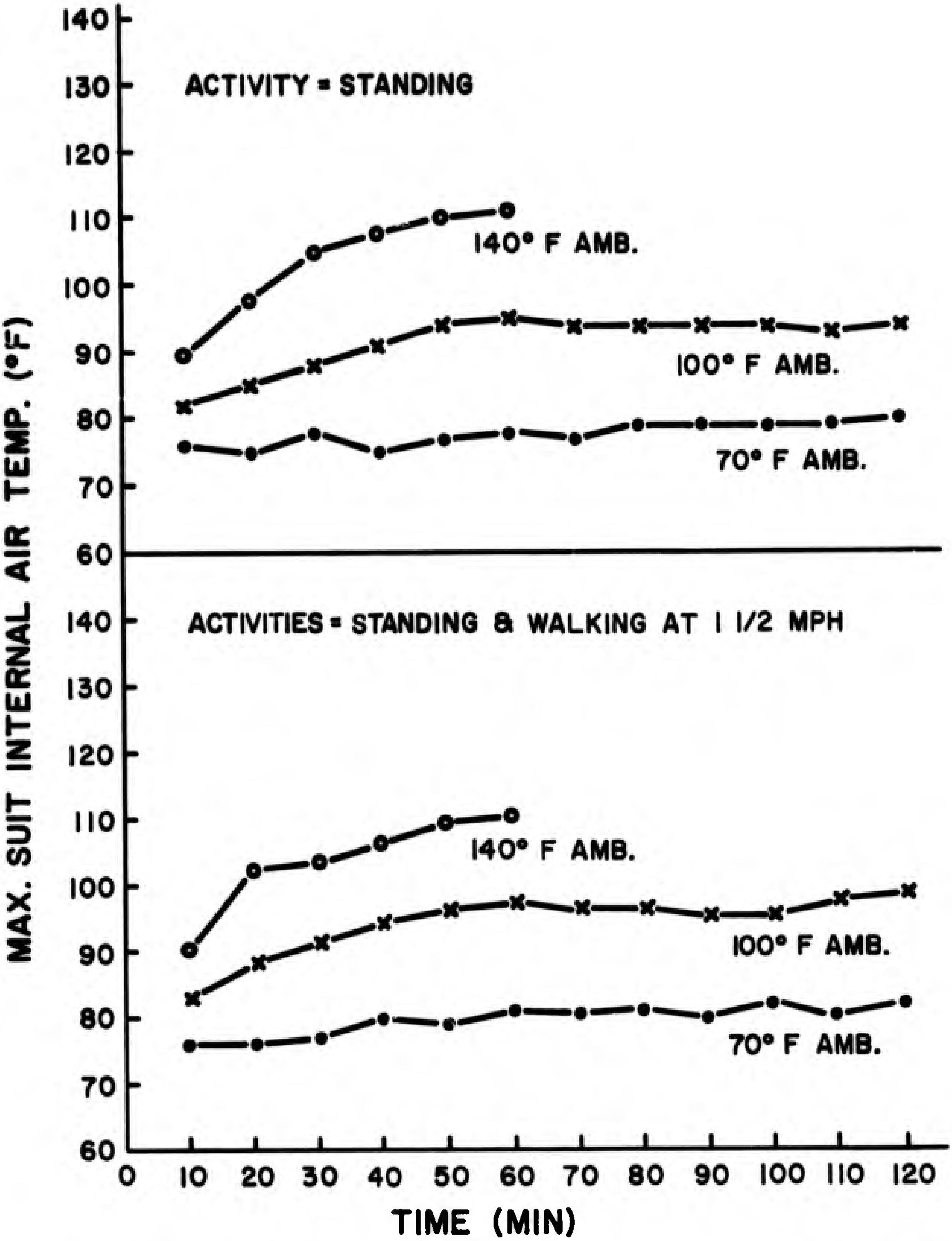


FIG. 5 MAXIMUM INTERVAL SUIT TEMPERATURES FOR ACTIVITY AMBIENT TEMPERATURE CONDITIONS SHOWN

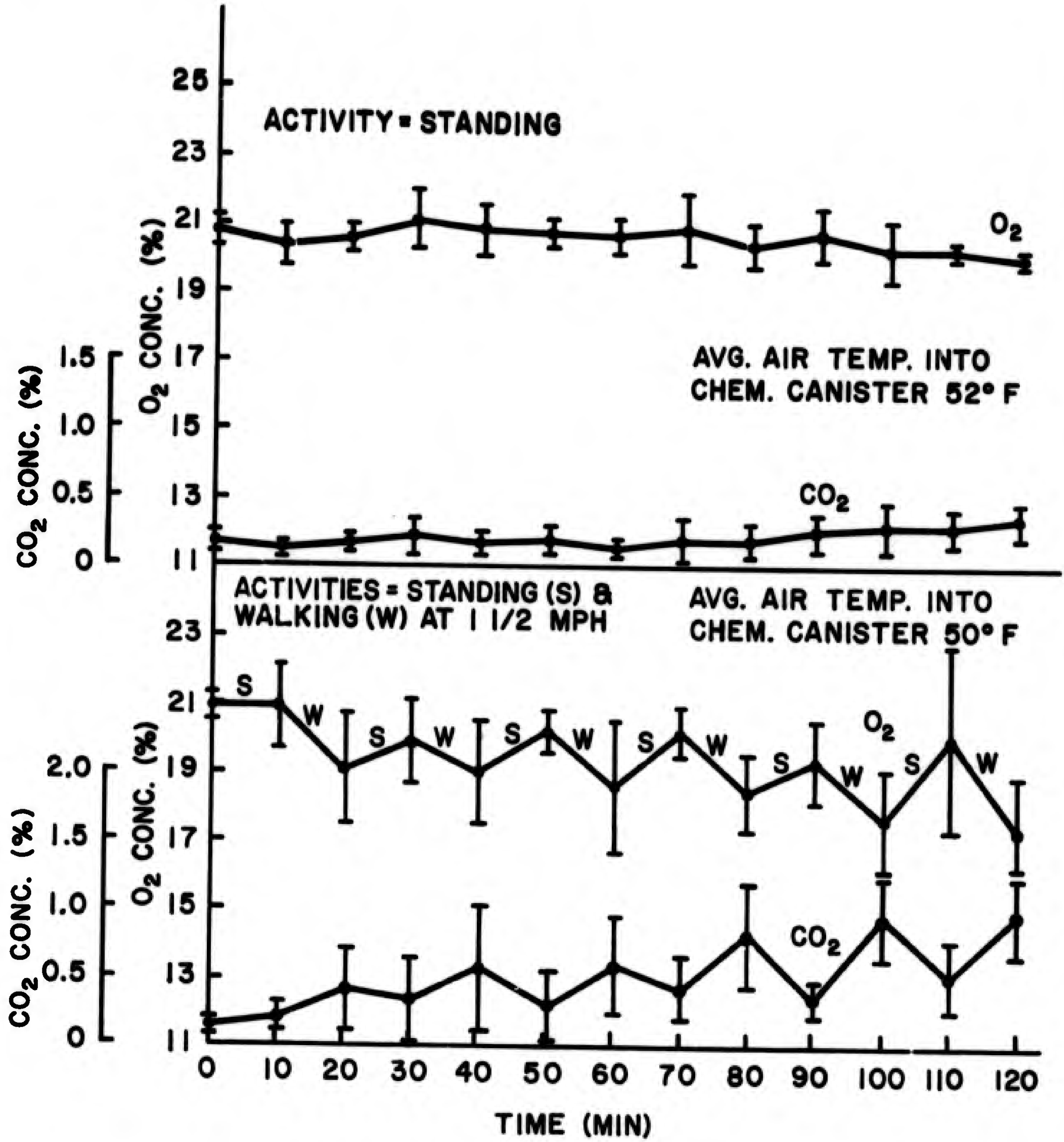


FIG. 6 DAMAGE-CONTROL-SUIT O_2 AND CO_2 CONCENTRATIONS FOR TWO ACTIVITIES WITH AN AMBIENT TEMPERATURE OF 70° F

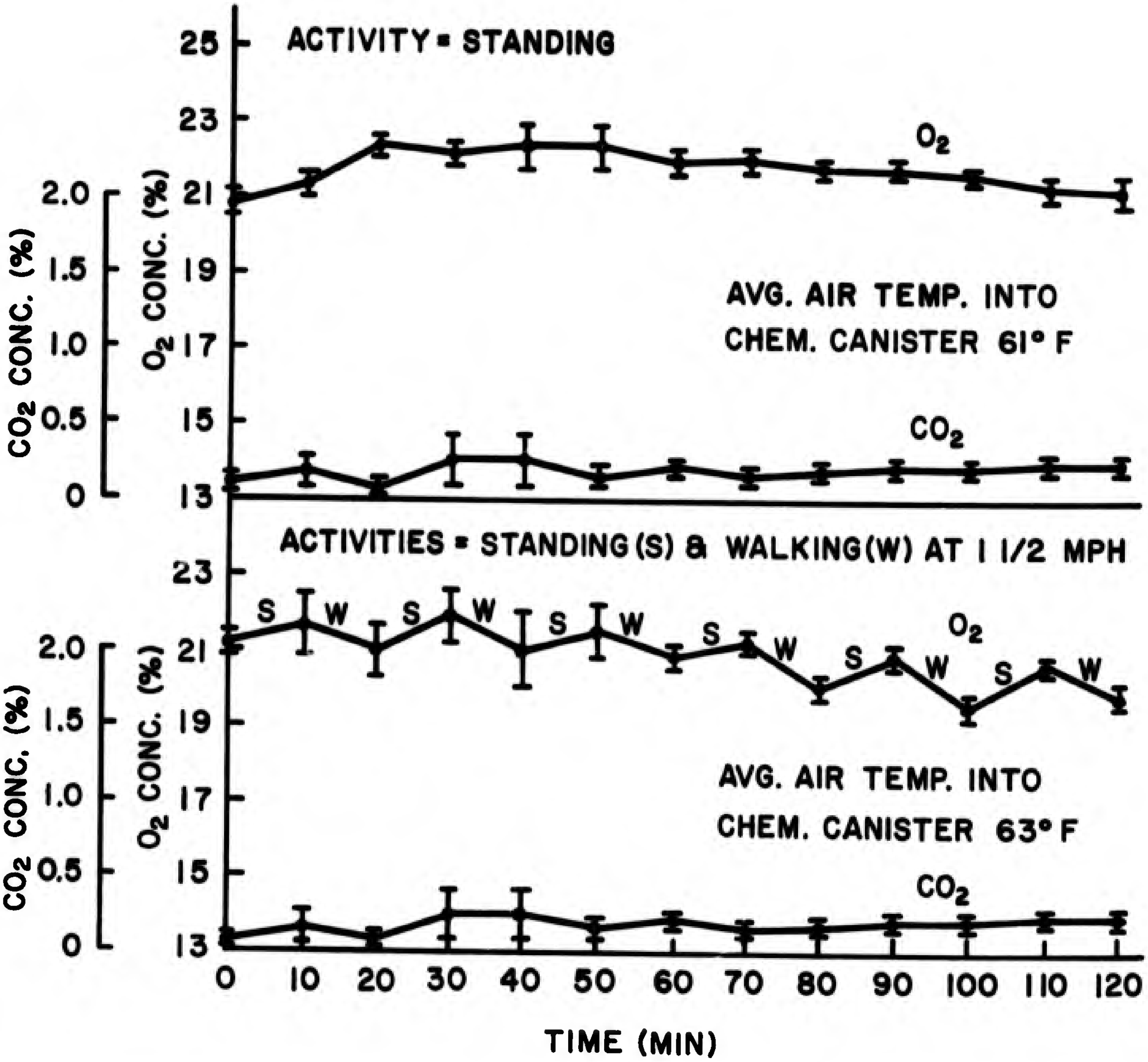


FIG. 7 DAMAGE-CONTROL-SUIT O_2 AND CO_2 CONCENTRATIONS FOR TWO ACTIVITIES WITH AN AMBIENT TEMPERATURE OF 100° F

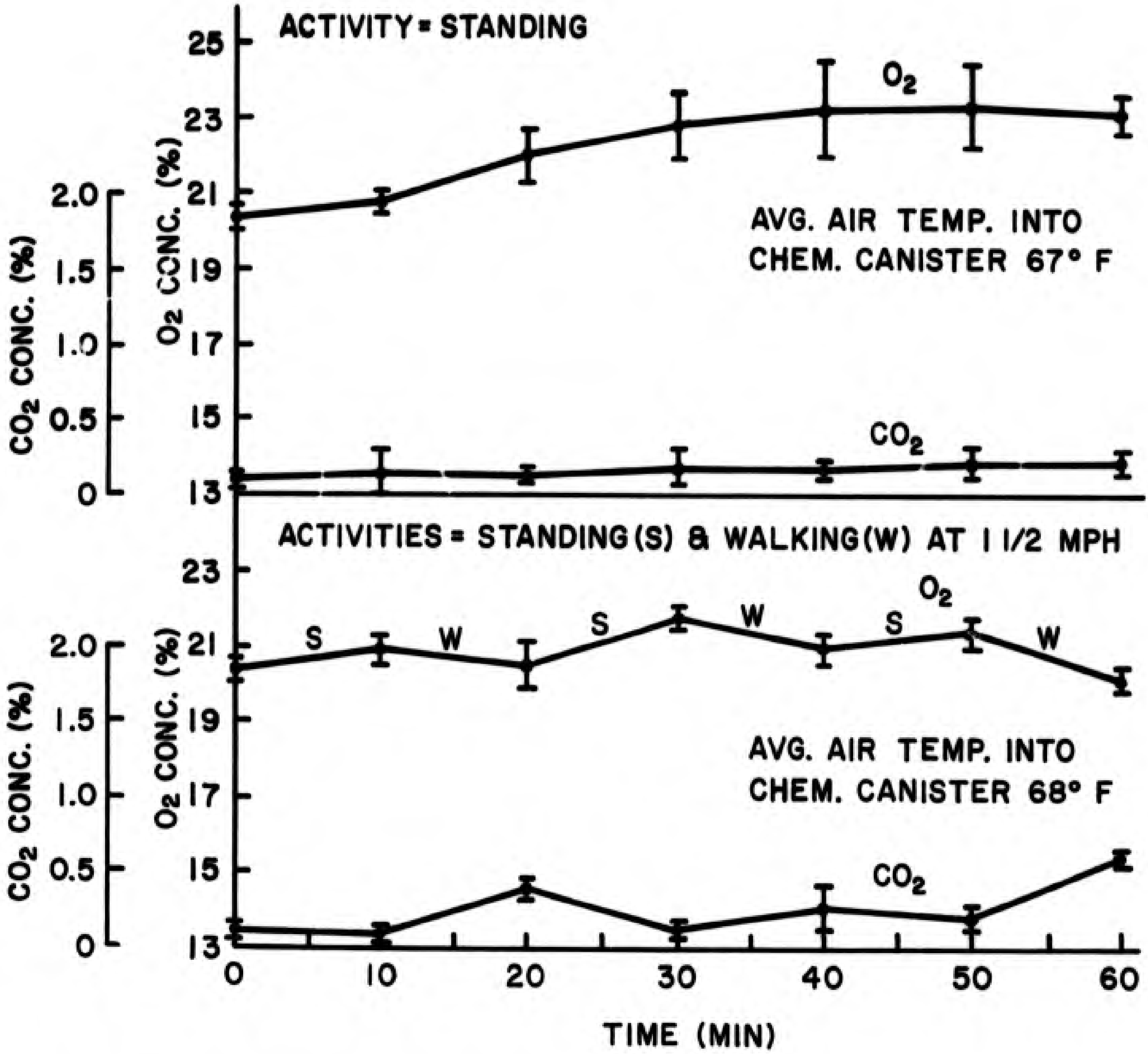


FIG. 8 DAMAGE-CONTROL-SUIT O_2 AND CO_2 CONCENTRATIONS FOR TWO ACTIVITIES WITH AN AMBIENT TEMPERATURE OF 140° F

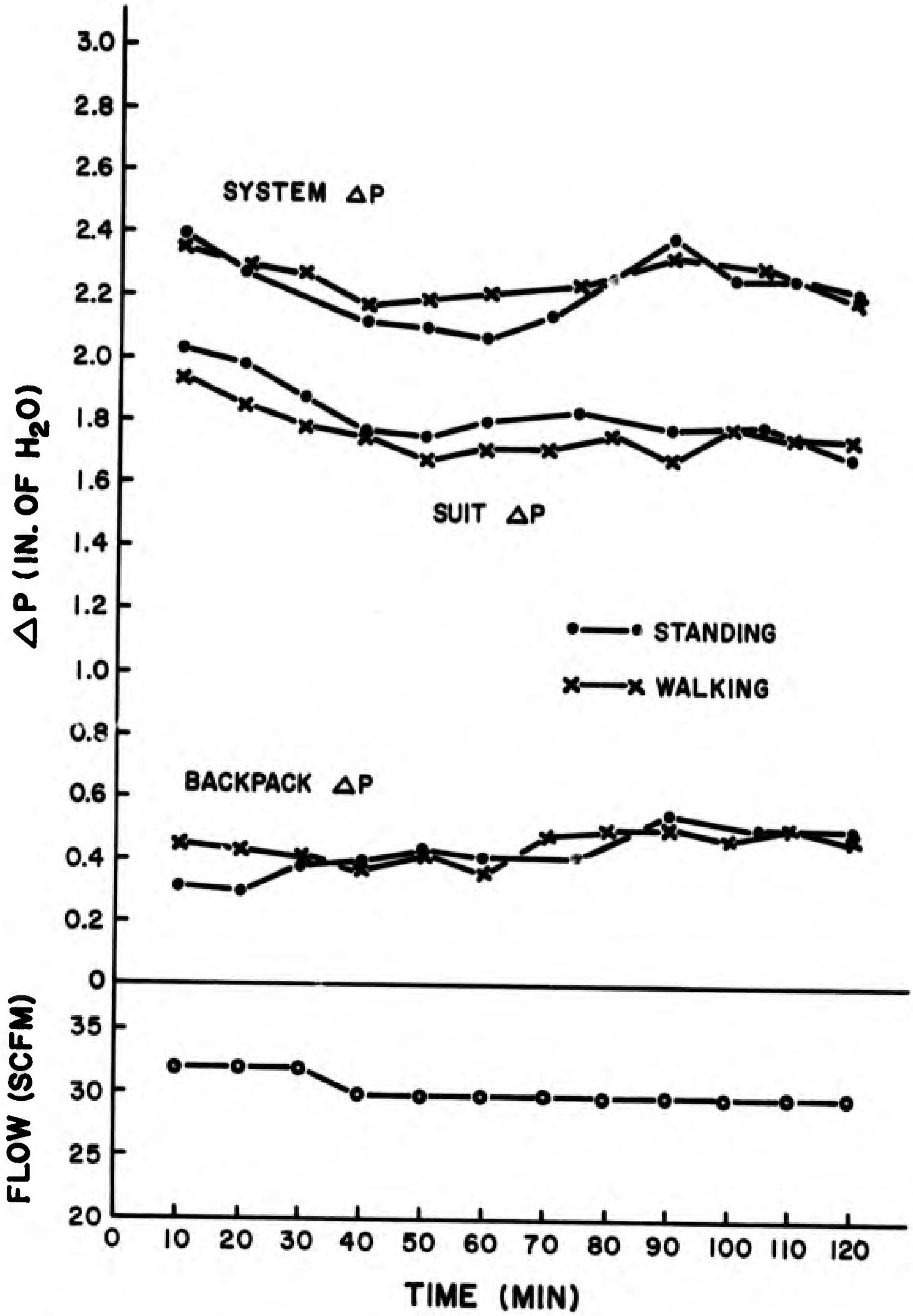


FIG. 9 AVERAGE VENTILATING AIR FLOW-PRESSURE DROP CHARACTERISTIC FOR DCSS FOR ALL TEST TEMPERATURES

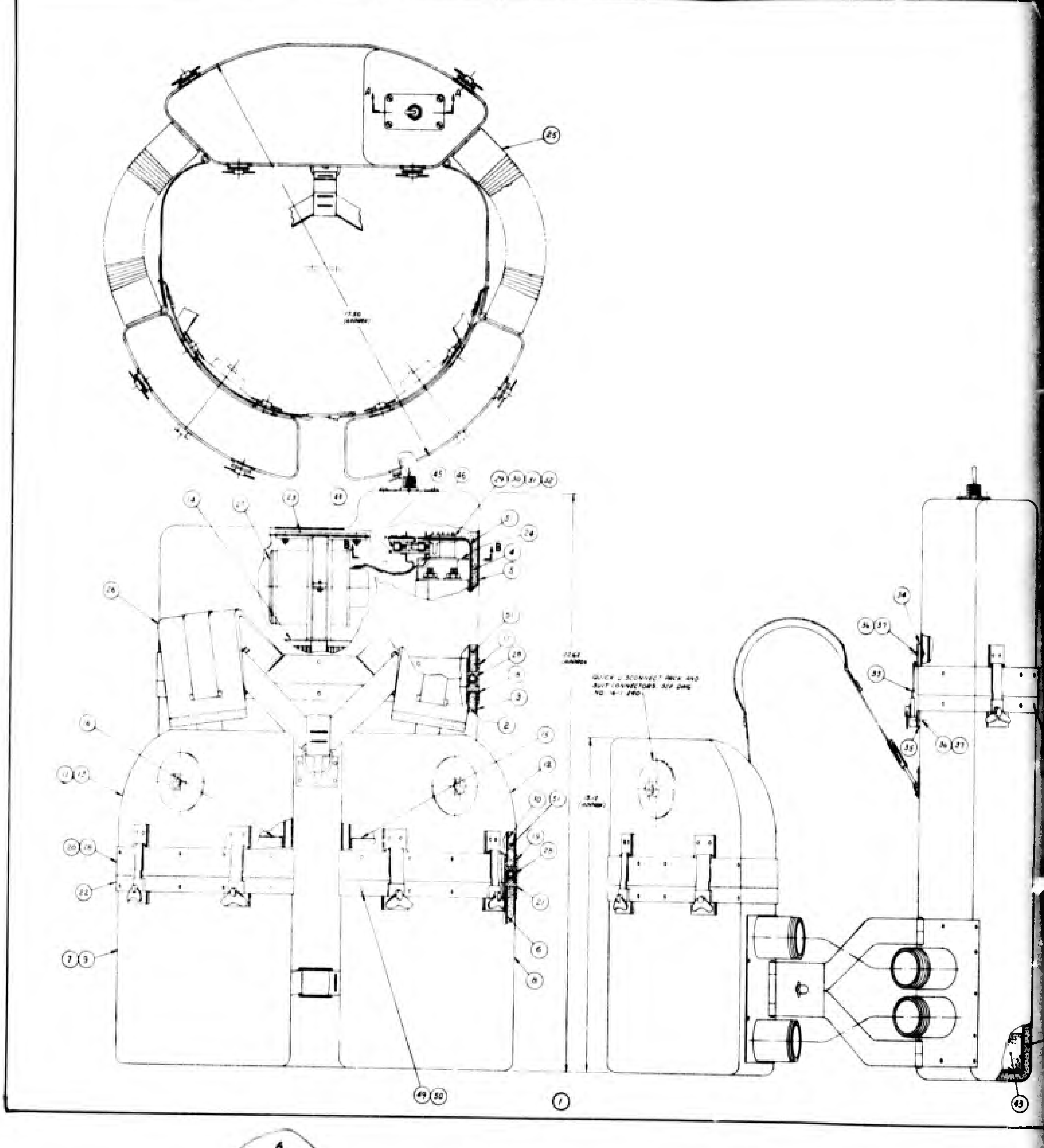
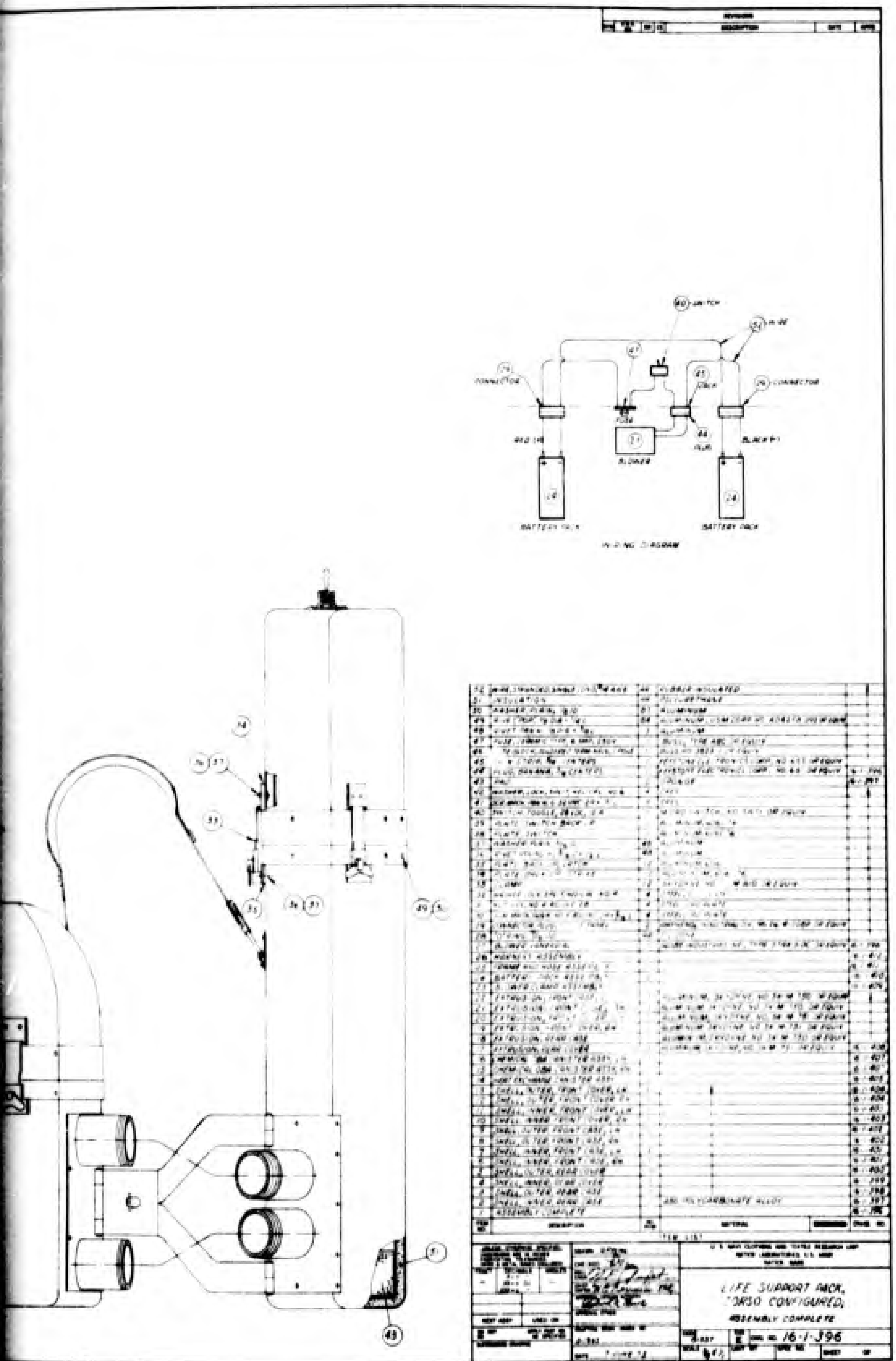


Figure 10. Life-Support Pack, Torso-Configured.



...rt Pack, Torso-Configured.

B

APPENDIX D. REFERENCES

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