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UNMANNED TEST AND EVALUATION OF TWO DOUBLE LOCK RECOMPRESSION CHAMBER (DLRC) CARBON DIOXIDE SCRUBBERS: THE KINERGETICS DH-21 AND AQUA BREEZE II 5000S

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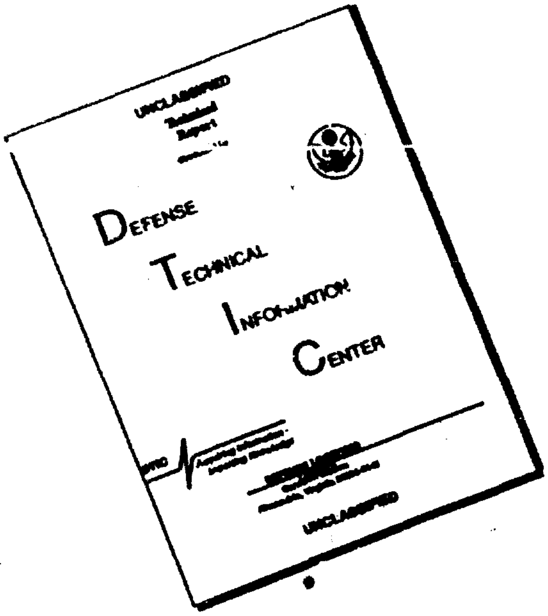

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ABSTRACT

The unmanned test and evaluation of two carbon dioxide scrubbers for use in the standard U.S. Navy double-lock recompression chamber are presented. Tests and evaluations were conducted under the auspices of the Navy Experimental Diving Unit to determine suitability of the Kinergetics Incorporated Scrubber, Model DH-21, and Amron International Diving Supply Scrubber, Model Aqua Breeze II 5000S for use in shore-based and shipboard Navy chambers. Both scrubbers were found suitable for shore-based chamber use after extensive performance, safety, and engineering testing. Due to design deficiencies, the Kinergetics DH-21 was determined inadequate for shipboard use. The Amron Aqua Breeze II was found suitable for shipboard use. The Aqua Breeze II will normally require operation using its two stacked CO_2 canister configuration being that the single canister configuration is incapable of maintaining a low chamber CO_2 partial pressure with multiple or working chamber occupants. In this double canister configuration the Aqua Breeze II canister durations with 3 simulated chamber occupants (CO_2 production = 1.86 Standard Liters Per Minute, Dry) was 5 1/2 hours or greater dependent on chamber depth. The Kinergetics DH-21 canister durations were 3 to 3 1/2 hours under similar circumstances. Generally, CO_2 scrubbers are more effective at maintaining low chamber CO_2 partial pressures when operated at shallow chamber depths. The need for continuous O_2 and CO_2 monitoring when using chamber CO_2 scrubbers is emphasized.

KEY WORDS:

- NEDU Test Plan 86-06
- NAVSEA Task No. 86-10
- Carbon Dioxide
- Carbon Dioxide Scrubber
- Tests
- Hyperbaric Chamber
- Evaluation
- Safety
- Equipment
- Kinergetics DH-21 Carbon Dioxide Scrubber
- Aqua Breeze II 5000S Carbon Dioxide Scrubber
- Breathing Mixtures

ABBREVIATIONS

AC	Alternating Current
ATA	Atmospheres Absolute
ATM	Atmosphere
CO_2	Carbon Dioxide
DC	Direct Current
DLRC	Double-Lock Recompression Chamber
ECS	Environmental Control System
FSW	Feet-of-seawater
G-Force, g's	Gravitational Forces
HP 1000	Hewlett Packard 1000 computer
HP 41CX	Hewlett Packard 41CX Portable Computer
H.P. Sodasorb	High Performance Sodasorb
kg	Kilogram
ℓ/min	Liters per minute
MIL-STD	Military Standard
NAVFAC	Naval Facilities
NAVMAT	Naval Material
NAVSEAINST	Naval Sea Systems Command Instruction
NEDU	Navy Experimental Diving Unit
NFPA	National Fire Protection Association
PCO_2	Partial Pressure of Carbon Dioxide
SEV	Surface Equivalent Value
SLPMD	Standard Liters Per Minute (Dry)
$\dot{V}O_2$	Oxygen flow rate or consumption
°C	Degrees Celsius
°F	Degrees Fahrenheit
%	Percentage

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I. INTRODUCTION

The standard double-lock aluminum recompression chamber (DLRC) is in common use in the U.S. Navy, Army and Coast Guard. It is designed for either permanent installation on ships and shore locations, or for portable use at diving sites. Environmental Control Systems (ECS) for these chambers have been commercially produced to provide heating, cooling, and removal of carbon dioxide (CO_2). The benefits of ECS are reduced compressed air consumption, reduced ventilation noise, enhanced habitability, and prolongation of chamber operating time compared to routine chamber ventilation using compressed air. For the past several years, the Navy Experimental Diving Unit (NEDU) has been evaluating ECS for DLRC use (1).

This report describes the unmanned test and evaluation process used to evaluate two DLRC carbon dioxide scrubbers, the Kinergetics DH-21 (Kinergetics Incorporated, 6029 Resada Blvd., Tarzana, CA 91356) and the Aqua Breeze II 5000S (Amron International Diving Supply, Incorporated, U.S.A., 759 West Fourth Avenue, Escondido, CA 92025).

II. METHODS

A three phase test and evaluation process was used. Phase I encompassed a standard engineering design and safety review. Phase II consisted of bench testing procedures to determine suitability of the scrubbers for shore and shipboard DLRC use, and Phase III was simulated operational testing of the two scrubbers to delineate specific scrubber operating characteristics and limitations.

Phase I Engineering and Safety Review

Personnel with expertise in engineering, electronics, human factors and technical support at NEDU reviewed the two scrubbers based on accepted design criteria, performance standards, electrical requirements, and various safety codes. In the course of this review, the scrubbers were examined along with their operations and maintenance manuals. Additionally, manufacturer testing documentation and tests substantiated or performed by outside reputable facilities or organizations were also reviewed.

DLRC CO_2 scrubbers are life support components which operate with electrically powered fan ventilation. Venting of the chamber with compressed air is an acceptable alternative to the use of DLRC scrubbers (2). This is less desirable though for reasons previously mentioned. In general, the CO_2 scrubbers were not considered in the category of equipment absolutely necessary for chamber operations or as combat hardened. Standards that apply to equipment such as these two scrubbers are listed below. For detailed evaluator findings based on these standards, consult Annex A and B of this report.

Standards Reviewed:

MIL-STD-454H	Standard General Requirements for Electronic Equipment, 30 July 1982.
MIL-STD-167	(Ships) Mechanical Vibrations of Shipboard Equipment,20 December 1954.
SE-019-049-2H REV A	SRB Vibration, Acoustic, Shock Design and Test Criteria (Ships), Marshall Space Flight Center Document No. SE-019-049-2H REV A, 17 NOV 1976, Change #50.
MIL-STD-1472C	Human Engineering Design Criteria For Military Systems, Equipment and Facilities, 31 December 1974
	Human Engineering Guide to Equipment Design VanCott, H.P. and Kinkade, R.G. (Eds), 1972.
MIL-STD-108E	Definitions of and Basic Requirements for Enclosures for Electric and Electronic Equipment. 27 June 1958.
MIL-STD-810C	Environmental Test Methods, 15 June 1987.
NAVFAC DM-39	Hyperbaric Facilities Design Manual 39, July 1982.
NAVMAT P-9290	System Certification Procedures and Criteria Manual For Deep Submergence Systems, June 1976.
NFPA 70-1984	National Electrical Codes, 1984.
NFPA 99	National Fire Protection Association, 1987.
NEDU REPORT 3-50	Tilt Standards, Motion Standards, 1950.
	NASA Lubricants List for O_2 Enriched Atmospheres, 15 November 1986
NAVSEAINST 9597.1A	Promulgation of List of Diving Equipments Which are Authroized for Navy Use (ANU).

Phase II Bench Testing Procedures

Based on Phase I standards review, five areas for further bench testing were identified (see Annexes A and B). In summary, these areas encompass environmental testing for: shock, vibration, heat, cold and operability at extremes of ship roll or tilt. Levels of testing in general reflected an active shipboard environment but did not classify the scrubbers as absolutely necessary for chamber operations or as combat hardened.

SHOCK

Shock testing was conducted IAW Environmental Test Methods (3), (c.f.3, Section 516.2, Procedure V, Bench Handling Test). This test assessed the durability of the equipment to routine shipboard shock experienced during installation and maintenance. The scrubbers are placed on a wood work bench tilted on edge to 45° and allowed to fall, right, left, front and back four times each. The test is done without power to the motors and a passing test requires the scrubber to operate normally after the 16 shock exposures.

VIBRATION

Vibration testing was conducted at Marshall Space Flight Center, Huntsville, Alabama. The test procedures were according to shipboard transportation Test Criteria, reference (4). The test consists of a resonant frequency search from 5-300 hertz in each of the three defined spacial planes (Figure 1). This was followed by an exposure of 15 minutes at the predetermined frequency in each of the three spacial planes. The scrubbers were packed with H.P. Sodasorb and their blowers were operating during the test.

HEAT

Thermal stress was tested to 71°C (160°F) for 48 hours IAW reference (3) procedures I, Section 501.1.

COLD

Freezing stress was tested to -29°C (-20°F) for 24 hours IAW reference (3) procedures I, Section 501.2. The temperature of -29°C was the coldest temperature attainable due to technical constraints but was judged by NEDU engineers as a suitable freezing stress for these components.

TILT

To evaluate the failure rate of the scrubber motor and bearings during at-sea conditions of tilt, testing was conducted for 96 hours of scrubber operation at 30° of either port or starboard tilt. This was in the configuration of the scrubbers mounted on a transverse chamber bulkhead. Ninety-six hours represents twice the length of a U.S.N. Treatment Table 7 (5), which is the longest expected continuous use of a chamber CO_2 scrubber.

Phase III Operating Characteristics

A double-lock aluminum recompression chamber was used which is 3.4m (11 ft) long and has a diameter of 1.4m (5 ft). The volume of the inner lock is 3,850 liters, and the outer lock is 1,840 liters. Instrumentation penetrators were installed in place of two view ports which allowed addition of carbon dioxide (CO_2) and sampling of chamber atmosphere (Figure 2).

A Kinergetics ECS heater-chiller Model DH-21 was installed with the Kinergetics DH-21 CO_2 scrubber (Figure 22, Appendix A). This system has two independent components; the CO_2 scrubber and a heater-chiller. The heater-chiller and its blower were used during this study to control temperature at 21°C (75°F ± 3°F), and to help mix chamber atmosphere during all studies. A second blower was used in the first 14 compression-decompression trials to aid in mixing the chamber atmosphere. The second blower was found not to be necessary. No layering of CO_2 was noted with a single scrubber blower and the Kinergetics heater-chiller. Therefore the second blower was discontinued in the final 21 trials. These later compression-decompression trials were done with the Kinergetics DH-21 CO_2 scrubber replaced by an Aqua Breeze II DLRC CO_2 scrubber (Figure 28, Annex A).

Both the scrubbers employ CO_2 absorbent canisters with a radial air flow design instead of the axial flow design used in the older Kinergetics Models DH-10 and DH-11 which were previously tested at NEDU. The Kinergetics DH-21 canister is two canisters, an inner perforated aluminum cylinder within a larger cylinder having an overall weight of 1.62 kg and containing 5.9 kg of CO_2 absorbent (Figure 23, Annex A). The Aqua Breeze II canister is smaller but similar in design and is available in either aluminum or stainless steel. The canister has a fine mesh screen in addition to the perforated cylinder walls. The Aqua Breeze II aluminum canister weighs 1.90 kg and 2.84 kg if made of stainless steel, both contain 3.75 kg of CO_2 absorbent (Figure 29, Annex A). The Aqua Breeze II CO_2 scrubber can be used with a single canister or can be used with two or three canisters stacked in series, one on top of the other. In both scrubbers, chamber air is drawn radially through the CO_2 absorbent bed by a 20-28 volt AC or DC electric blower and exhausted out the other end of the scrubber.

The air inlet surface area of the Kinergetics DH-21 CO_2 absorbent canister is 2,224 cm^2 with an absorbent bed depth of 6.35 cm. In the Aqua Breeze II canister the air inlet surface area is 1,040 cm^2 and the bed depth was also 6.35 cm.

During all studies, canisters were packed with fresh H.P. Sodasorb (W.R. Grace and Co., Atlanta, GA 30336) and weighed to ensure uniformity. All H.P. Sodasorb used had an expiration date of July 1987. Initial chamber relative humidity was controlled below 70%. With liberation of water from the CO_2 absorbent bed during the chemical scrubbing of CO_2, the DLRC relative humidity rapidly approached 90-100% as is commonly seen during manned chamber operations (6). Temperatures and relative humidity readings were obtained by using YSI dry heat probes, one dry and one with a saturated wick (Yellow Springs Instruments Inc., Yellow Springs, Ohio, Model 705). Digitec electronic temperature monitors (United Systems Corporation, Dayton, Ohio, Model 2780A) were interfaced with a (Hewlett-Packard HP-1000) computer which updated temperature and relative humidity every two minutes.

All gas measurements were done using a fixed detector mass spectrometer Perkin-Elmer Gas Analyzer (Perkin Elmer, Pamona, CA, Model MGA 1100).

Measurements were recorded by the computer at 30-second intervals, rotating among four sample lines placed at various positions in the chamber.

(1) Canister Duration:

The canister duration studies were done using the inner lock of the DLRC at depths of 1.91 ATA, 2.82 ATA, and 6.0 ATA (30, 60, and 165 FSW) on air.

The chamber was first compressed to the appropriate test depth and CO_2 was added to bring the initial chamber CO_2 concentration to a 1.5% Surface Equivalent Value (SEV) or partial pressure of 11.4 mmHg. This level of chamber CO_2 concentration represents the highest level permissible in U.S. Navy DLRC during manned operations (2).

Once all initial chamber parameters were set, the test run was begun with simultaneous initiation of a 2 ℓ/min CO_2 flow rate into the chamber and the switching on of the CO_2 scrubber fan which initiated air flow through the CO_2 absorbent canister.

At depth, CO_2 was added continuously to the chamber at 2 ℓ/min at ambient temperature (1.86 Standard Liters Per Minute Dry, SLPMD). This rate was chosen to simulate the CO_2 which would be produced by 3 chamber occupants, 1 working (VO_2 = 1 SLPMD) and 2 occupants resting (VO_2 = 0.5 SLPMD), with respiratory quotients of 0.93. This respiratory quotient is a reasonable assumption chosen to simplify the experimental design such that the ambient flow would be 2ℓ/mix of CO_2. The actual CO_2 add rate would be 1.86 SLPMD (7). The CO_2 was added mid chamber at a position providing good mixing. CO_2 addition rate was controlled by a mass flow meter and mass flow controller (Matheson Gas Products, East Rutherford, N.J. Model 8100 series). The CO_2 was introduced to the chamber through 1/8" nylon tubing (Figure 3).

Gas flow was verified by timed flow into a Tissot spirometer (Collins Chain-Compensated Gasometer, Warren E. Collins, Inc., Braintree, MA, Model 120) and by net weight change of the CO_2 supply cylinder as measured by an electroscale weightmeter (Electroscale Corporation, Santa Rosa, CA, Model 532). The entire arrangement is shown diagramatically in Figure (3) and pictured in Figure (4).

During the test runs mixed chamber CO_2 was sampled from three widely spaced locations; at the top, middle, and bottom of the chamber, to ensure that chamber air was well mixed. A canister effluent sample was taken from the center of the canister discharge directly below the scrubber exhaust fans. Data were recorded at two minute intervals and plots of P_{CO_2} versus time were generated by computer.

(2) Canister Flow:

Actual air flow through CO_2 canister absorbent beds in axial flow canisters has been found to be a major factor in determining chamber CO_2

removal rate (8). This also holds true for the new radial flow canisters. However, due to different design characteristics in the effluent air pathway between the Kinergetics DH-21 and Aqua Breeze II scrubbers it is technically difficult to ensure similar effluent air flow samples. Furthermore, these two scrubbers also differ in design from the Kinergetics DH-10 with which comparison will be made. For these reasons flow analysis is based mainly on the effective air flow through the CO_2 absorbent canisters. Effective air flow is the theoretical liters per minute of air flow that would result if all CO_2 were scrubbed from air passing through the absorbent bed.

In the Kinergetics DH-10 axial flow canister the effective and actual air flows were essentially the same until the canister began to break through. With the marked increased cross-sectional area in the radial flow canister and with diminished CO_2 absorbent bed depth, it is likely that all CO_2 will not be removed from the circulating air on a single pass through the CO_2 absorbent bed in the newer radial flow designs. With these design and technical differences it is pragmatically beneficial to compare all CO_2 scrubbers based on effective air flow. For historical perspective actual liter per minute (LPM) flow rates will be calculated but should be viewed with caution due to potential calculation error. Effective and actual flow rates were based on calculations in The Physiology and Medicine of Diving (7). The specific formula used were adapted for use with the HP 41CX portable computer (Hewlett Packard, Portable Computer Division, Corvallis, OR). Below are the equations and the HP-41CX program is listed in Figure 5.

$$F_E = \frac{[(\dot{V}_{CO_2} \bullet (T_E - T_I)] - [(\%CO_{2I} - \%CO_{2E}) \bullet .01CH_V)] \bullet 100}{(\%CO_{2_I} + [(\%CO_{2_E} - \%CO_{2_I})/2]) \bullet (T_E - T_I)} \quad [1]$$

$$F_A = F_E / CO_2 \text{ Fraction} \quad [2]$$

Where:

Variable		Parameter	Computer Data Point
	-	Test run number	RCL 00
$\dot{V}_{CO_2}$	-	CO_2 flow rate SLPMD	RCL 01
T_I	-	Time at Initiation of Flow Calculation	RCL 02
T_E	-	Time at End of Flow Calculation	RCL 03
$\%CO_{2I}$	-	Mixed Chamber % CO_2 at Initiation of Flow Calculation	RCL 04
$\%CO_{2E}$	-	Mixed Chamber % CO_2 at End of Flow Calculation	RCL 05
CH_V	-	Chamber Volume (liters)	
CO_2 Fraction	-	Fraction of CO_2 removed each pass through CO_2 absorbent bed	RCL 06
F_E	-	Effective scrubber flow (ℓ/min)	
F_A	-	Actual scrubber flow (ℓ/min)	

The CO_2 fraction scrubbed with each passage of air through the canister was computed from the low asymptote of mixed chamber CO_2 compared with canister effluent at that time, or from the steady state values interpolated back to the lowest mixed chamber CO_2 if steady state had not been attained at that earlier time as shown on Run 34 (Figure 19).

Chamber CO_2 scrubbers in actual use will be required to function under a wide range of environmental conditions. For this reason selected canister studies were undertaken with variations from the parameters previously described for the standard canister duration and flow studies. Specifically, the initial chamber CO_2 level was modified to fresh air (0.03% SEV) from 1.5% SEV and the CO_2 add rates were either reduced to 1 ℓ/min at ambient conditions or increased to 4 ℓ/min. These new parameters define the range of carbon dioxide loads which a DLRC might realistically be subject to. Although no predictive results can be derived from these independent canister studies, they do allow better delineation of the efficiency characteristics of the CO_2 scrubbers under various operating conditions.

III. RESULTS

Standards Review

Standard reviews completed by NEDU Engineering, Technical Support and Human Factors evaluators identified five areas where further testing was felt warranted. (These areas where subsequently tested in the Bench Testing phase.) Both the Kinergetics DH-21 and the Aqua Breeze II were found safe from the standpoints of hyperbarics, electrical, and materials based on the standards reviewed.

Mild concern were noted by individual evaluators and suggestions for modifications to enhance human factors acceptability and safety on both scrubbers were set forth (see Annexes A and B).

Nearly all evaluators felt the design and workmanship was far superior on the Aqua Breeze II compared to the Kinergetics DH-21. One evaluator (see Annex A) expressed doubt that the Kinergetics DH-21 would hold up under shipboard use.

Bench Testing

(1) Shocks:

Both scrubber motors, the Kinergetics DH-21 and the Aqua Breeze II, completed the 16 bench handling shocks without breakage. Both scrubbers continued to operate after testing was completed.

(2) Vibration:

The Aqua Breeze II showed reasonant frequencies at 100 and 200 hertz with vibration in the vertical plane (Figure 6). Resonance direction was also in the vertical plane. In the tangential plane, parallel with the mounting bulkhead, a vertical in-line resonance was detected at 254 hertz (Figure 7). Fifteen minutes of dwell was conducted in each of these planes at the previously detected resonant frequencies. G-force was 0.75 g's. No deterioration of the Aqua Breeze II performance or structural failure was seen during these exposures and no excessive resonant vibrations were generated.

The Kinergetics DH-21 showed resonant frequencies at 6, 19, and 120 hertz with vibration in the vertical plane (Figure 8). Resonance response at 19 hertz was also in the vertical plane but resonance response at 9 and 120 hertz was most manifest in the radial plane, perpendicular to the mounting bulkhead (Figure 9). Fifteen minutes of dwell at 6 hertz produced no structural or performance changes in the DH-21 but excessive motion in the radial plane was noted even with vibration applied in the vertical plane. At 19 hertz excessive vertical vibration caused dust formation in the Kinergetics DH-21 canister. This dust escaped through the canister holes and created a sodasorb dust cloud for approximately a 1.5 meter radius around the scrubber. Within 30 seconds a mounting clip, which attaches the canister to the scrubber motor, came unlatched and the test was halted for fear the canister would fall off the motor housing. No further vibration testing was done on the Kinergetics DH-21.

(3) Heat, Cold and Tilt:

Both scrubbers continued to operate without malfunctions after the environmental stresses of 48 hours high temperature, 24 hours sub-freezing, and 96 hours of tilt exposure as delineated in the Methods section. No excessive moisture accumulation was noted and no alterations in normal scrubber functions occurred due to moisture condensation.

Canister Duration Studies

The standard canister duration studies are shown in Figures (10 - 21). These figures show a plot of PCO_2 in % SEV (100% SEV = 1 ATA = 760mmHg) versus time. The data from these studies is summarized in Table 1, which gives the initial time required for canister effluent PCO_2 to reach 0.5% SEV and 1.0% SEV. The table is broken down into the three depths studied 1.91 ATA (30 FSW), 2.82 ATA (60 FSW), and 6.00 ATA (165 FSW); and also by the CO_2 scrubber and canister configuration used.

The Aqua Breeze II was tested both with a single and double canister arrangement, due to short single canister durations at moderate to high rates of CO_2 addition. Also noted in Table 1 is the mixed chamber CO_2 level when canister effluent levels reached 0.5% SEV and 1.0% SEV. Carbon dioxide scrubber capabilities rapidly deteriorate once effluent levels pass 0.5% SEV. This level has traditionally been used by investigators to define the end of usefullness or the break through point of that particular CO_2 scrubber canister.

Variations from the standard scrubber test parameters of 1.5% initial CO_2

concentration and a 2 ℓ/min CO_2 add rate showed interesting characteristics of the scrubbers. Beginning a canister duration study with fresh air (0.03% SEV of CO_2) had little effect on the ultimate canister duration as can be seen in run 11 (Figure 13). The major influence on canister duration seemed to be CO_2 add rate or simulated chamber occupant CO_2 production rate. At an add rate of 1.0 ℓ/min all scrubbers and canister configurations perform well. The DH-21 was able to maintain mixed chamber CO_2 below 0.5% SEV at 165 FSW for 11 1/2 hours, and the Aqua Breeze II with a double canister was able to maintain mixed chamber CO_2 below 0.5% SEV at 165 FSW for nearly 6 hours (see runs 14 and 27 in Figures 14 and 21 respectively). High CO_2 add rates near 4 ℓ/min quickly overwhelmed the CO_2 scrubbing capabilities of all scrubbers and canister configurations. This rate of 4ℓ/min would simulate three attendents involved in a resusitation type effort. At this CO_2 production rate the mixed chamber CO_2 levels quickly reached the 1.5% SEV which would require chamber venting. At this high CO_2 add rate, the DH-21 reached 1.5% SEV mixed chamber CO_2 in approximately 2 hours when operated at 30 FSW, and in approximately 1 hour at 165 FSW, see runs 9 and 12 in (Figure 13 and 14) respectively. The double canister Aqua Breeze II performed better under this CO_2 load and maintained below 1.5% SEV mixed chamber CO_2 for nearly 4 hours at 30 FSW and for 2 hours at 165 FSW, see runs 33 and 36 respectively (Figure 21).

Canister Flow Studies

A typical canister flow study is shown using run 34 (Figure 19). the variables described in the methods section are as labeled and were used to compute the effective and actual flows. A comparison of flows among the Kinergetics DH-10 and DH-21 along with the single and double canister Aqua Breeze II is presented in Table 2.

IV. DISCUSSION

Standards Review

NEDU Engineering and Technical Support staff found the Kinergetics DH-21 and Aqua Breeze II CO_2 scrubbers to be acceptable based on their extensive review of engineering, material, electrical and safety standards as listed in the Methods section. The only comment of significance concerning the Aqua Breeze II identified a deficiency in the repair manual which failed to mention the need to purge the motor compartment with 100% nitrogen prior to hermetically sealing it after repairs. This is necessary to prevent an atmosphere in the motor compartment capable of supporting fire. Although the Aqua Breeze II is manufactured with either aluminum or stainless steel canisters, the NEDU engineers recommend the stainless steel because the Sodasorb reaction with aluminum causes pitting of the metal. NEDU's Human Factors Engineer felt the Kinergetics DH-21 was a marginal pass for design and workmanship, and the Aqua Breeze II, though much better, still had some deficiencies. Specifically identified with the Kinergetics DH-21 was poor workmanship leaving sharp edges; hard to operate, flimsy latches; and a structurally weak canister susceptible to easy damage. The large hole configuration of the canister allowed Sodasorb dust into the chamber. Seven deficiencies were noted in the Kinergetics DH-21 Operations and Maintenance Manuals while only two deficiencies were noted in the Operating and Maintenance Manuals for the Aqua Breeze II. Both scrubber motors had open areas when disassembled which could allow finger access to turning fans. Finger guards or a pressure activated cutoff switch was recommended for increased safety along with a permanently fixed warning tag.

Bench Testing

Bench testing procedures showed the Aqua Breeze II chamber CO_2 scrubber to be superior in durability when exposed to the shipboard environment. The Kinergetics DH-21 has design and workmanship flaws that leave it with a high failure potential when exposed to shipboard vibrations. The DH-21's tendency to create Sodasorb dusting under these circumstances constitutes a health risk to chamber occupants.

Both scrubbers show good capabilities to withstand hot and cold environments and both seem reasonably reliable based on NEDU's operating experience. The Aqua Breeze II has been operated for greater than 400 non-continuous hours with one start-up bearing failure. No electrical or fire hazard developed from this failure. The Kinergetics DH-21 has been operated for over 500 non-continuous hours with one failure also. The exact nature of this failure is under investigation. It occurred sometime after the cold exposure and perhaps during transportation to Marshall Space Flight Center.

Canister Duration and Flow Studies

During a chamber treatment, the chamber initially is filled with fresh air at a CO_2 concentration of approximately 0.03% SEV. Chamber occupants produce CO_2 at a rate which can be estimated. Frequently there is a single chamber tender and one patient on an oxygen treatment table with overboard dumping of exhaled oxygen and CO_2 from the patient. In this limited situation the CO_2 load entering the chamber may be less than 1.0 SLPMD. On the other hand, if multiple tenders are involved in basic or advance cardiac life support with a patient in the chamber, the CO_2 load would reach or exceed 4 SLPMD.

Two methods exist for removing CO_2 from the chamber; one is periodic venting and the other is the CO_2 scrubbers. At low to moderate levels of CO_2 production (1.0 SLPMD) CO_2 scrubbers of the radial flow design (Kinergetics DH-21 and Aqua Breeze II) act similar to axial flow designed canisters and maintain a low asymptotic level of mixed chamber CO_2 see runs 14 and 27 (Figures 14 and 21).

As CO_2 production rates inside a chamber rise to moderate or high levels the radial flow canisters and to a certain degree the axial flow canisters, fail to maintain the low asymptotic mixed chamber CO_2 level. The mixed chamber CO_2 level begins to rise at a rate dependent on CO_2 production rate and chamber volume. A greater CO_2 production rate or a smaller chamber volume will increase the chamber mixed CO_2 concentration more rapidly. This effect can readily be seen in the CO_2 scrubber runs where the CO_2 add rate was varied with other parameters being held constant. The tendency for mixed chamber CO_2 to rise more quickly in a smaller chamber volume becomes a simple mathematical equation of CO_2 addition, removal, and accumulation per liter of chamber volume.

All scrubbers perform better at shallower depths 1.91 ATA as compared to 6.0 ATA but the radial flow design with higher actual air flow has made the depth variable less pronounced (Tables 1 and 2).

Canister breakthrough is an arbitrary term given to a specific point during the gradual rise in canister effluent PCO_2. Canister duration is the time required to reach canister breakthrough. Since the ultimate purpose of the canister is to keep chamber PCO_2 at acceptable levels, the canister breakthrough should be an effleunt PCO_2 which will still allow chamber PCO_2 to remain at or below 1.5% SEV, the recommended maximum for chambers stated in the U.S. Navy Diving Manual (2). Defining canister breakthrough as that point when canister effluent is 0.5% SEV meets this goal and is a commonly used reference level (1,7). When applied as such, the breakthrough point in this study never produced mixed chamber CO_2 levels above 1.06% SEV.

Table 3 shows predicted canister durations for the three scrubbers compared in this study. The Aqua Breeze II is presented with single and double canisters, and it can be used with as many as three stacked canisters. Times are rounded to the nearest half hour. A major factor in the canister durations is the actual weight of H.P. Sodasorb used in the various canisters. The Kinergetics DH-10 and the single Aqua Breezed II carry similar loads at 3.75 kg. The Kinergetics DH-21 carries 5.27 kg of H.P. Sodasorb and the double canister Aqua Breeze II carries 7.49 kg. The single canister Aqua Breeze II configuration should not be used where moderate to high CO_2 production is expected. In the limited setting of a single tender and patient on an uncomplicated treatment, or two patients breathing oxygen with an overboard oxygen and CO_2 dump system, the single canister Aqua Breeze II would be appropriate if careful and consistent chamber oxygen and CO_2 levels could be measured.

Indeed, chamber oxygen and carbon dioxide levels should always be monitored when using the CO_2 scrubbers. Table 3 simply serves as a guideline for chamber operators in stocking HP Sodasorb, and should not be used in lieu of CO_2 monitoring equipment. Various factors will influence the actual canister durations. Durations are expected to be longer if there are fewer chamber occupants, if an oxygen built in breathing system with an overboard dump is used, or if the chamber is ventilated. Cold temperatures, inadequate packing of the canister, and increased CO_2 production from chamber occupants may shorten the duration. The best method of determining when to change canister contents operationally is by monitoring mixed chamber PCO_2, and absorbent should be changed when the value approaches 1.5% SEV. If canister changes are being made more frequently than predicted by Table 3 the operator should trouble shoot such areas as the scrubber fan for correct flow, adequacy of absorbent packing, expiration date and moisture content of H.P. Sodasorb.

If mixed chamber CO_2 levels cannot be kept below 1.5% SEV for known (e.g. tenders are working hard at resuscitation) or unknown reasons then supplementary ventilation will be required.

Chamber CO_2 levels can be easily monitored with chemical detection tubes (e.g. Draeger CH 23501) or in the near future with electronic CO_2 monitors currently under evaluation at NEDU. It should be noted that estimated canister durations in this study are based on a scrubber effluent PCO_2 of 0.5% SEV. Using a mixed chamber PCO_2 of 1.5% SEV as an indication to change canister absorbents, may result in canister durations longer than those in Table 3 even if conditions are similar to those in the study. The duration may be shorter for conditions of cold atmosphere, low humidity, outdated or ineffective Sodasorb, or unplanned high CO_2 production rates by occupants.

The radial flow designs of the Kinergetics DH-21 and the Aqua Breeze II (tested in the double canister configuration) allowed effective use of the Sodasorb absorbing capabilities. Complete (100%) efficiency of the Sodasorb-CO_2 reaction would result in .497 grams of CO_2 scrubbed for each gram of absorbent used (8). The DH-21 showed a maximum efficiency of 66% in run #14 (Figure 14) and the double canister Aqua Breeze II attained 45% efficiency in run #33 (Figure 21). Efficiencies on both scrubbers as low as 15% were seen in CO_2 overload situations such as runs #9 and #36 (Figures 14 and 21 respectively).

It can readily be discerned from Table 2 that all scrubbers had good effective scrubbing air flow and effectively circulated the chamber atmosphere. The high actual flow rates of the Kinergetics DH-21 and single canister Aqua Breeze II reduce the air residence time in the canister absorbent bed and therefore reduce the amount or fraction of CO_2 removed with each pass of air through the canister. This problem seemed to improve some with increased gas density at 6.0 ATA (165 FSW). The addition of the second canister on the Aqua Breeze II greatly increased the fraction of CO_2 removed from the air with each pass but this may have actually deteriorated with increased gas density at 6.0 ATA (165 FSW).

V. CONCLUSIONS

Standards and Bench Testing

With minor exceptions, both the Kinergetics DH-21 and Aqua Breeze II DLRC CO2 Scrubbers are suitable for shore-based hyperbaric use. The minor exceptions involve recommendations to augment personnel safety, increase usefulness of operating and maintenance manuals, and in the case of the Kinergetics DH-21 to exert better quality control on design and workmanship.

The Aqua Breeze II DLRC CO_2 Scrubber is suitable for shipboard hyperbaric use. The deficient design and workmanship of the Kinergetics DH-21 does not hold up to the rigors of a simulated shipboard environment.

Operating Characteristics

Canister durations for the Kinergetic DH-21 and double canister Aqua Breeze II DLRC CO2 scrubbers were found to be; 3.5 hours at 30 FSW and 60 FSW, with 3.0 hours at 165 FSW for the DH-21; 9.5 hours at 30 FSW, 8.5 hours at 60 FSW, and 5.5 hours at 165 FSW for the double canister Aqua Breeze II. The single canister Aqua Breeze II was found useful only for selected DLRC applications. Operationally, mixed chamber PCO_2 levels, rather than expected canister durations, should be monitored and canister contents changed when mixed chamber PCO_2 levels reach 1.5% SEV. The operational canister duration time may be shorter or longer than found in this study depending on the numerous variables addressed in the Discussion section.

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5. Blockwick, T.N.: The Evaluation of the Beckman Model "C" and the Beckman Model "D" Oxygen Analyzers for Accuracy, Simplicity of Operation, and Other Characteristics Under Various Conditions of Motion and Inclination, Navy Experimental Diving Unit Report 3-50, 26 April 1950.

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7. Bennett, P.B. and Elliott, D.H. (Eds): The Physiology and Medicine of Diving, Third Edition, Bailliere Tindall, London, 1982.

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TABLE 1

Duration of Time to Canister Effluent CO_2
Tensions of 0.5% SEV and 1.0% SEV
in Minutes Mixed Chamber CO_2 Tension in (% SEV)

DEPTH ATA (FSW)	KINERGETICS DH-21 0.5% SEV	1.0% SEV	Aqua Breeze II (Single) 0.5% SEV	1.0% SEV	Aqua Breeze II (Double) 0.5% SEV	1.0% SEV
1.91	232(.625)	421(1.12)	71(.57)	149(1.08)	556(.89)	665(1.40)
(30)	182(.62)	368(1.12)	61(.58)	136(1.10)	599(.85)	692(1.32)
	184(.62)	381(1.11)	66*(.53)	142*(.91)	622(.84)	719(1.31)
Mean	199.3(.62)	390(1.12)	66(.56)	142.5(1.03)	592.3(.86)	692(1.34)
± S. D.	28.3(.005)	27.6 (.01)	7.1(.03)	9.2 (.12)	33.5 (.03)	27.0 (.06)
2.82	189(.60)	367(1.09)	87(.81)	135(1.30)	525(.86)	638(1.32)
(60)	234(.60)	411(1.09)	65(.68)	111(1.18)	542(.90)	643(1.38)
			90(.77)	148(1.22)	510(.88)	615(1.38)
Mean	211.5(.60)	389(1.09)	80.7(.75)	131.3(1.23)	525.7(.88)	632(1.36)
± S. D.	31.8 (0.0)	31.1 (0.0)	13.7 (.07)	18.8 (.07)	16.0 (.02)	14.9 (.04)
6.00	180(.60)	290(1.10)	64(.77)	93(1.28)	342(.975)	478(1.42)
(165)	175(.60)	273(1.11)	64*(.90)	93*(>1.05)	342*(.91)	478*(1.35)
	177*(.58)	281*(.97)			342*(1.06)	478*(1.63)
Mean	177.5(.59)	281.5(1.06)	64(.84)	93(1.16)	342(98)	478(1.47)
± S. D.	3.5 (.01)	12.0 (.09)			(.08)	(.16)

Weight of SODASORB Mean	5.27 ± .10 Kg	3.67 ± .11 Kg	7.49 ± .26 Kg

Initial conditions:

Chamber CO_2 1.5% ± 0.07; Temperature 75°F (24°C) ± 3°F; Initial Relative Humidity 60% ± 10%; CO_2 Flow Rate 2 ℓ/min at ambient conditions (1.87SLPMD ± 0.18).

* Collection canual failures at these times required evaluation of mixed chamber CO_2 tensions at the mean time that previous, similar studies had reached levels of 0.5% and 1.0% SEV of canister effluent CO_2 tension.

TABLE 2

Effective Canister Flows Rate Liters Per Minute
(Calculated Actual Flow Rate)

DEPTH ATA (FSW)	KINERGETICS DH-10	KINERGETICS DH-21	AQUA BREEZE II (Single Canister)	AQUA BREEZE II (Double Canister)
1.91		262 (872)	251 (481)	362 (388)
(30)		287 (917)	310 (635)	415 (427)
		287 (990)	221	410 (410)
		315 (907)	215	
			258	
Mean	274(274)	288 (921)	251 (558)	396 (408)
S.D.		21.7 (49.6)	37.8	29.3 (19.6)
2.82	278	291 (927)	316 (681)	338 (352)
(60)	251	283 (962)	413 (1,033)	345 (360)
	260		471 (826)	353 (363)
	289			
Mean	270(270)	287 (944.5)	400 (847)	345 (358)
S.D.	17		78.3(176.9)	7.5 (5.7)
6.0		353 (971)	388 (665)	295 (367)
(165)		426 (1,101)	333 (605)	322 (417)
		385	310	312
				283
Mean		388 (1,036)	344 (635)	303 (392)
S.D.		36.6	40.1	17.4

TABLE 3

Canister Duration Estimates for Three DLRC Occupants
In Hours and Minutes

DEPTH ATA (FSW)	KINERGETICS DH-10	KINERGETICS DH-21	AQUA BREEZE II (Single Canister)	AQUA BREEZE II (Double Canister)
1.91 (30)	3.5 Hours 210 Minutes	3.5 Hour 210 Minutes	1.0 Hour 60 Minutes	9.5 Hours 570 Minutes
2.82 (60)	1.5 Hours 90 Minutes	3.5 Hour 210 Minutes	1.0 Hour 60 Minutes	8.5 Hours 510 Minutes
6.00 (165)	1.5 Hours 90 Minutes	3.0 Hour 180 Minutes	1.0 Hour 60 Minutes	5.5 Hours 330 Minutes

VIBRATION TEST SWEEP

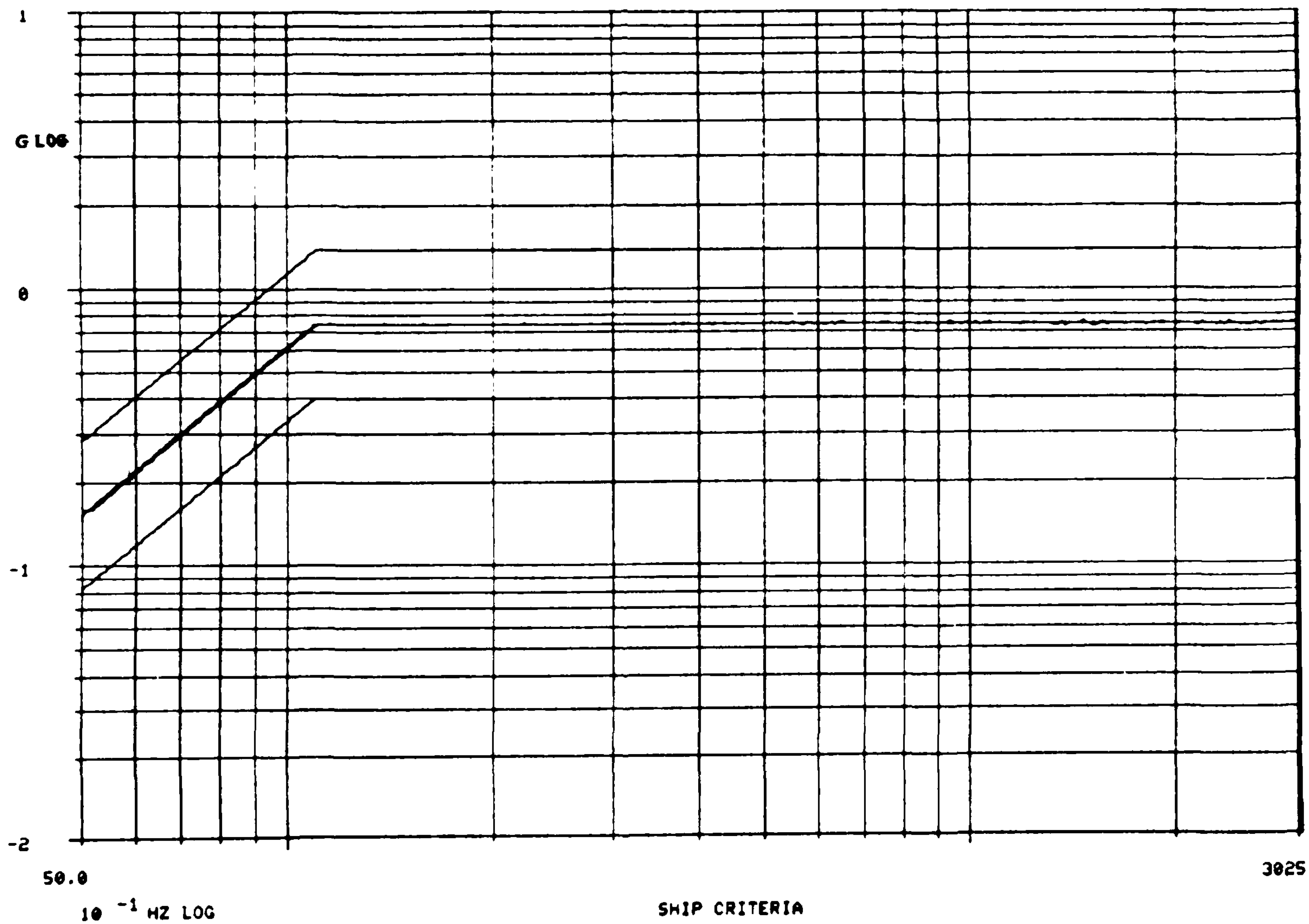

FIGURE 1

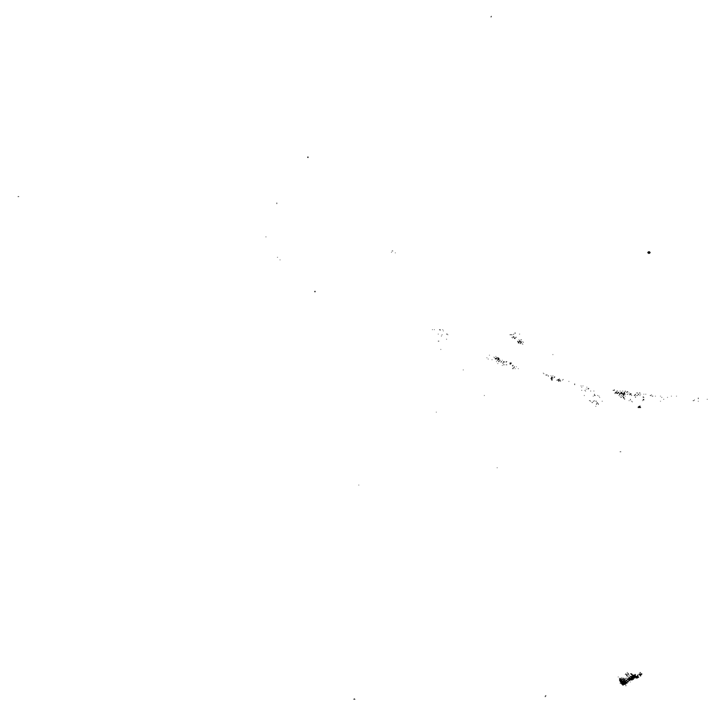

FIGURE 2

INSTRUMENTATION PENETRATOR

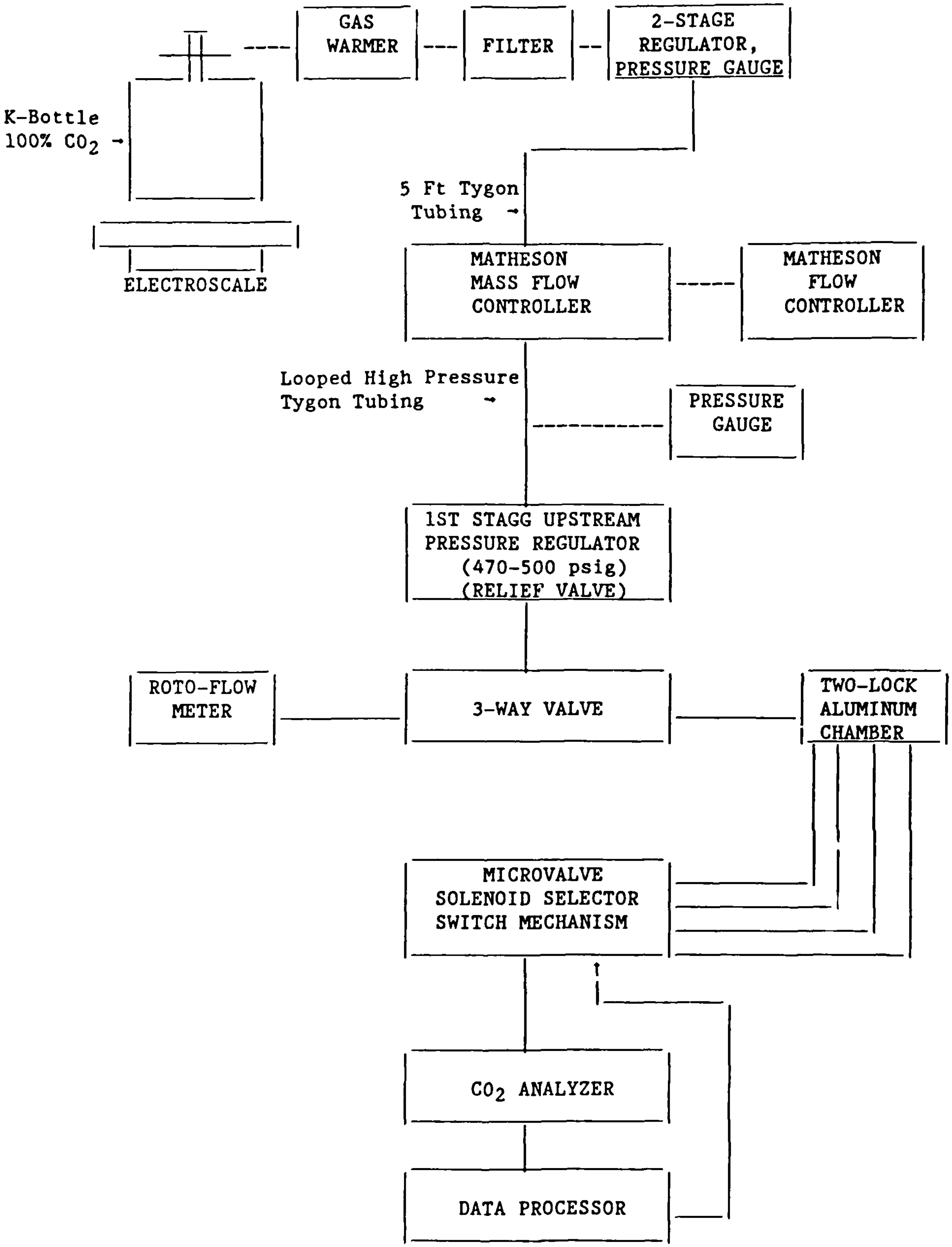

FIGURE 3

DIAGRAM OF CO_2 SCRUBBER TEST SET-UP

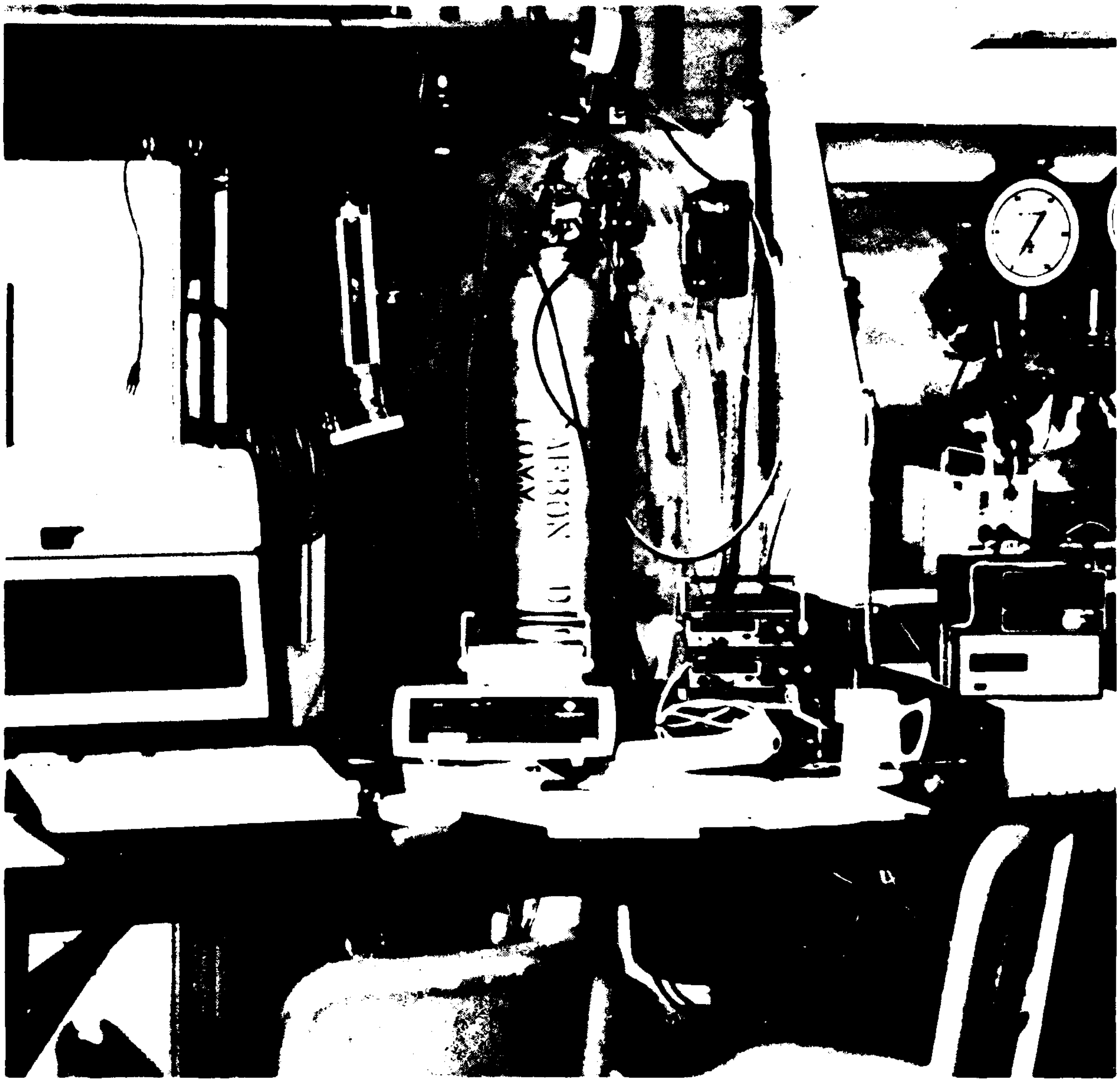

FIGURE 4

PICTURE OF CO_2 SCRUBBER TEST SET-UP

FIGURE 5

EFFECTIVE AND ACTUAL CO_2 SCRUBBER AIR FLOW RATE PROGRAM

```
PRP "FLOWPR"

01♦LBL "FLOWPR"
02 RCL 00
03 ENTER↑
04 "RUN= "
05 ARCL Y
06 AVIEW
07 RCL 03
08 ENTER↑
09 RCL 02
10 -
11 RCL 01
12 *
13 STO 01
14 RCL 05
15 ENTER↑
16 RCL 04
17 -
18 38.5
19 *
20 CHS
21 RCL 01
22 +
23 100
24 *
25 ENTER↑
26 STO 01
27 RCL 05
28 ENTER↑
29 RCL 04
30 -
31 2
32 /
33 RCL 04
34 +
35 STO 04
36 RCL 03
37 ENTER↑
38 RCL 02
39 -
40 RCL 04
41 *
42 STO 04
43 RCL 01
44 ENTER↑
45 RCL 04
46 /
47 ENTER↑
48 "EFF.FL="
49 ARCL Y
50 AVIEW
51 RCL 06
52 /
53 ENTER↑
54 "ACT.FL="
55 ARCL Y
56 AVIEW
57 END
```

VERTICAL AXIS VIBRATION TEST OF AQUA BREEZE II
CO_2 SCRUBBER (VERTICAL AXIS RESPONSE)

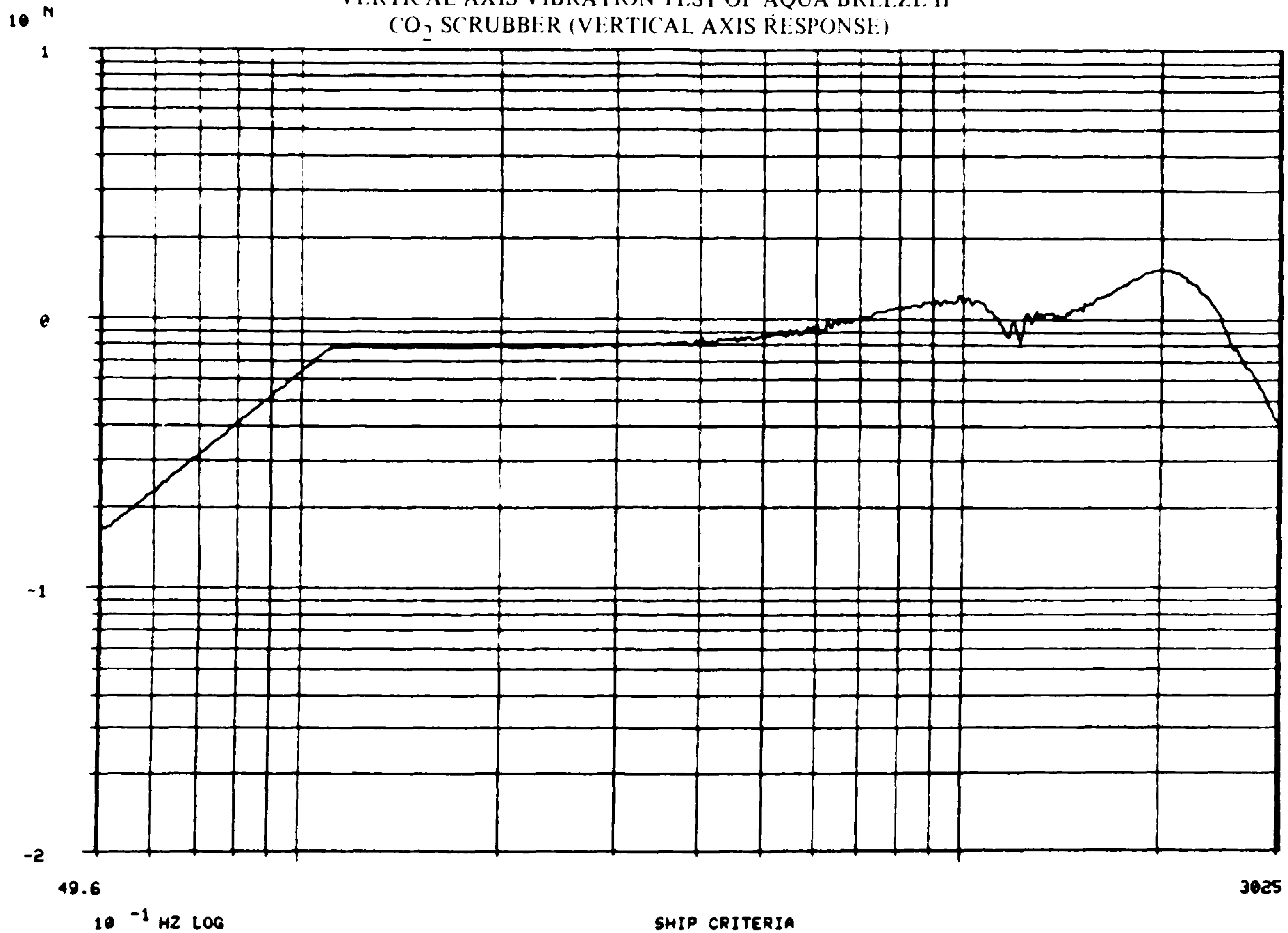

FIGURE 6

TANGENTIAL AXIS VIBRATION TEST OF AQUA BREEZE II
CO_2 SCRUBBER (VERTICAL AXIS RESPONSE)

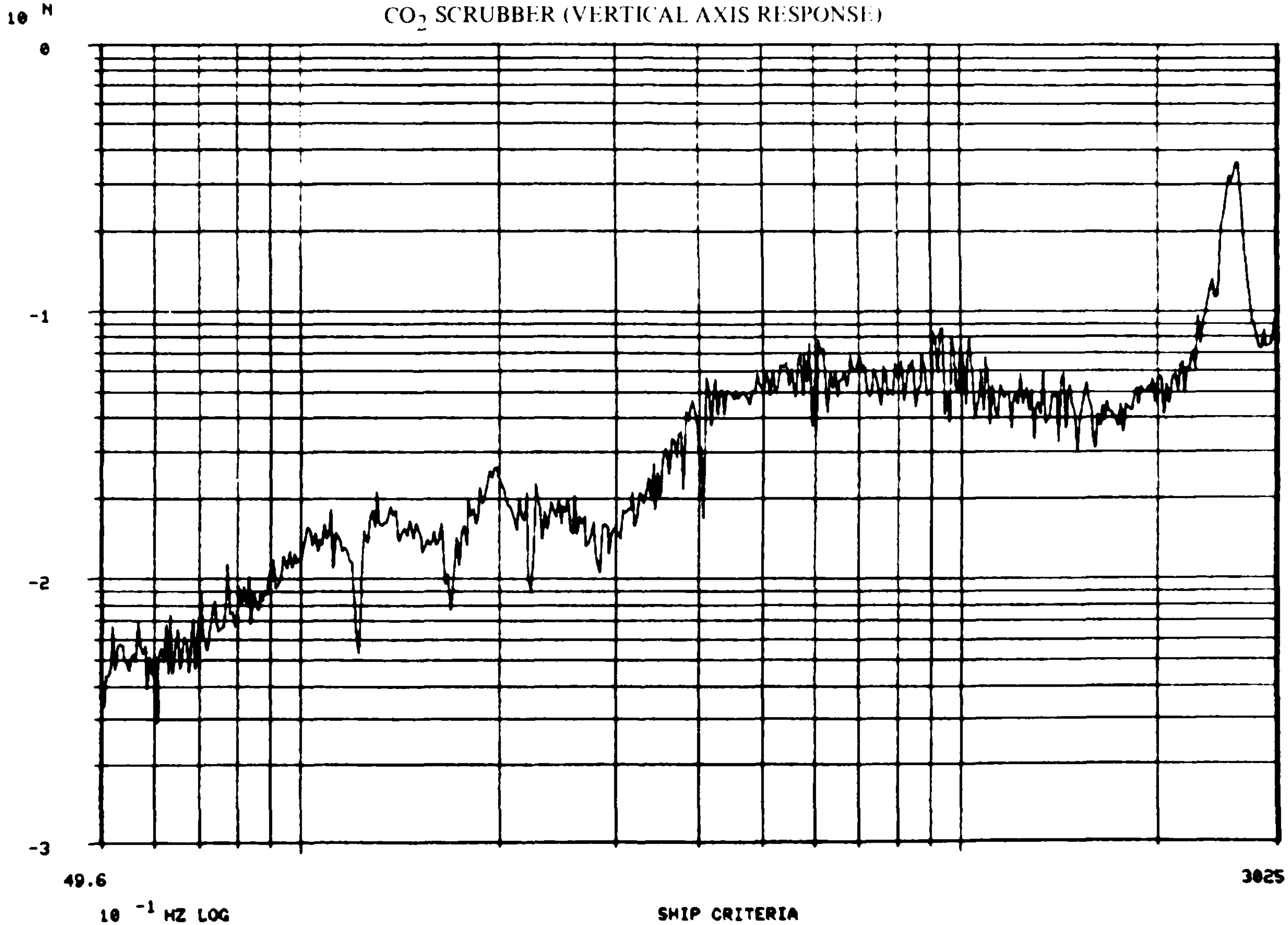

FIGURE 7

VERTICAL AXIS VIBRATION TEST OF KINERGETICS DH-21
CO_2 SCRUBBER (VERTICAL AXIS RESPONSE)

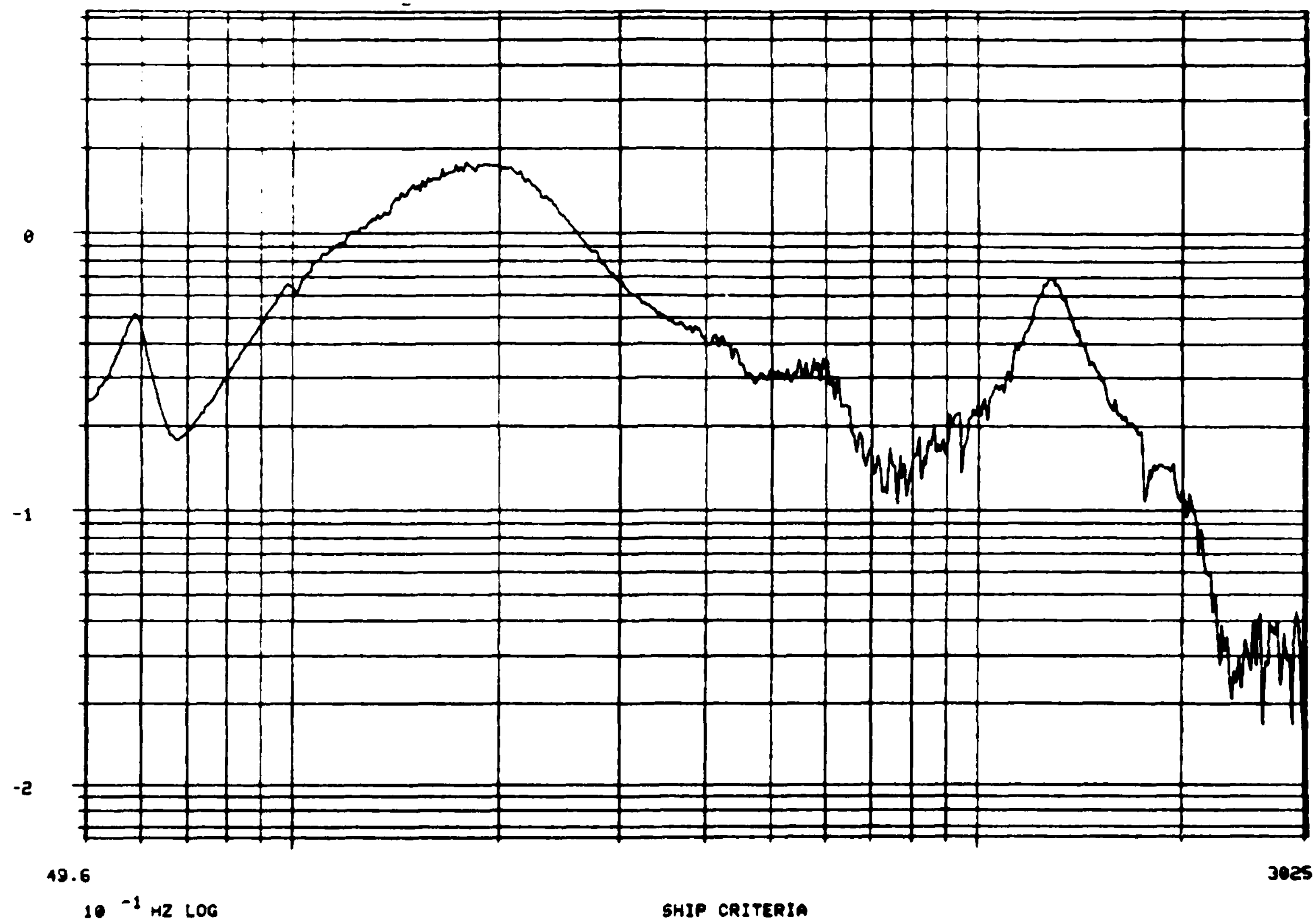

FIGURE 8

VERTICAL AXIS VIBRATION TEST OF KINERGETICS DH-21
CO_2 SCRUBBER (RADIAL AXIS RESPONSE)

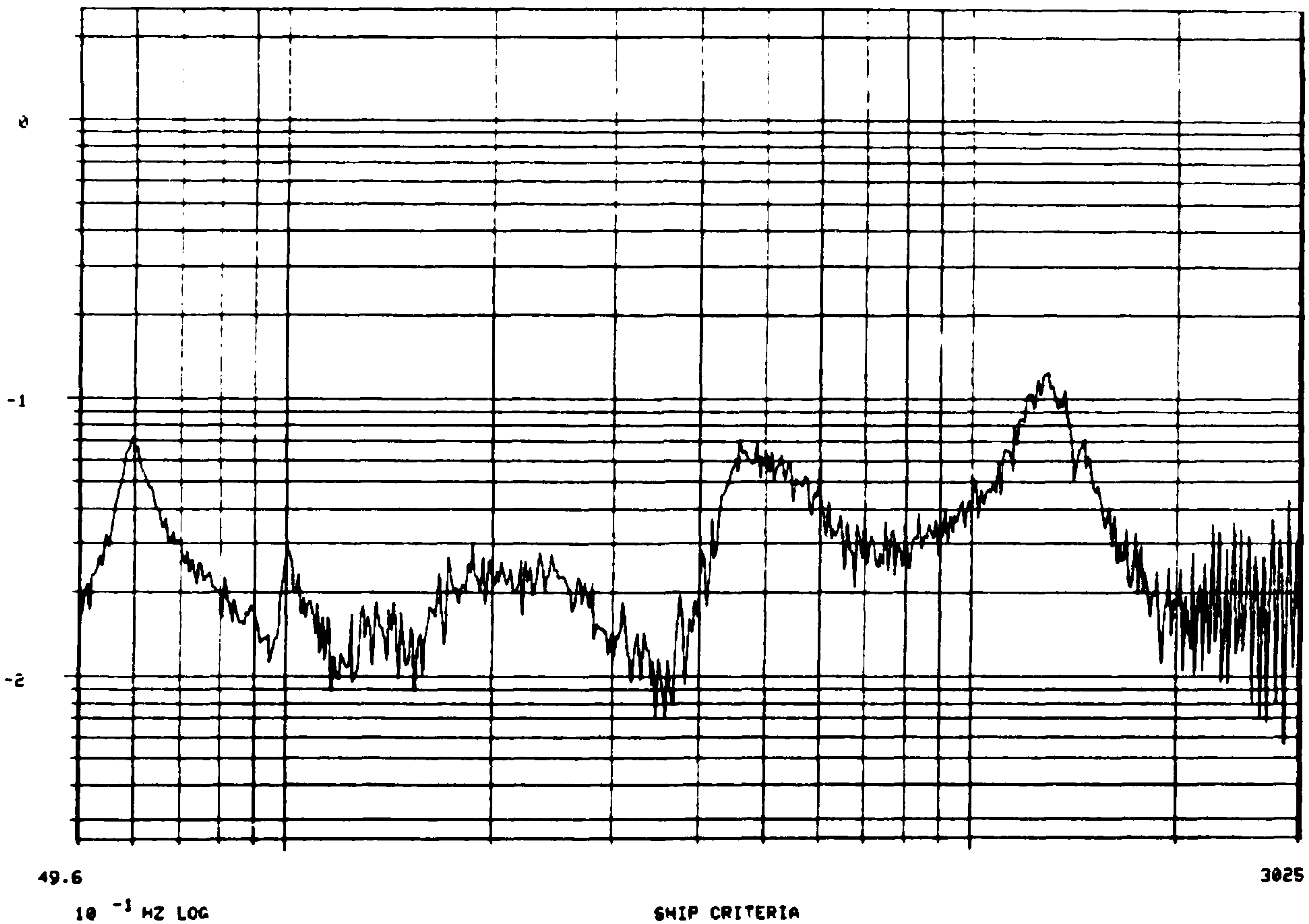

FIGURE 9

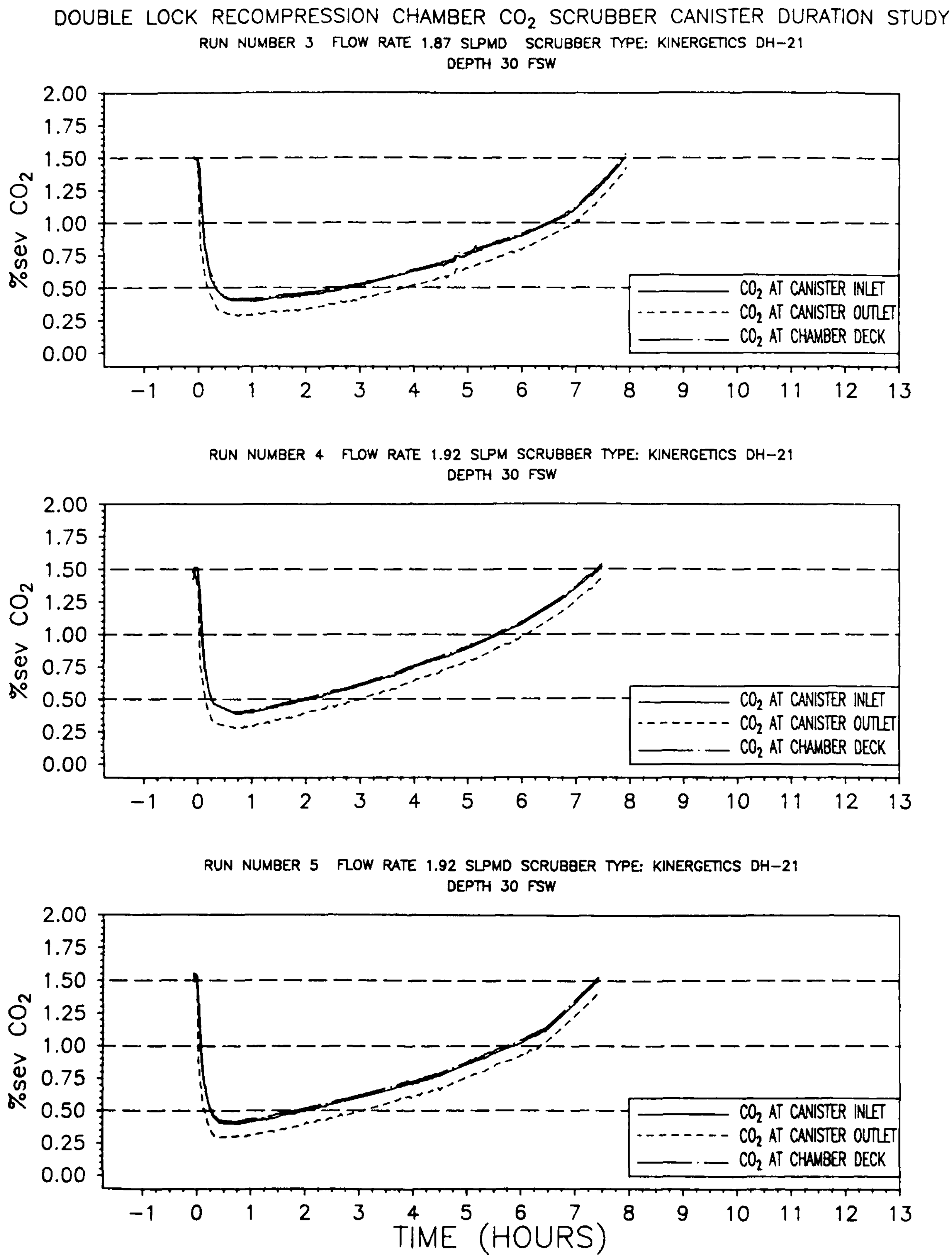
DOUBLE LOCK RECOMPRESSION CHAMBER CO_2 SCRUBBER CANISTER DURATION STUDY
RUN NUMBER 3 FLOW RATE 1.87 SLPMD SCRUBBER TYPE: KINERGETICS DH-21
DEPTH 30 FSW
%sev CO_2
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
RUN NUMBER 4 FLOW RATE 1.92 SLPM SCRUBBER TYPE: KINERGETICS DH-21
DEPTH 30 FSW
%sev CO_2
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
RUN NUMBER 5 FLOW RATE 1.92 SLPMD SCRUBBER TYPE: KINERGETICS DH-21
DEPTH 30 FSW
%sev CO_2
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
TIME (HOURS)

FIGURE 10

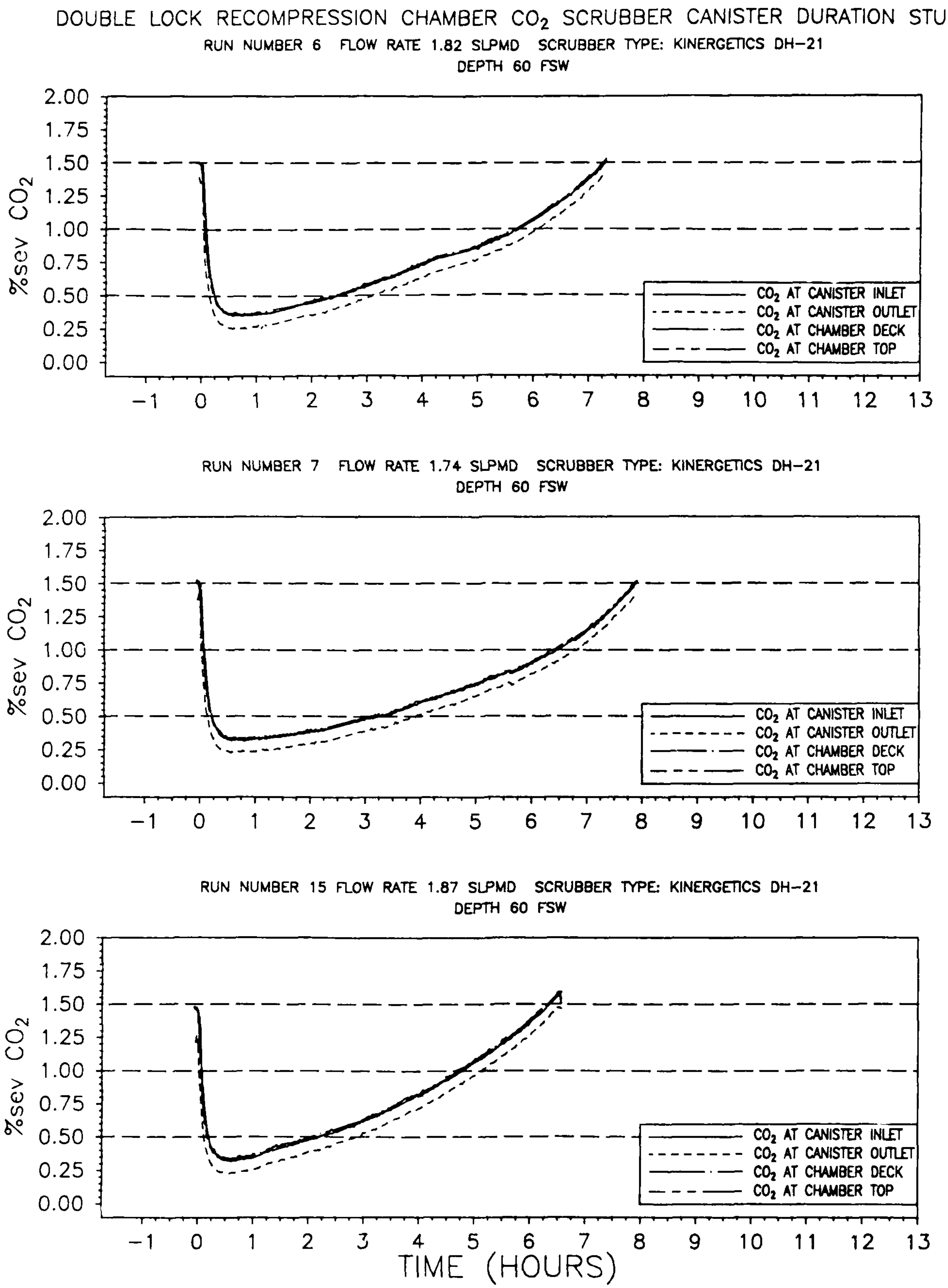
DOUBLE LOCK RECOMPRESSION CHAMBER CO_2 SCRUBBER CANISTER DURATION STUDY
RUN NUMBER 6 FLOW RATE 1.82 SLPMD SCRUBBER TYPE: KINERGETICS DH-21
DEPTH 60 FSW
%sev CO_2
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
RUN NUMBER 7 FLOW RATE 1.74 SLPMD SCRUBBER TYPE: KINERGETICS DH-21
DEPTH 60 FSW
%sev CO_2
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
RUN NUMBER 15 FLOW RATE 1.87 SLPMD SCRUBBER TYPE: KINERGETICS DH-21
DEPTH 60 FSW
%sev CO_2
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
TIME (HOURS)

FIGURE 11

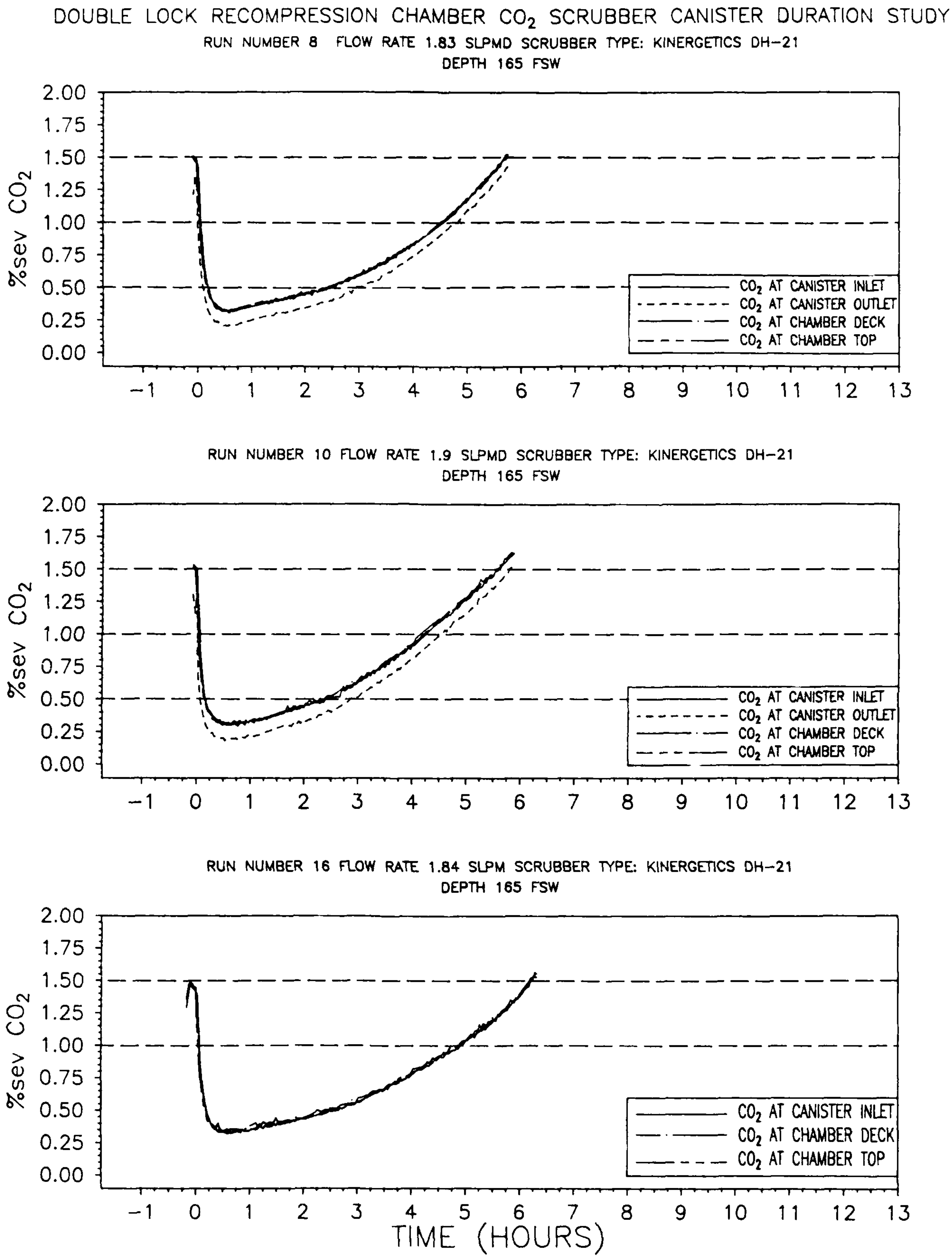
DOUBLE LOCK RECOMPRESSION CHAMBER CO_2 SCRUBBER CANISTER DURATION STUDY
RUN NUMBER 8 FLOW RATE 1.83 SLPMD SCRUBBER TYPE: KINERGETICS DH-21
DEPTH 165 FSW
%sev CO_2
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
RUN NUMBER 10 FLOW RATE 1.9 SLPMD SCRUBBER TYPE: KINERGETICS DH-21
DEPTH 165 FSW
%sev CO_2
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
RUN NUMBER 16 FLOW RATE 1.84 SLPM SCRUBBER TYPE: KINERGETICS DH-21
DEPTH 165 FSW
%sev CO_2
CO_2 AT CANISTER INLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
TIME (HOURS)

FIGURE 12

DOUBLE LOCK RECOMPRESSION CHAMBER CO_2 SCRUBBER CANISTER DURATION STUDY

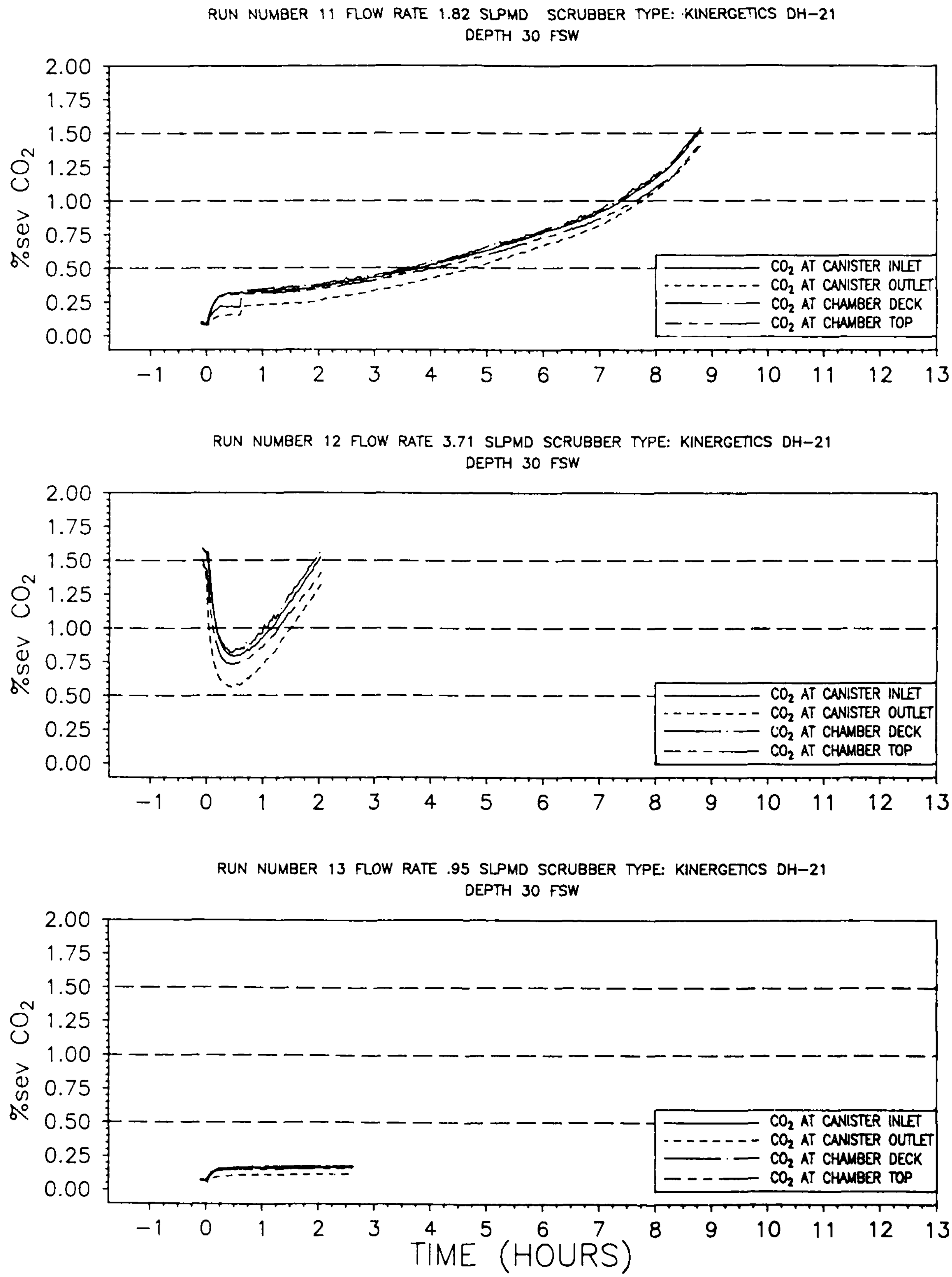

FIGURE 13

DOUBLE LOCK RECOMPRESSION CHAMBER CO_2 SCRUBBER CANISTER DURATION STUDY

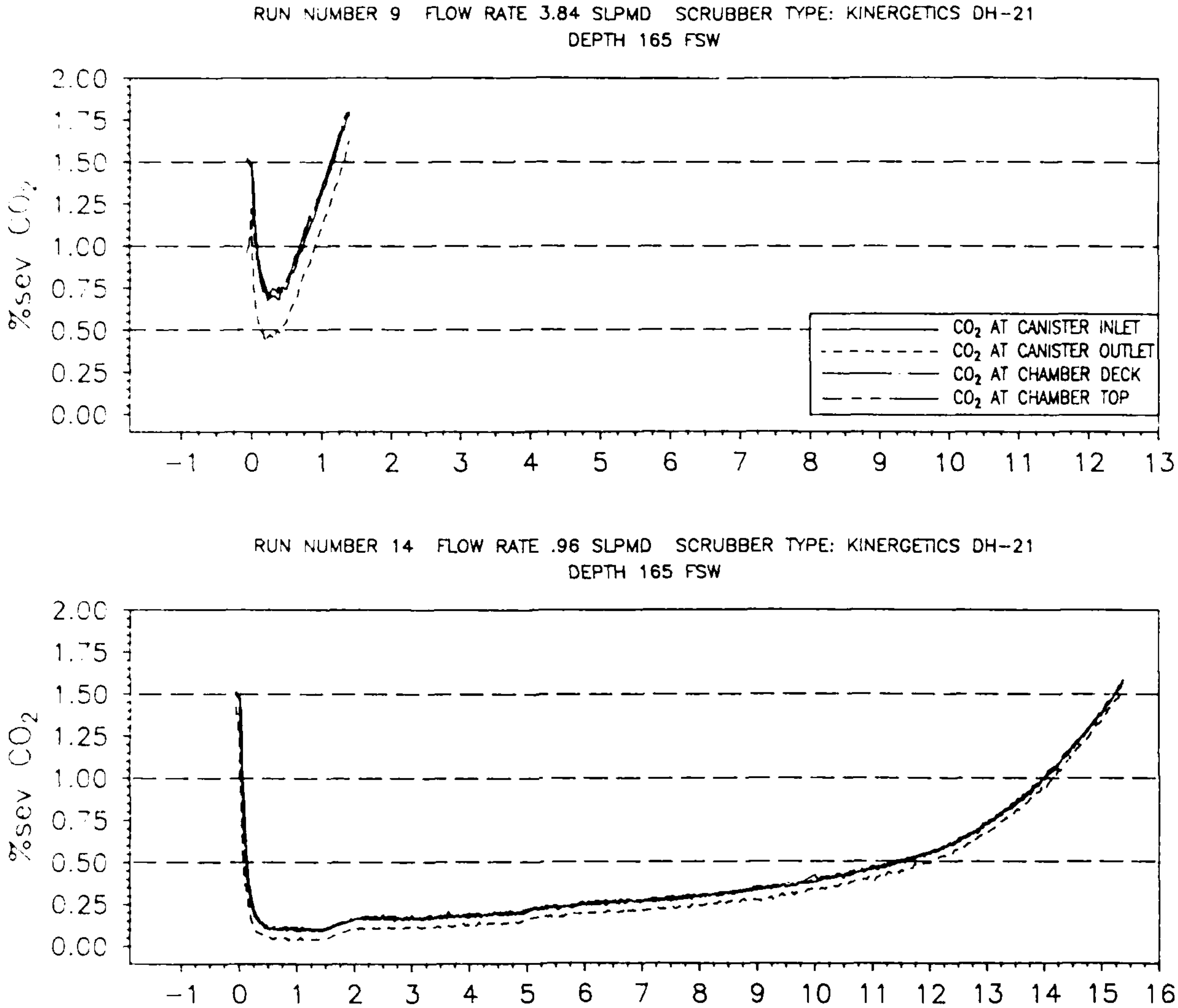

FIGURE 14

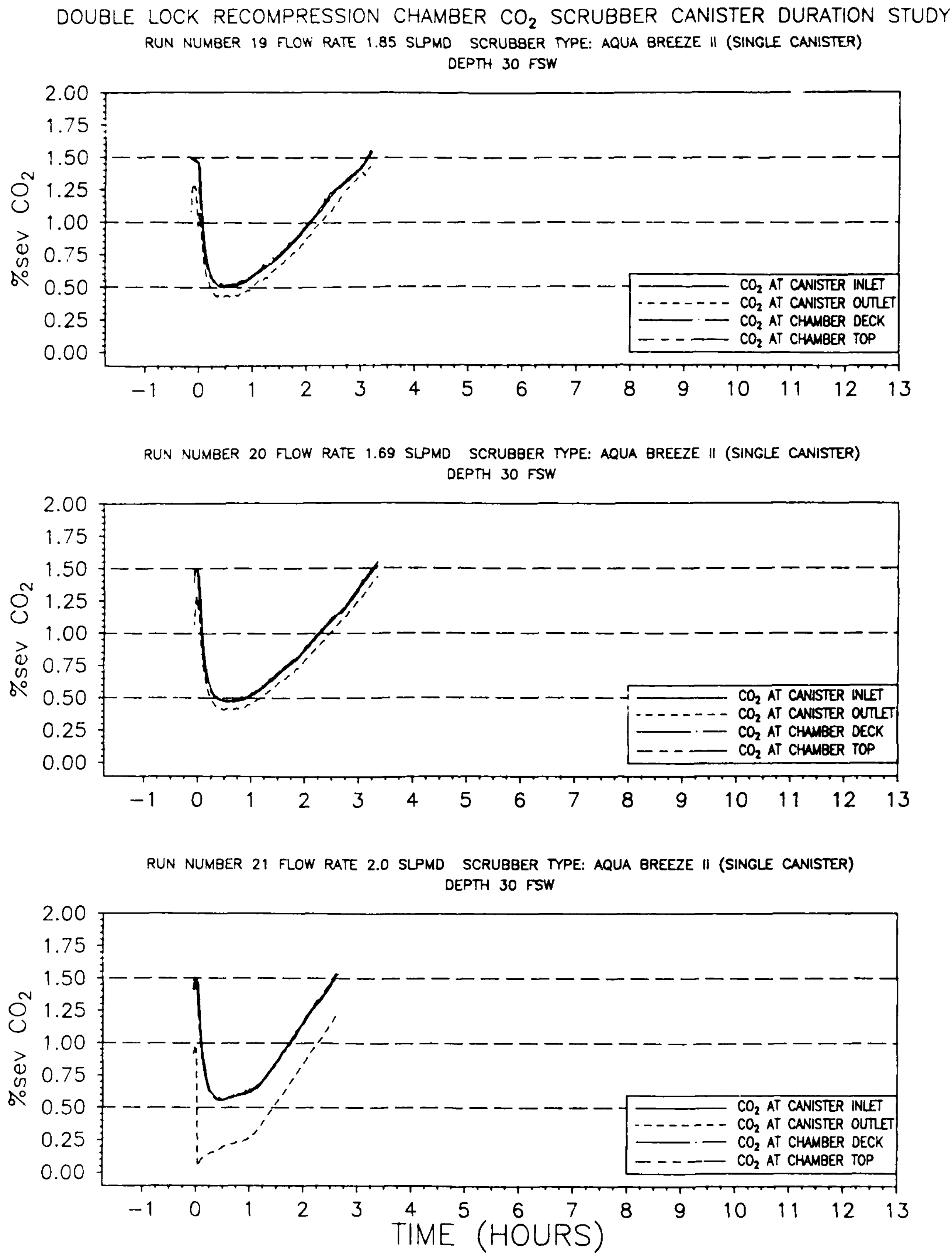
DOUBLE LOCK RECOMPRESSION CHAMBER CO_2 SCRUBBER CANISTER DURATION STUDY
RUN NUMBER 19 FLOW RATE 1.85 SLPMD SCRUBBER TYPE: AQUA BREEZE II (SINGLE CANISTER)
DEPTH 30 FSW
%sev CO_2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
−1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
RUN NUMBER 20 FLOW RATE 1.69 SLPMD SCRUBBER TYPE: AQUA BREEZE II (SINGLE CANISTER)
DEPTH 30 FSW
%sev CO_2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
−1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
RUN NUMBER 21 FLOW RATE 2.0 SLPMD SCRUBBER TYPE: AQUA BREEZE II (SINGLE CANISTER)
DEPTH 30 FSW
%sev CO_2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
−1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
TIME (HOURS)

FIGURE 15

DOUBLE LOCK RECOMPRESSION CHAMBER CO_2 SCRUBBER CANISTER DURATION STUDY

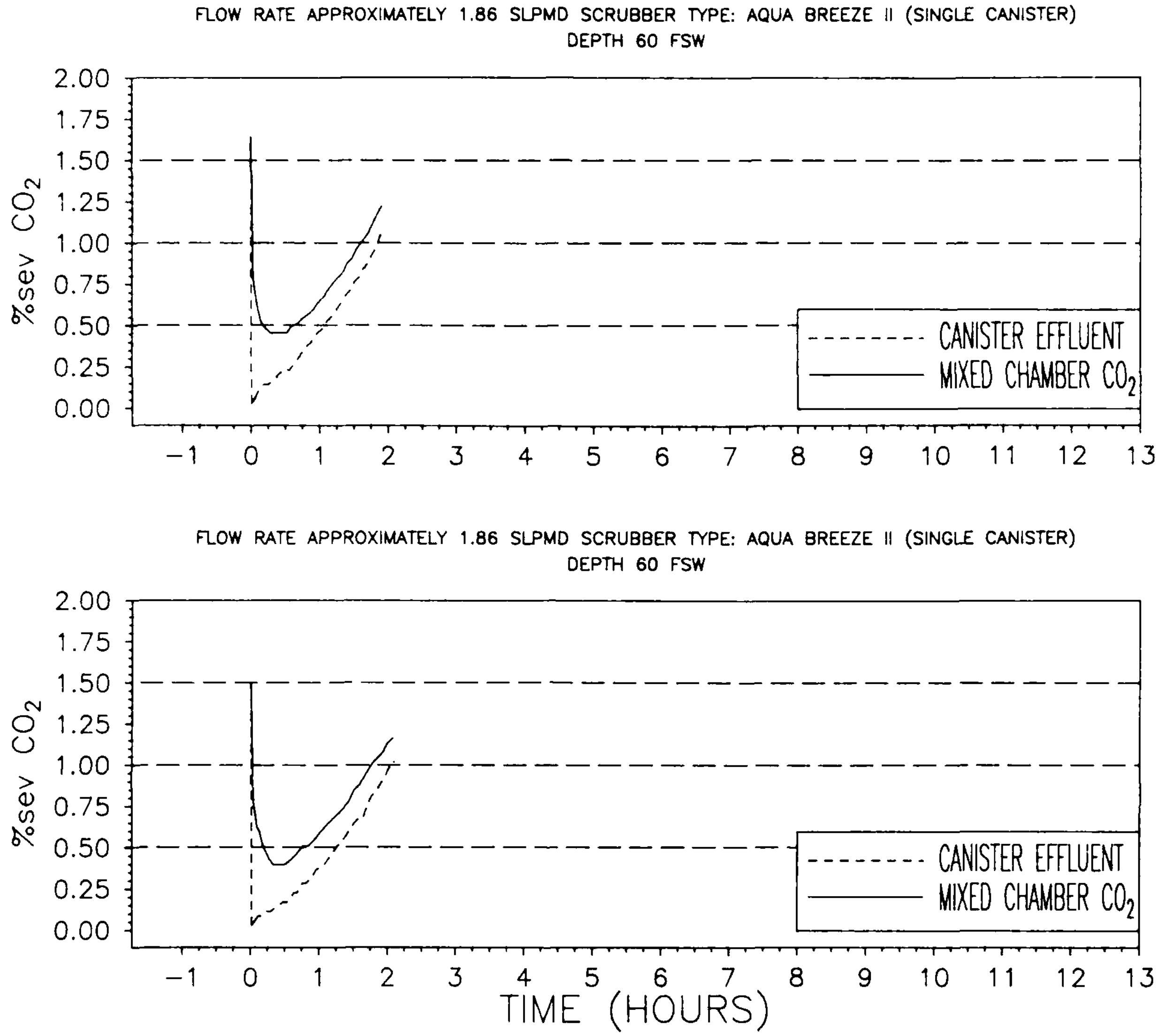

FIGURE 16

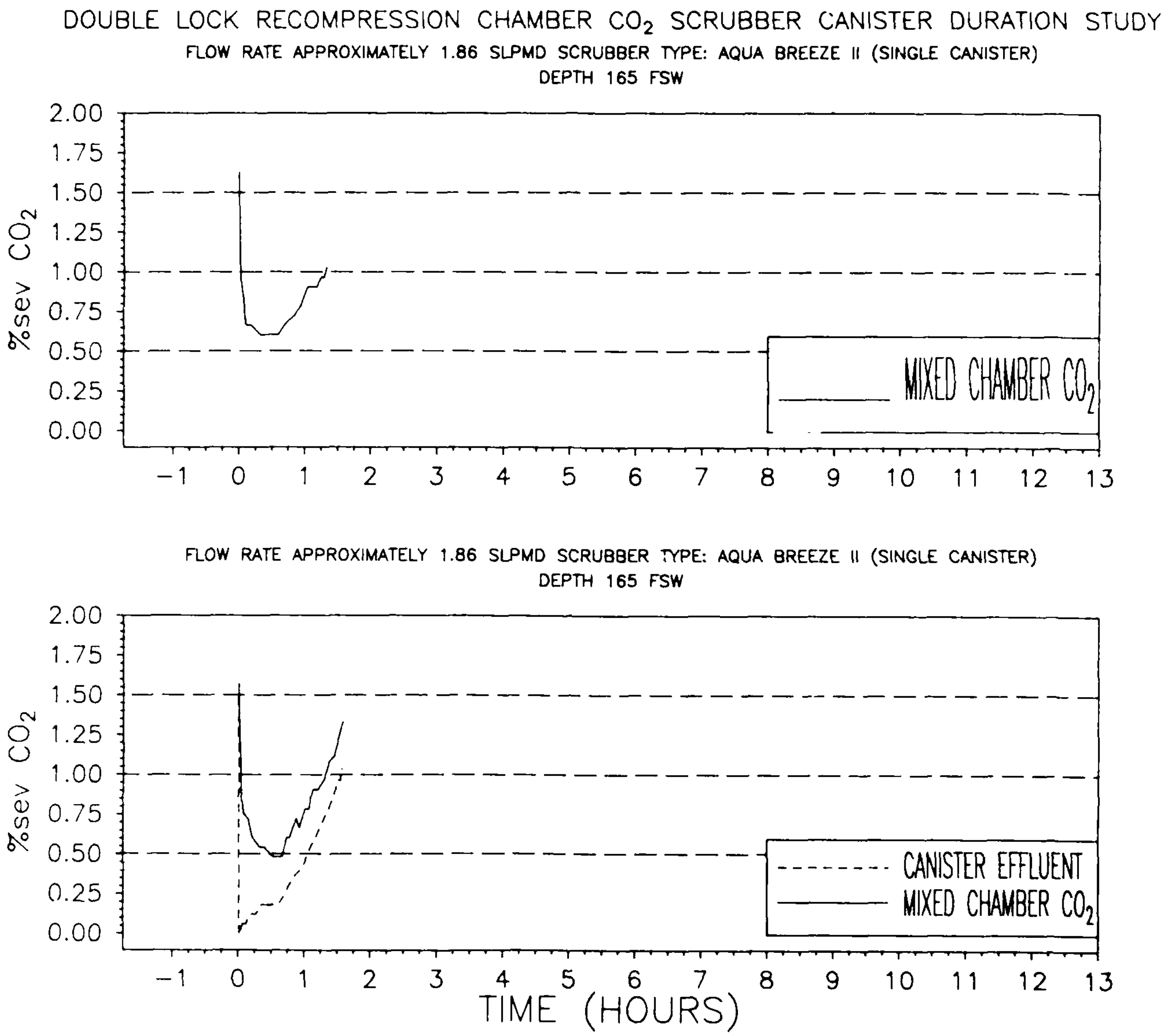
DOUBLE LOCK RECOMPRESSION CHAMBER CO_2 SCRUBBER CANISTER DURATION STUDY
FLOW RATE APPROXIMATELY 1.86 SLPMD SCRUBBER TYPE: AQUA BREEZE II (SINGLE CANISTER)
DEPTH 165 FSW
%sev CO_2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
MIXED CHAMBER CO_2
-1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
FLOW RATE APPROXIMATELY 1.86 SLPMD SCRUBBER TYPE: AQUA BREEZE II (SINGLE CANISTER)
DEPTH 165 FSW
%sev CO_2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
CANISTER EFFLUENT
MIXED CHAMBER CO_2
-1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
TIME (HOURS)

FIGURE 17

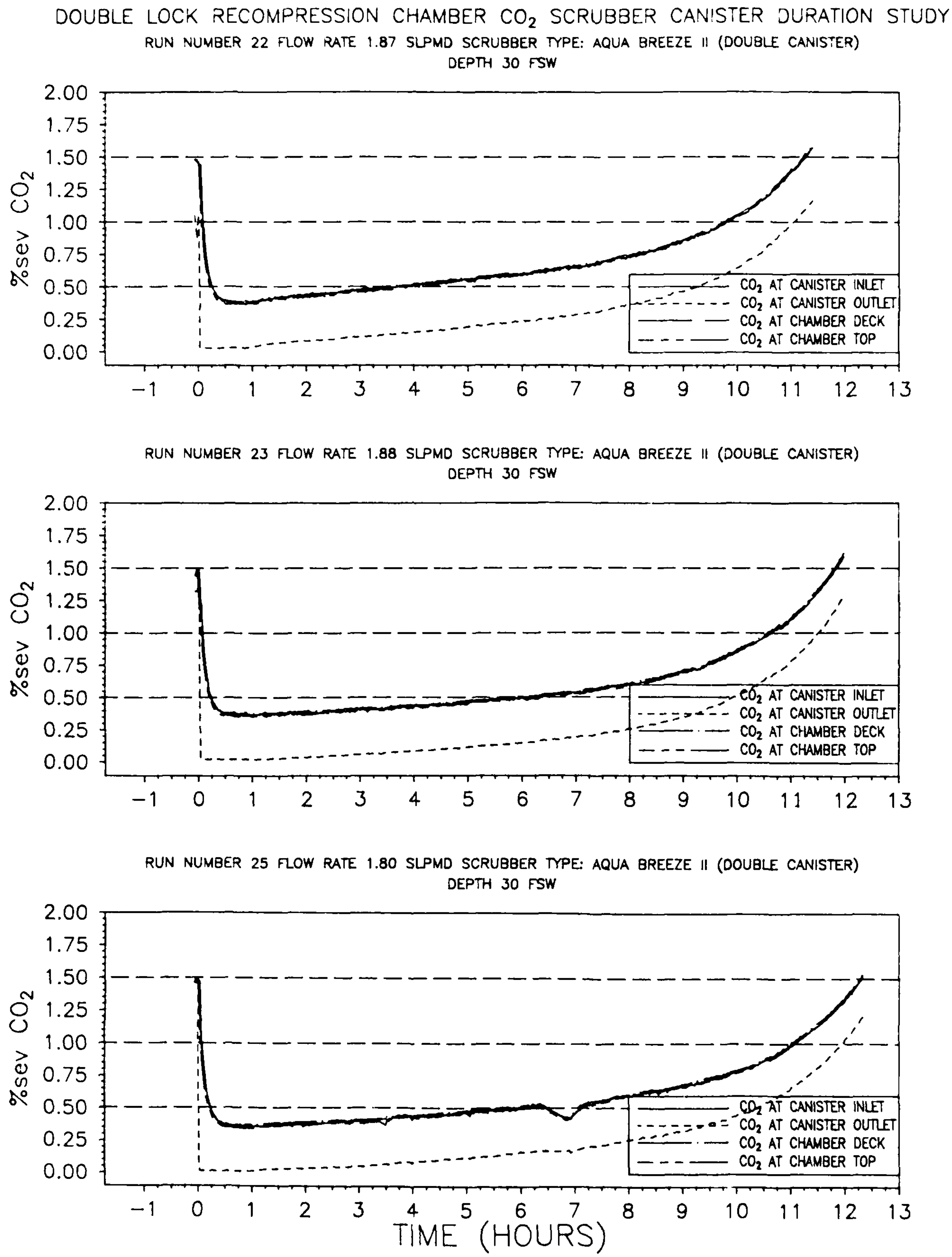
DOUBLE LOCK RECOMPRESSION CHAMBER CO_2 SCRUBBER CANISTER DURATION STUDY
RUN NUMBER 22 FLOW RATE 1.87 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 30 FSW
RUN NUMBER 23 FLOW RATE 1.88 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 30 FSW
RUN NUMBER 25 FLOW RATE 1.80 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 30 FSW
%sev CO_2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
−1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
TIME (HOURS)
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP

FIGURE 18

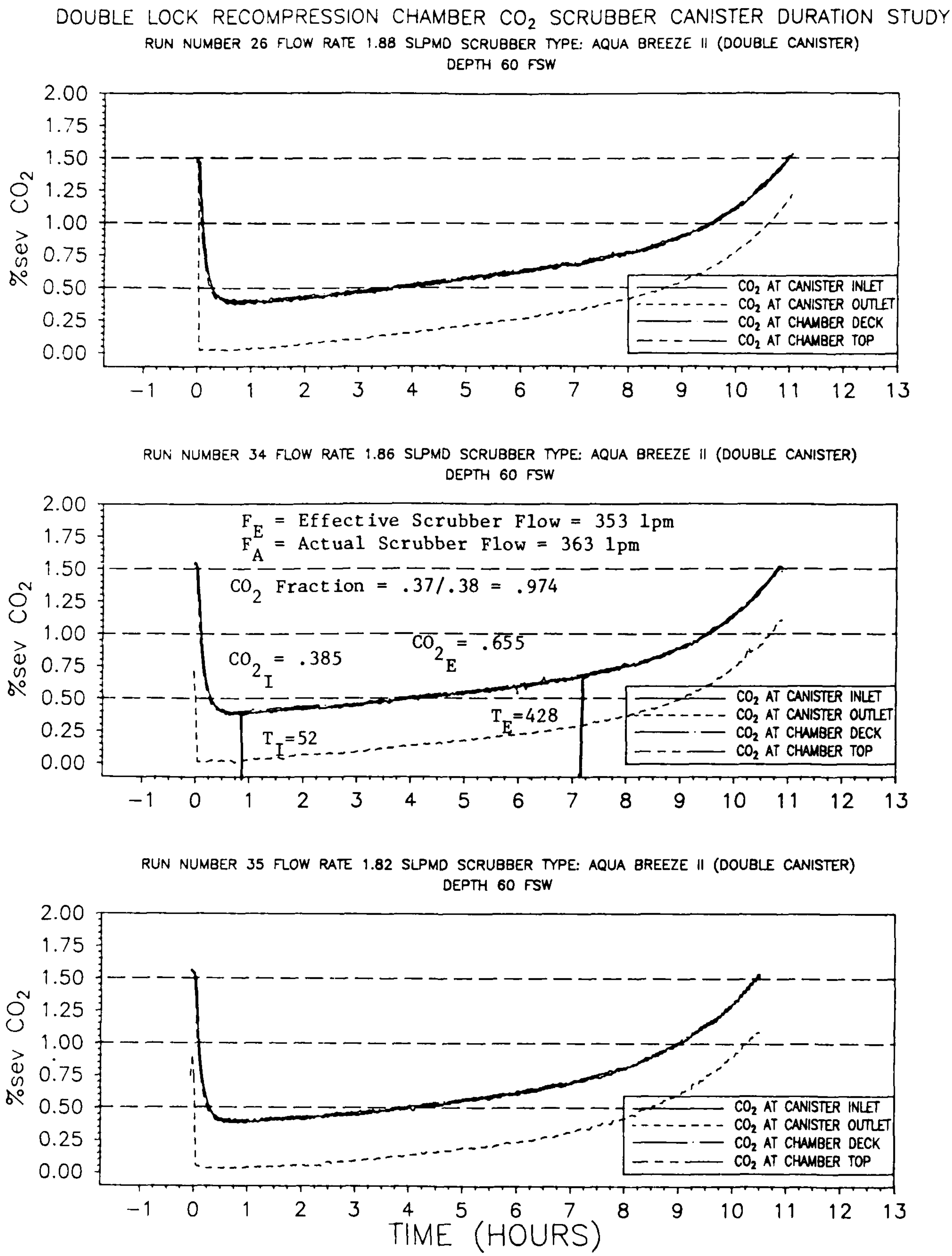
DOUBLE LOCK RECOMPRESSION CHAMBER CO2 SCRUBBER CANISTER DURATION STUDY
RUN NUMBER 26 FLOW RATE 1.88 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 60 FSW
%sev CO2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
CO2 AT CANISTER INLET
CO2 AT CANISTER OUTLET
CO2 AT CHAMBER DECK
CO2 AT CHAMBER TOP
RUN NUMBER 34 FLOW RATE 1.86 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 60 FSW
F_E = Effective Scrubber Flow = 353 lpm
F_A = Actual Scrubber Flow = 363 lpm
CO2 Fraction = .37/.38 = .974
CO2_E = .655
CO2_I = .385
T_E=428
T_I=52
%sev CO2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
CO2 AT CANISTER INLET
CO2 AT CANISTER OUTLET
CO2 AT CHAMBER DECK
CO2 AT CHAMBER TOP
RUN NUMBER 35 FLOW RATE 1.82 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 60 FSW
%sev CO2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
TIME (HOURS)
CO2 AT CANISTER INLET
CO2 AT CANISTER OUTLET
CO2 AT CHAMBER DECK
CO2 AT CHAMBER TOP

FIGURE 19

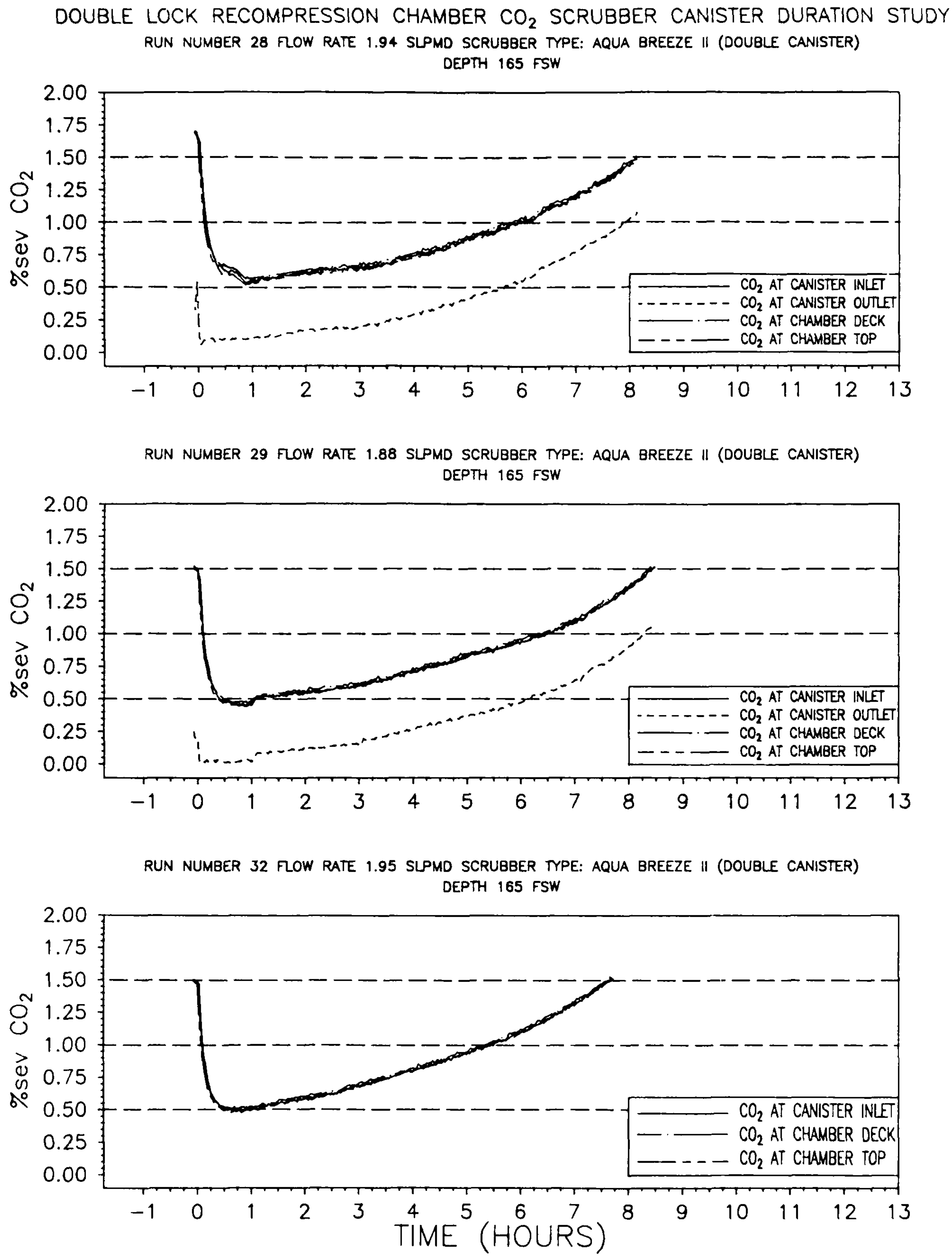
DOUBLE LOCK RECOMPRESSION CHAMBER CO_2 SCRUBBER CANISTER DURATION STUDY
RUN NUMBER 28 FLOW RATE 1.94 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 165 FSW
%sev CO_2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
−1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
RUN NUMBER 29 FLOW RATE 1.88 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 165 FSW
%sev CO_2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
−1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
RUN NUMBER 32 FLOW RATE 1.95 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 165 FSW
%sev CO_2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
CO_2 AT CANISTER INLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
−1 0 1 2 3 4 5 6 7 8 9 10 11 12 13
TIME (HOURS)

FIGURE 20

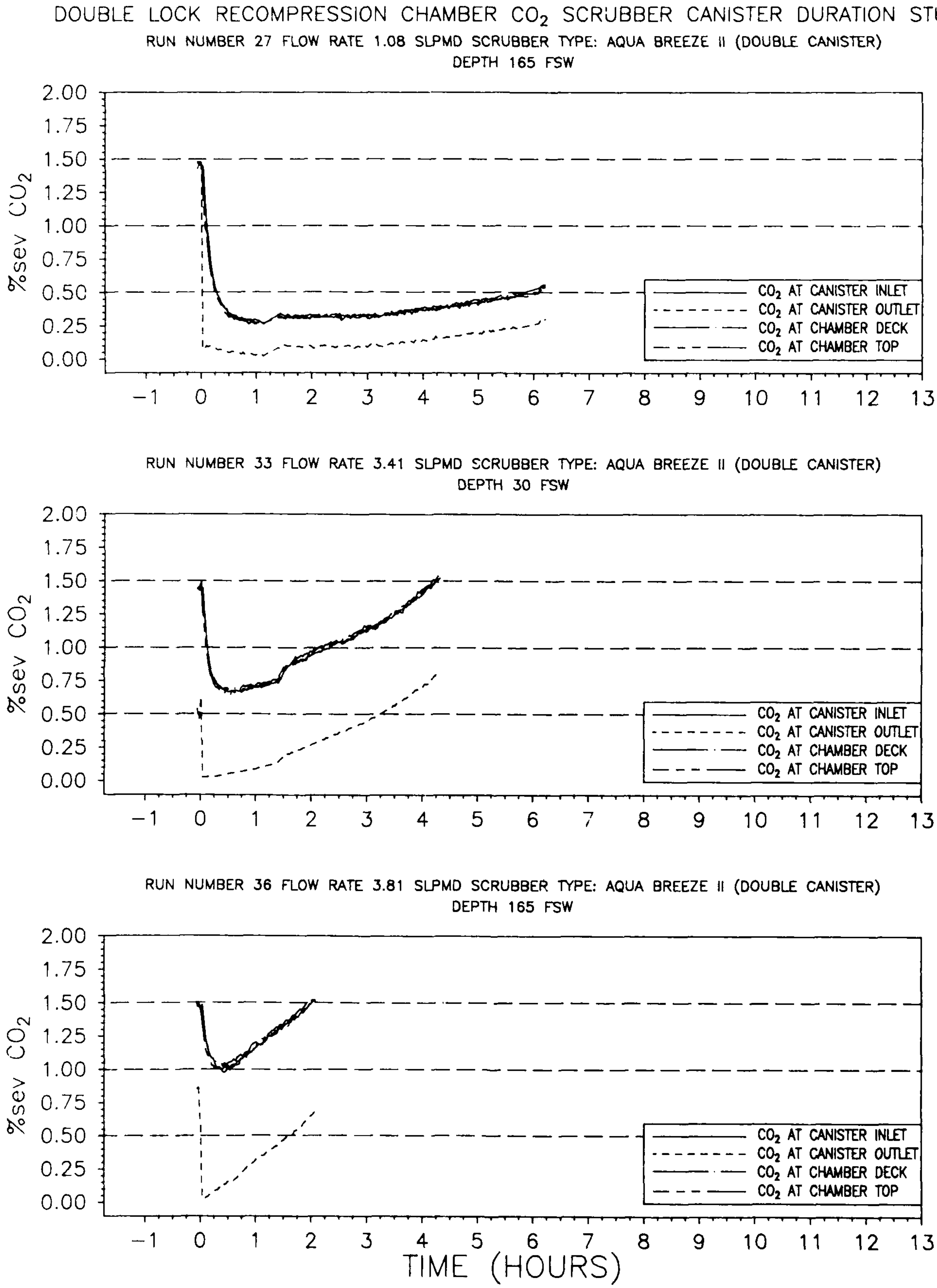
DOUBLE LOCK RECOMPRESSION CHAMBER CO_2 SCRUBBER CANISTER DURATION STUDY
RUN NUMBER 27 FLOW RATE 1.08 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 165 FSW
%sev CO_2
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
CO_2 AT CANISTER INLET
CO_2 AT CANISTER OUTLET
CO_2 AT CHAMBER DECK
CO_2 AT CHAMBER TOP
RUN NUMBER 33 FLOW RATE 3.41 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 30 FSW
RUN NUMBER 36 FLOW RATE 3.81 SLPMD SCRUBBER TYPE: AQUA BREEZE II (DOUBLE CANISTER)
DEPTH 165 FSW
TIME (HOURS)

FIGURE 21

ANNEX A
HUMAN FACTORS EVALUATION

I. Methodology

A human factors evaluation of the Kinergetics, Inc. Model DH-21 Carbon Dioxide (CO_2) scrubber and Aqua Services Aqua Breeze II CO_2 chamber scrubber was conducted in April, 1987. This evaluation consisted of an examination of the scrubbers mounted in the Navy Experimental Diving Unit's (NEDU) standard double lock recompression chamber. A review of the prototype Kinergetics manual dated March 1986 and photodocumentation of both scrubbers were undertaken also. Each article was evaluated using the guidelines set forth in Military Standard 1472-B (Human Engineering Design Criteria For Military Systems, Equipment and Facilities), Van Cott and Kinkade (1972), and Appendix 1 (Human Factors Engineering Evaluation of Carbon Dioxide Scrubbers).

II. General Comments

A. Kinergetics DH-21 CO_2 Scrubber

The DH-21 scrubber was mounted in the chamber IAW instructions provided in the accompanying manual (Figure 22). This scrubber appeared to be a simple unit to operate, and consisted of a motor attached to a mounting plate. A basket canister was attached to the motor housing. The motor powered a fan which drew the chamber atmosphere through the canister filled with CO_2 absorbent material.

The basket portion of the canister was made of malleable metal and was easily flexed with slight hand pressure (Figure 23). If dropped, the basket appeared susceptible to easy deformation. The top edge of the canister was very sharp, and would cause lacerations of the skin if care was not exerted during the handling and filling of the canister (Figure 24). Another sharp edge was also found on the lid of the canister, which also is a potential source of injury. There was a lack of a contoured edge around the lid, and thus an ill-fitting seal may result when the absorbent filled canister is mounted. Small particles of carbon dioxide absorbent (e.g. Sodasorb®) can squeeze through the circles in the side of the canister basket (Figure 25). Soiling of the chamber interior and suspension of CO_2 particulate matter during gas movement in the chamber can result and pose a hazard to the chamber occupants, especially during the longer treatment tables. Canister latches appeared to be constructed of molded steel wire and fit over the top lid of the canister and under the mating rim of the motor housing (Figure 26). These latches were non-adjustable, appeared susceptible to distortion with repeated use, and were difficult to unlatch without incurring trauma to the fingers (due to "snap-back" when releasing the latches). Further, the canister lid was only slightly raised around its outer edge to provide a friction base against which the latch wire exerts pressure (Figure 23).

The electrical feed to the motor was encased in a molded connector and securely fastened. An allen wrench was required for access to the motor (Figure 27). Fan blades were located at the bottom of the housing. A screen guard was provided below the fan blades, but not above the fan blades. Inadvertent injury could occur if fingers were extended down into the housing with the motor running and the blades turning. A rubber gasket fit over the bottom frame, and formed a seal when the canister was placed upon it and latched (Figure 27). Due to the design of the canister, it was simple to align and the top and bottom cannot be confused easily.

DH-21 Recommendations:

(1) Canister basket should be either reinforced with ribs or constructed of heavier gauge material to minimize distortion.

(2) Top edge of canister basket should be dulled to prevent lacerations during handling.

(3) Outer edge of canister lid should be dulled to prevent lacerations during handling.

(4) Mesh presently used in canister basket should be replaced with smaller diameter hole mesh to prevent spillage of commonly used CO_2 absorbent.

(5) Canister latches should be re-designed to provide adjustable tension, and constructed with more surface area contacting the top of the canister lid.

(6) Manual for the scrubber should incorporate:

a. Photographs of key components.
b. Description of construction materials.
c. Operating procedures, including filling canister with absorbent.
d. System of measurement used in diagrams (e.g. cm or inches?).
e. Definitions of terms before using abbreviations (e.g. NPT).
f. Rationale for assertion that scrubber will last 35-40 man-hours, and what methods were used to determine and define "man-hours".
g. Troubleshooting schematics.

(7) Parts should be labeled; a permanent tag should be placed on the motor housing to warn of potential injury from the fan blades.

(8) A finger guard should be placed above the fan blade, or a contact switch which would prevent the blower from being started without the canister in place.

B. Aqua Breeze II CO_2 Scrubber

The Aqua Breeze II was mounted in the vertical position in the chamber (Figure 28). No operational manual accompanied this scrubber, and NEDU staff followed the verbal guidance of the manufacturer and a specification sheet in installation and operation; subsequently, the operations and maintenance manuals were received. This scrubber appears simple to operate, and consists of a motor enclosed in a housing which supports one or two canisters. The motor drives a fan which draws chamber atmosphere through the canister(s).

The two basket canisters received for evaluation were similar, though not identical in construction. Each canister was fabricated with sturdy support around the upper and lower openings, and with a relatively wide, flat, smooth and beveled upper edge where the canister lid attached to the canister (Figure 29). A fine weave wire mesh was applied to one side of a coarser, circular-holed metal mesh which comprised the outer shell of the canister. The two canisters provided for testing differed in construction metal, aluminum versus stainless steel, and in the hole-size of the exterior metal mesh (Figure 30). The Manufacturer has explained the stainless steel canister will be the production model. The canister appeared to be well-constructed, and an accidental drop-test of a canister from a height of one meter did not result in any observable damage or distortion to the canister. No discernable particles of CO_2 absorbent were able to escape through the fine wire mesh. Canister latches were constructed of pre-formed metal, were secure, were adjustable for reach, and operated easily (Figure 31). Latches were provided so that two canisters could be attached to each other. The lid of the canister was also pre-formed to fit securely into the canister (Figure 32).

Electrical power to the motor entered via a molded electrical connector (Figure 33). Access to the motor required allen and adjustable wrenches, and a slotted screw driver (Figure 34). This scrubber unit did not provide a protective screen to prevent finger or hand trauma from the blower's blades. A beveled surface on the motor housing provided for a secure fit of the canister regardless of the scrubber's orientation in the chamber (Figure 34).

Aqua-Breeze Recommendations:

(1) Manual section for troubleshooting of unit be written and evaluated.

(2) All parts should be labeled; a permanent tag should be placed on the motor housing to warn of possible hand injury from blower blades.

(3) A pressure activated cutoff switch should be installed to secure the motor when the canister is removed, or a blade guard installed on the canister housing.

III. APPENDIX 1 Review Comments

These comments refer to the headings found in the human factors checklist (Appendix 1).

A. Labels

Both scrubbers lacked labeling of parts, and were without warning tags.

B. Maintainability

Neither scrubber provided a protective top cover for the blower or for blades.

C. Safety

No written techniques for operating either scrubber were provided, nor were any precautions or guidelines provided for filling the canister with CO_2 absorbent material.

D. Training

It is essential for the safe, efficient use of hyperbaric chamber CO_2 scrubbers that clear instruction be provided for the handling of CO_2 absorbent material, the filling of canisters, and the disposal and identification of the material.

HUMAN FACTORS ENGINEERING
EVALUATION OF CHAMBER
CARBON DIOXIDE SCRUBBERS

	Kinergetics DH-21		Aqua Breeze II	
LABELS	YES	NO	YES	NO
Are the labels of the equipment located on or near the items which they identify, so as to eliminate confusion with other items or labels?		✓		✓
Do the equipment labels clearly and correctly describe the equipment?		✓		✓
Are there any problems with labels wearing off or becoming obscured by dirt and grime?		N/A		N/A
Are equipment cases either labeled or designed so as to make it obvious which way units are to be placed in them?		✓	✓	
WORKSPACE				
Is there adequate workspace in which to mount the canister?	✓		✓	
MAINTAINABILITY				
Are the units that are most critical to the system the most accessible for repair and replacement?	✓		✓	
Have guides, tracks, or stops been provided on the equipment where necessary to prevent damage to the equipment or personnel injury?		✓		✓
Do any bulkheads or brackets or other units interfere with removal or opening of covers on units within which work must be performed?		✓		✓
Can all on-site removable units be replaced with nothing more than tools available?	✓		✓	

MAINTAINABILITY (Cont)	Kinergetics DH-21		Aqua Breeze II	
	YES	NO	YES	NO
Are the test points on the equipment easily accessible?		N/A		N/A
Have sufficient test points been provided so that it is not necessary to disassemble the equipment in order to accomplish trouble-shooting?		N/A		N/A
Are all the test points on the equipment marked and easy to identify?		N/A		N/A
Does the equipment utilize standard test equipment?		N/A		N/A
During the operation or the maintenance of the equipment, are there any mechanical design features which interfered with your performance of the assigned tasks?		N/A		N/A

OPERATING PROCEDURES

Can the equipment be satisfactorily operated using the prescribed procedure?		✓	✓	
Does the equipment require almost continual monitoring?		✓		✓

MAINTENANCE

Are the procedures for any of the maintenance tasks difficult to follow or understand?		✓		✓
Are there any specific aspects of the maintenance tasks which are extremely difficult?		✓		✓
Are any of the following maintenance tasks fatiguing in any way?		✓		✓
Is the equipment easy to assemble and disassemble?	✓		✓	

SAFETY	Kinergetics DH-21		Aqua Breeze II	
	YES	NO	YES	NO
Are the techniques for operating the equipment different from those given in the manual?		N/A		N/A
Has the equipment been designed so that it is impossible to insert the wrong plug into a receptacle?		N/A		N/A
Have all the connecting plugs and receptacles been clearly identified by color coding or some other appropriate means?		N/A		N/A
Have warning placards been mounted on or near any equipment which presents a hazard to personnel?		✓		✓
For maintenance and operation activities where special protective clothing or equipment is required, are they clearly identified?		✓		✓
Do all controls which initiate a hazardous operation or condition require the prior operation of a related locking control?		✓		✓
Are the units in the equipment mounted so that you can gain access to them without danger from electrical charge, heat, moving parts, chemical contamination, radiation, or other hazards?	✓		✓	
Have all exposed edges and corners been rounded sufficiently to prevent injury to personnel?		✓	✓	
Have guards, grounds, interlocks and warning placards been provided to minimize the possibility of exposing personnel to dangerous voltages where ever necessary?		✓		✓

TRAINING

Question	Kinergetics DH-21 YES	Kinergetics DH-21 NO	Aqua Breeze II YES	Aqua Breeze II NO
Are the techniques for operating the equipment different from those taught in the service school?		✓		✓
Can the equipment be operated without the benefit of going through operator's school first?	✓		✓	
Do you feel that prior experience with similar equipment is necessary to become a good operator?		✓		✓
Is there any specific knowledge not covered in the factory (or service) school that you needed in order to operate the equipment?	✓		✓	
Is there any particular skill that must be developed during training to operate the equipment?	✓		✓	
Did the technical manuals improve your ability to perform any of the following maintenance tasks beyond what it would have been by experience alone?	✓		✓	
Is there any specific knowledge not given you in the technical manual that must be acquired to perform any of the maintenance tasks?		✓		✓

DOCUMENTATION

	Kinergetics DH-21 Poor — Exc. 1 - 2 - 3 - 4 - 5	Aqua Breeze II Poor — Exc. 1 - 2 - 3 - 4 - 5
	(CIRCLE APPROPRIATE NUMBER)	
Readability of manual?	1- 2- **3**- 4- 5	1- 2- **3**- 4- 5
Presentation easily understood?	1- 2- **3**- 4- 5	1- 2- **3**- 4- 5
Adequacy of equipment description?	1- **2**- 3- 4- 5	1- 2- **3**- 4- 5
Usefulness as operator training aid?	1- **2**- 3- 4- 5	1- **2**- 3- 4- 5
Usefulness as maintenance aid?	1- 2- **3**- 4- 5	1- 2- **3**- 4- 5
Usefulness of the principles of operation?	1- **2**- 3- 4- 5	1- **2**- 3- 4- 5
Usefulness of the operating procedures?	1- **2**- 3- 4- 5	1- **2**- 3- 4- 5
Usefulness as illustrations?	1- 2- 3- **4**- 5	1- 2- 3- **4**- 5
Usefulness of troubleshooting details?	**1**- 2- 3- 4- 5	**1**- 2- 3- 4- 5
Usefulness of maintenance procedures?	1- 2- 3- **4**- 5	1- 2- 3- **4**- 5
Quantity of pictorial layouts?	1- 2- 3- 4- 5	1- 2- 3- **4**- 5
Quality of pictorial layouts?	1- 2- 3- 4- 5	1- 2- **3**- 4- 5
Quantity of the illustrations?	1- 2- **3**- 4- 5	1- 2- **3**- 4- 5
Quality of illustrations?	1- **2**- 3- 4- 5	1- 2- **3**- 4- 5
Usefulness of parts lists for ordering spares?	1- 2- 3- 4- **5**	1- 2- 3- 4- **5**
Usefulness of troubleshooting schematics?	1- 2- 3- 4- 5	1- 2- 3- 4- 5
Quantity of troubleshooting schematics?	1- 2- 3- 4- 5	1- 2- 3- 4- 5
Ruggedness of manual construction for extended use?	1- 2- **3**- 4- 5	1- **2**- 3- 4- 5
Usefulness of manual size?	1- 2- 3- **4**- 5	1- 2- 3- **4**- 5
Description of new terms, acronyms, and abbreviations adequate and clearly defined?	**1**- 2- 3- 4- 5	**1**- 2- 3- 4- 5

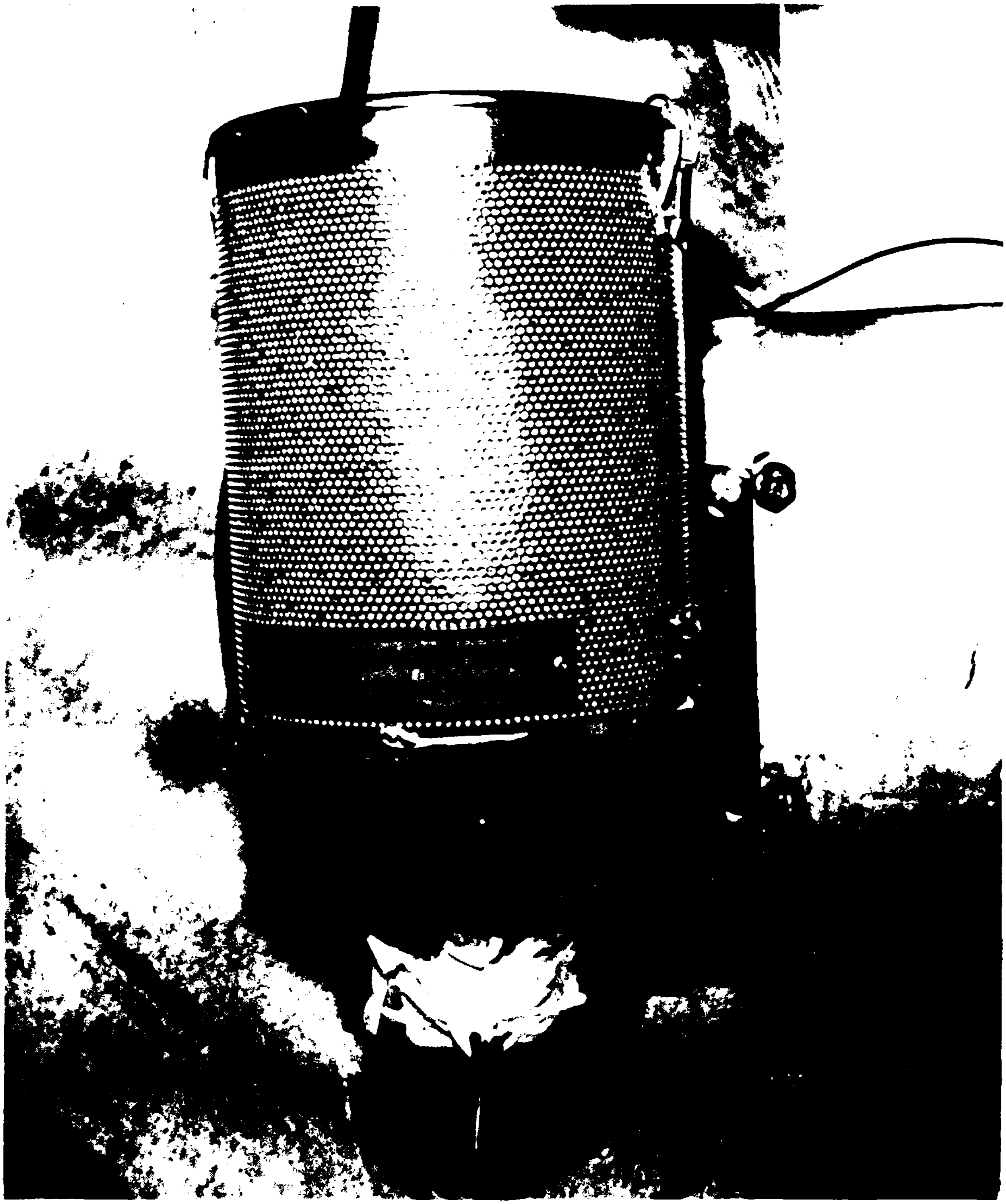

FIGURE 22. KINERGETICS DH-21 CO_2 SCRUBBER MOUNTED IN CHAMBER

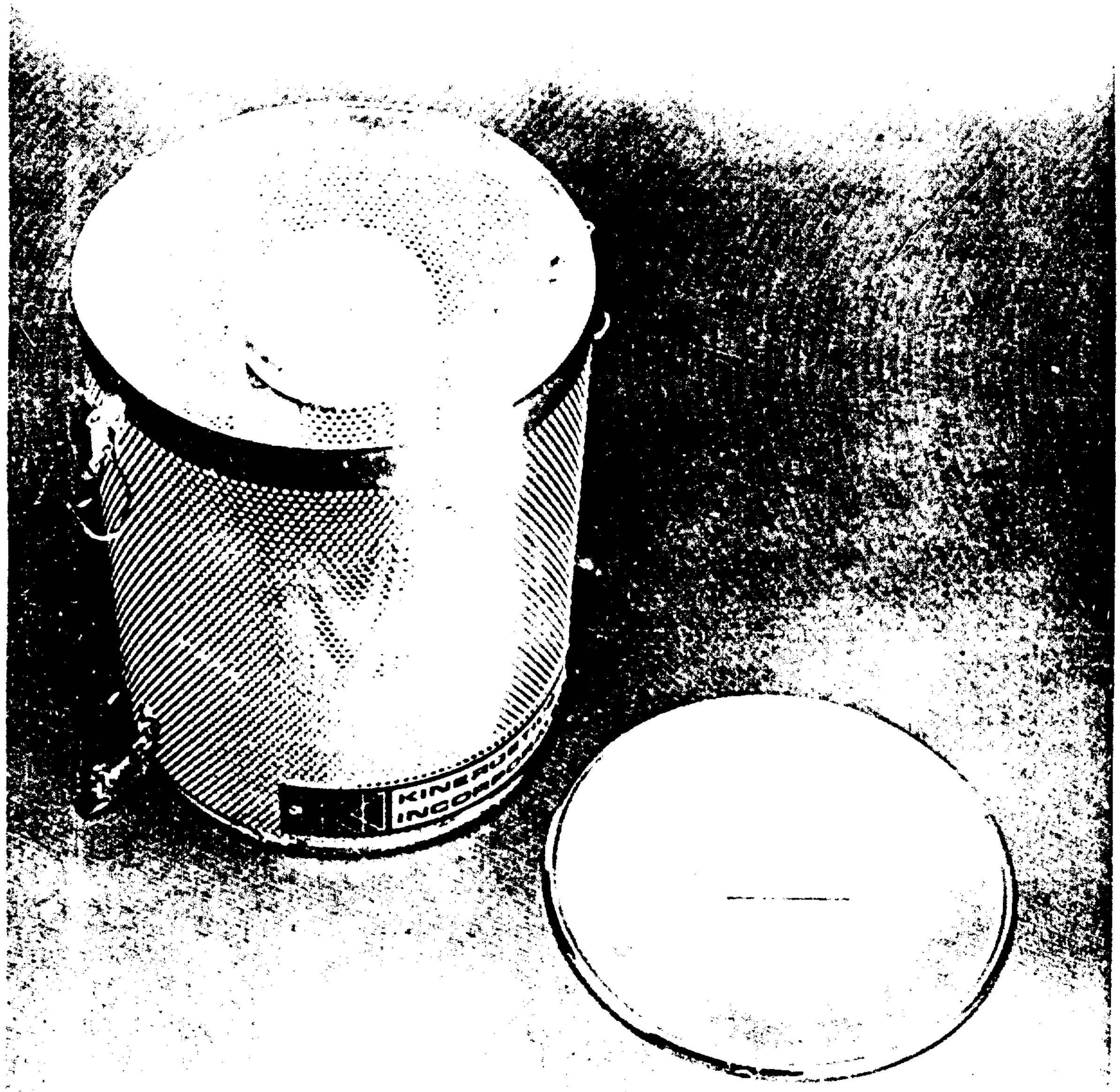

FIGURE 23. KINERGETICS CO_2 ABSORBENT CANISTER AND LID

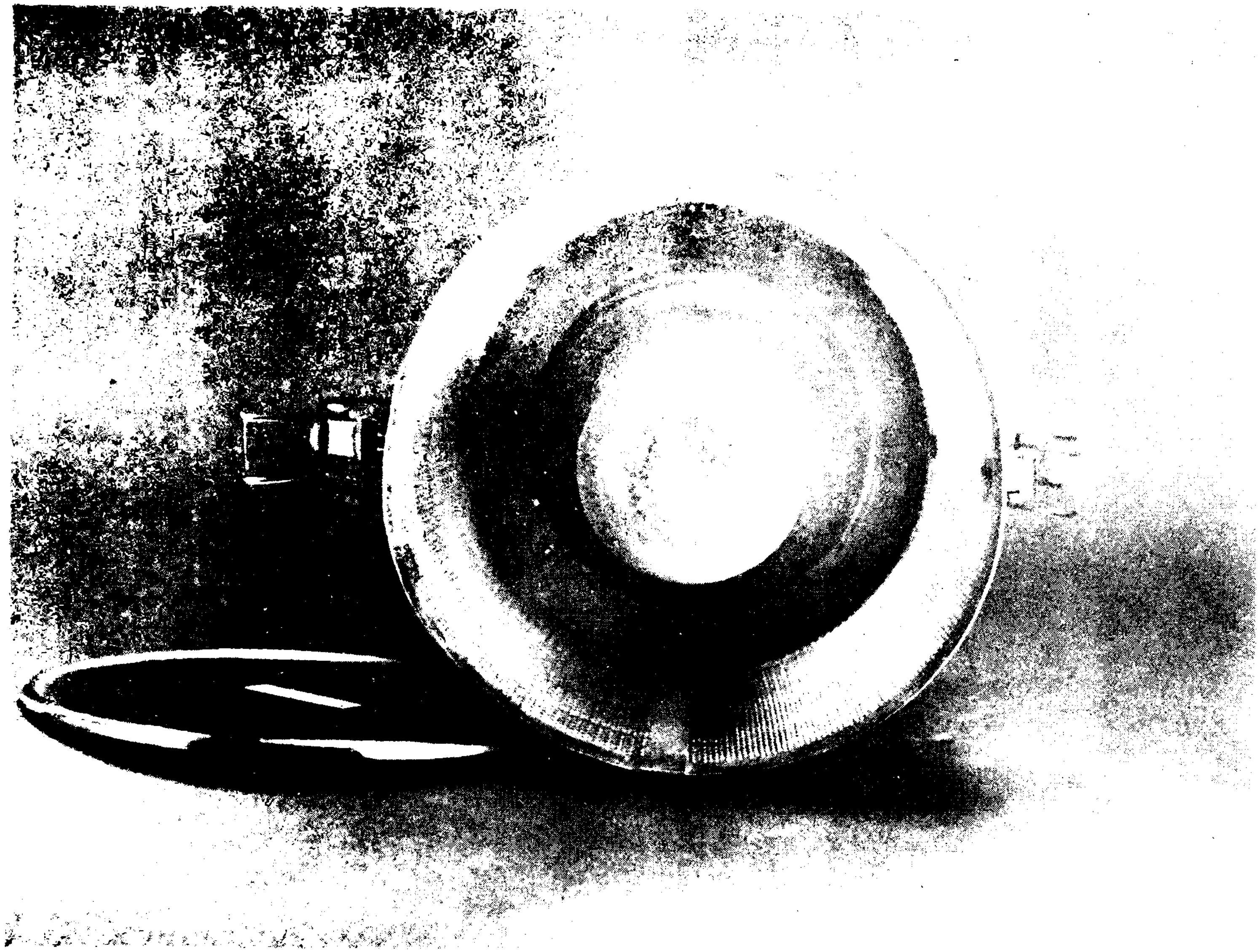

FIGURE 24. KINERGETICS CANISTER SHOWING SHARP TOP EDGE

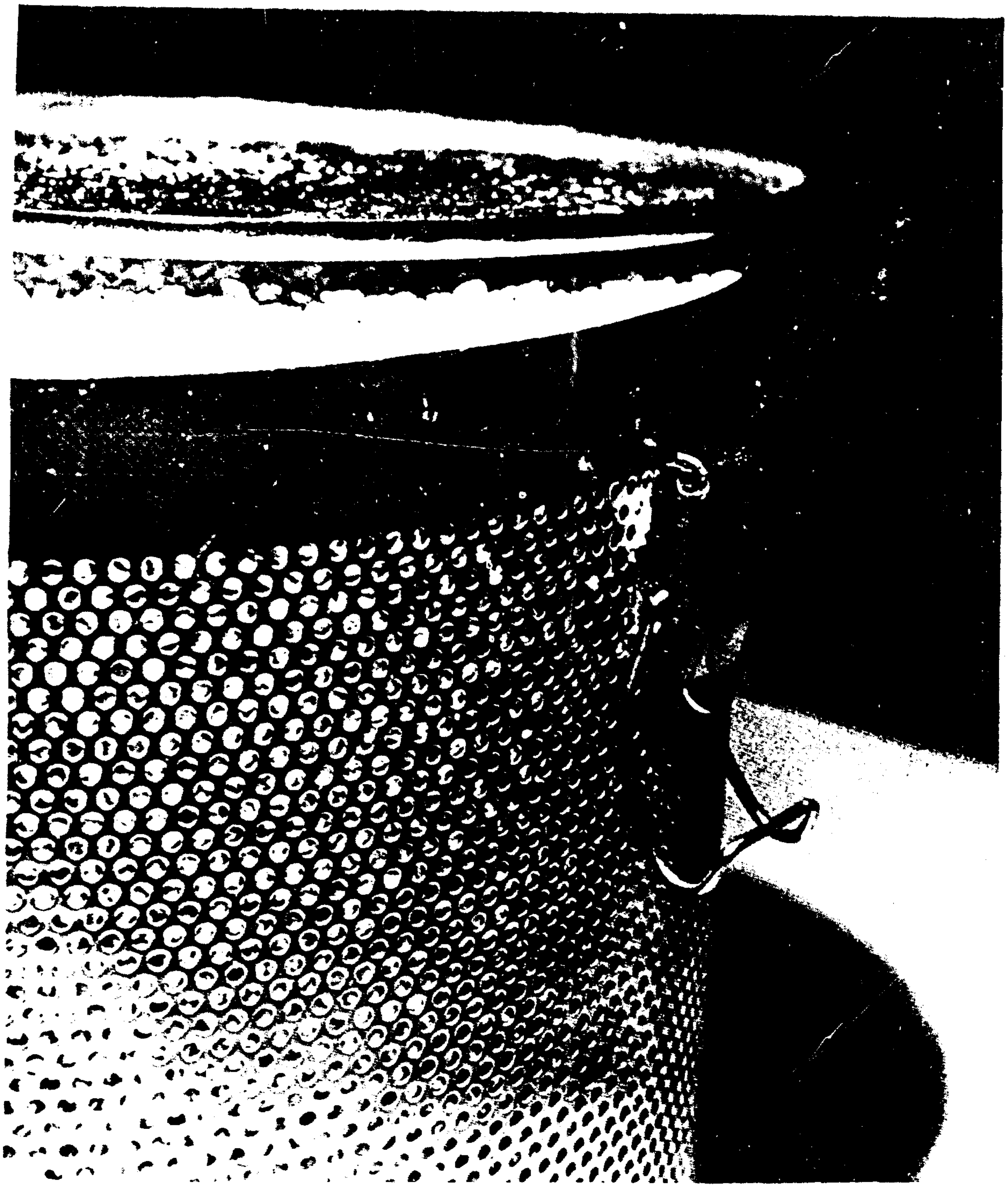

FIGURE 25. SODASORB ® PARTICLES PASSING THROUGH MESH OF KINERGETICS CANISTER

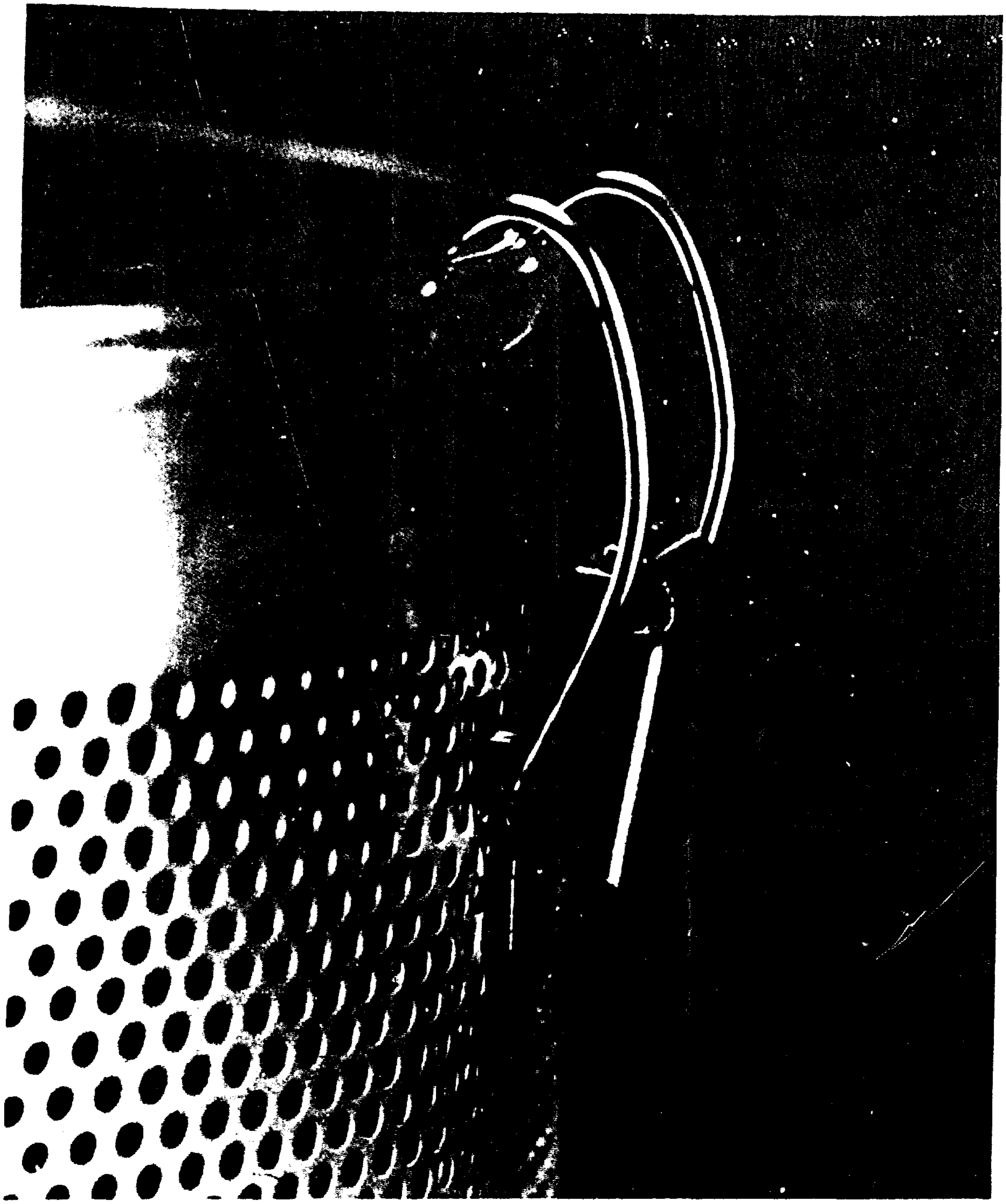

FIGURE 26. EXAMPLE OF LATCH USED ON KINERGETICS DH-21 SCRUBBER

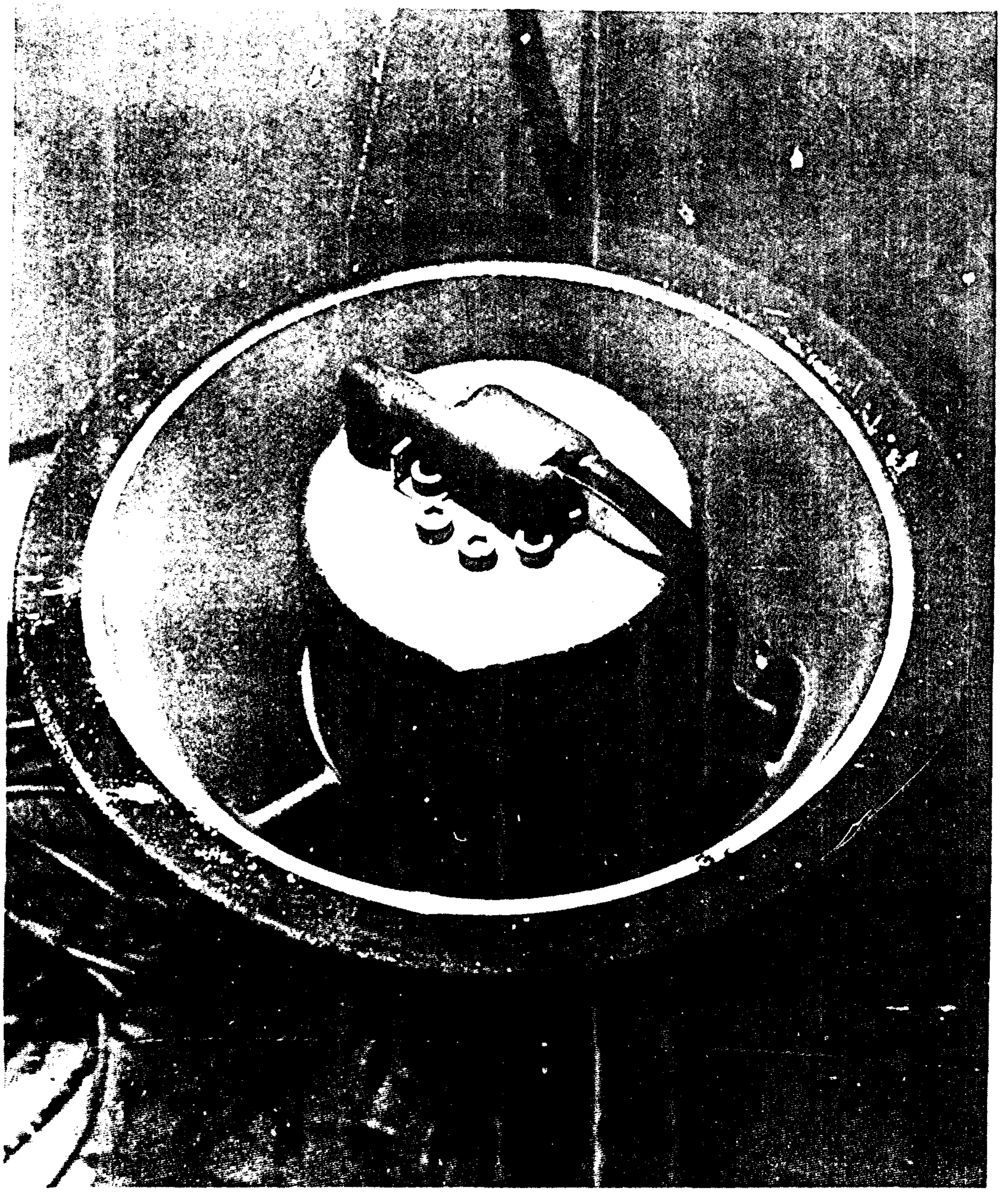

FIGURE 27. MOTOR HOUSING AND ELECTRICAL CONNECTOR FOR KINERGETICS DH-21 CANISTER

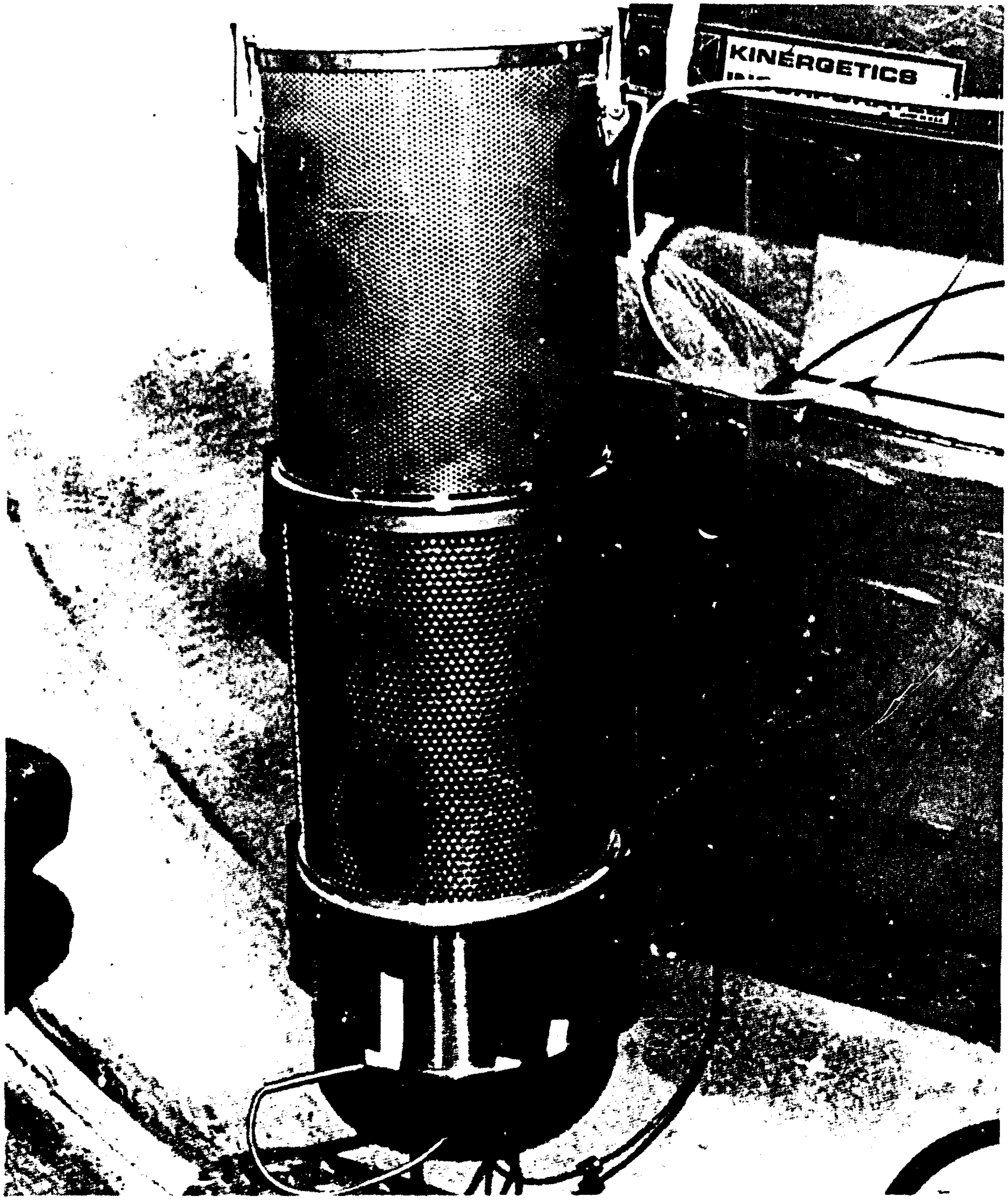

FIGURE 28. AQUA BREEZE II CO_2 SCRUBBER MOUNTED IN CHAMBER WITH TWO CANISTERS

FIGURE 29. TOP EDGE AND INTERIOR FINE WEAVE MESH OF AQUA BREEZE II CANISTER

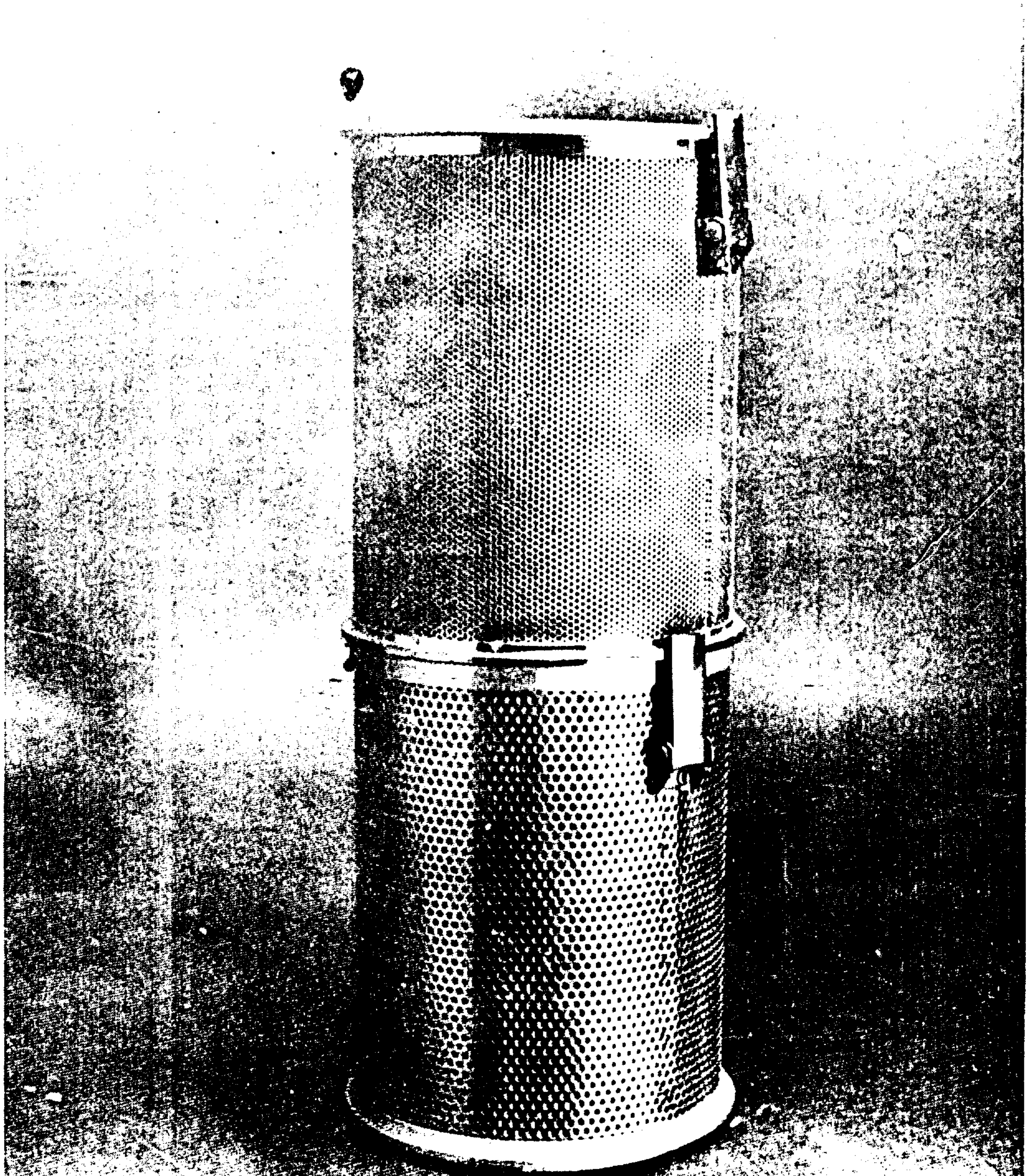

FIGURE 30 TWO AQUA BREEZE II CANISTERS WITH DIFFERENT SIZED EXTERIOR MESH

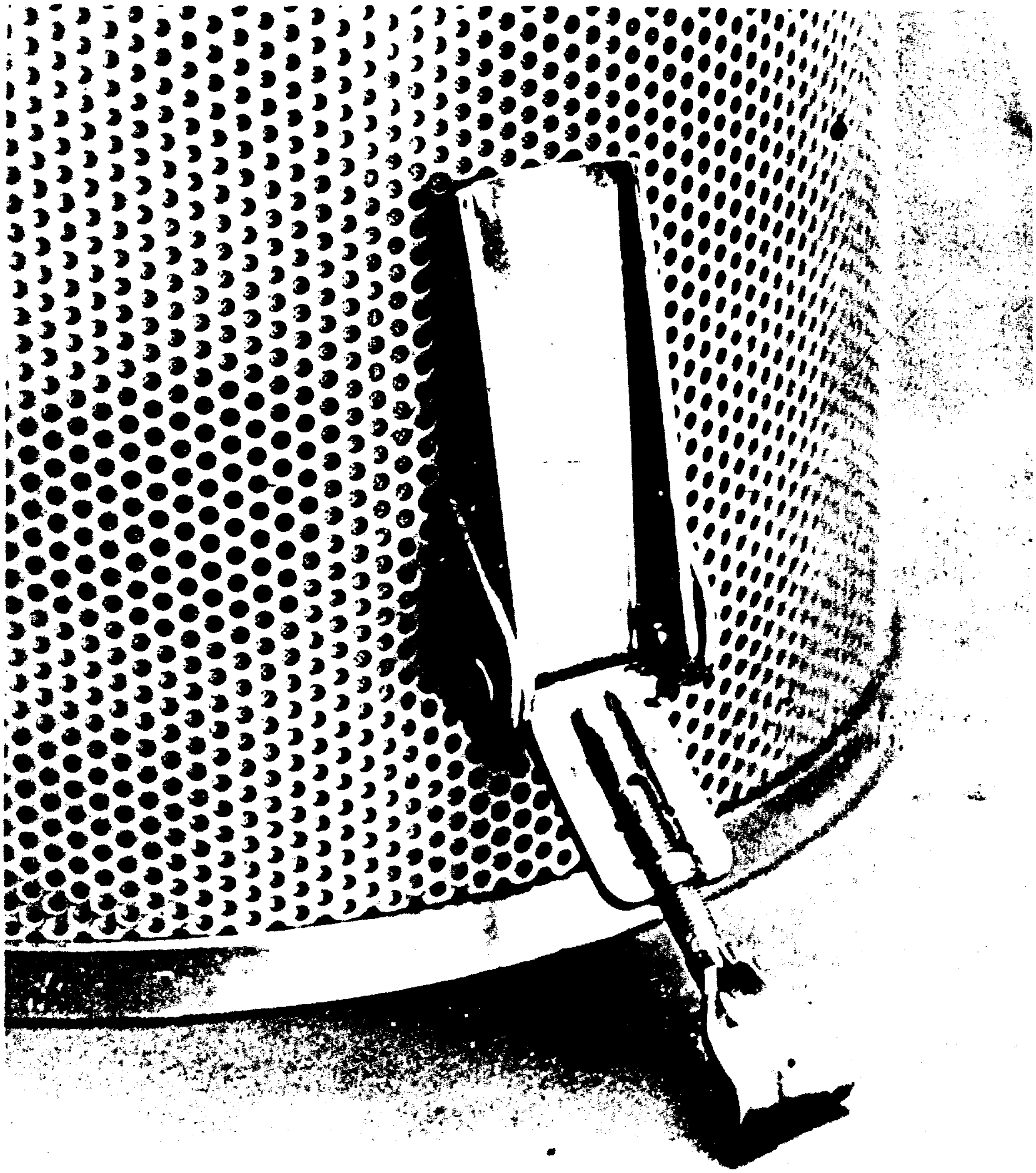

FIGURE 31. EXAMPLE OF LATCH USED ON AQUA BREEZE II SCRUBBER

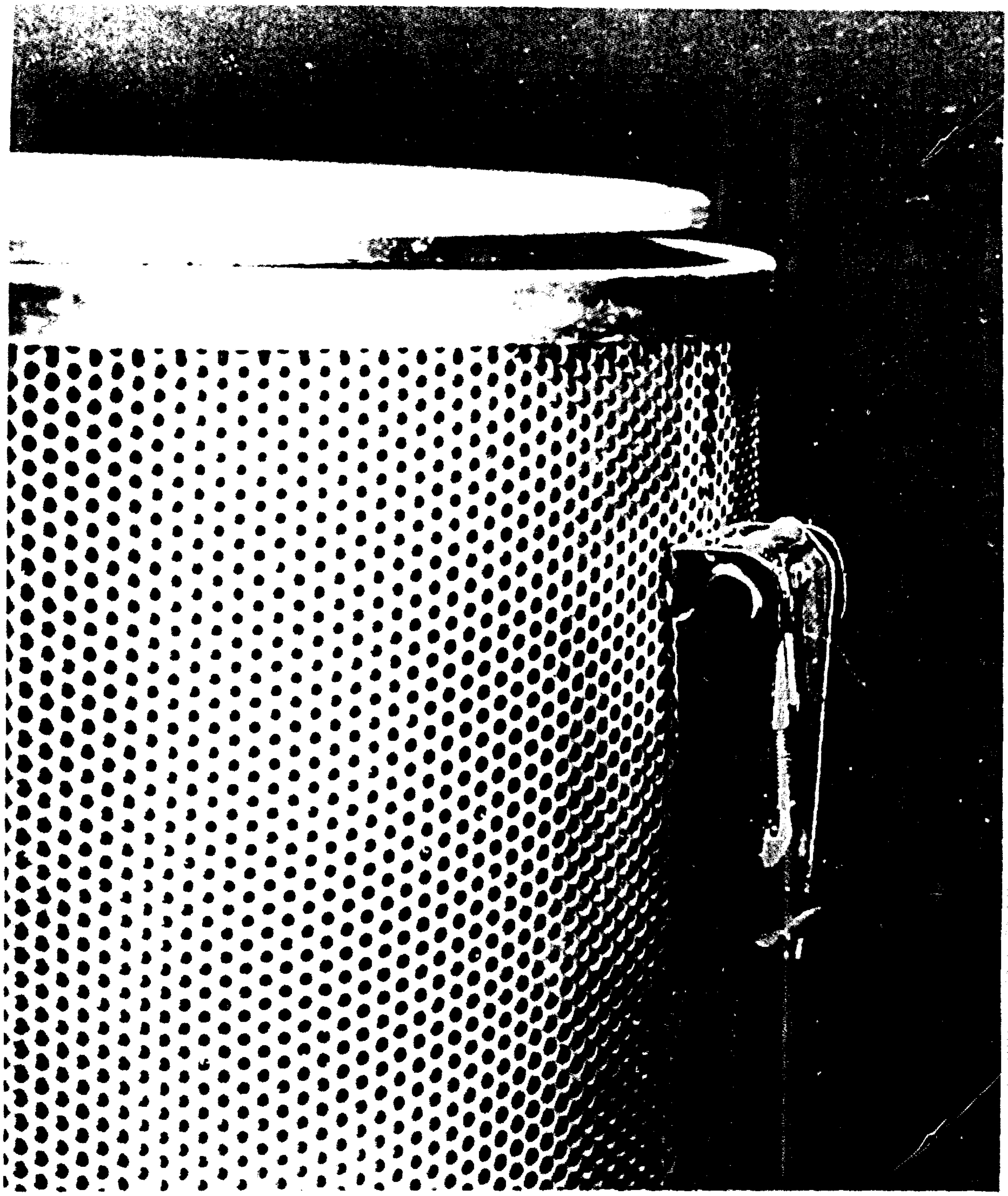

FIGURE 32. CANISTER LID/CANISTER INTERFACE ON AQUA BREEZE II CANISTER

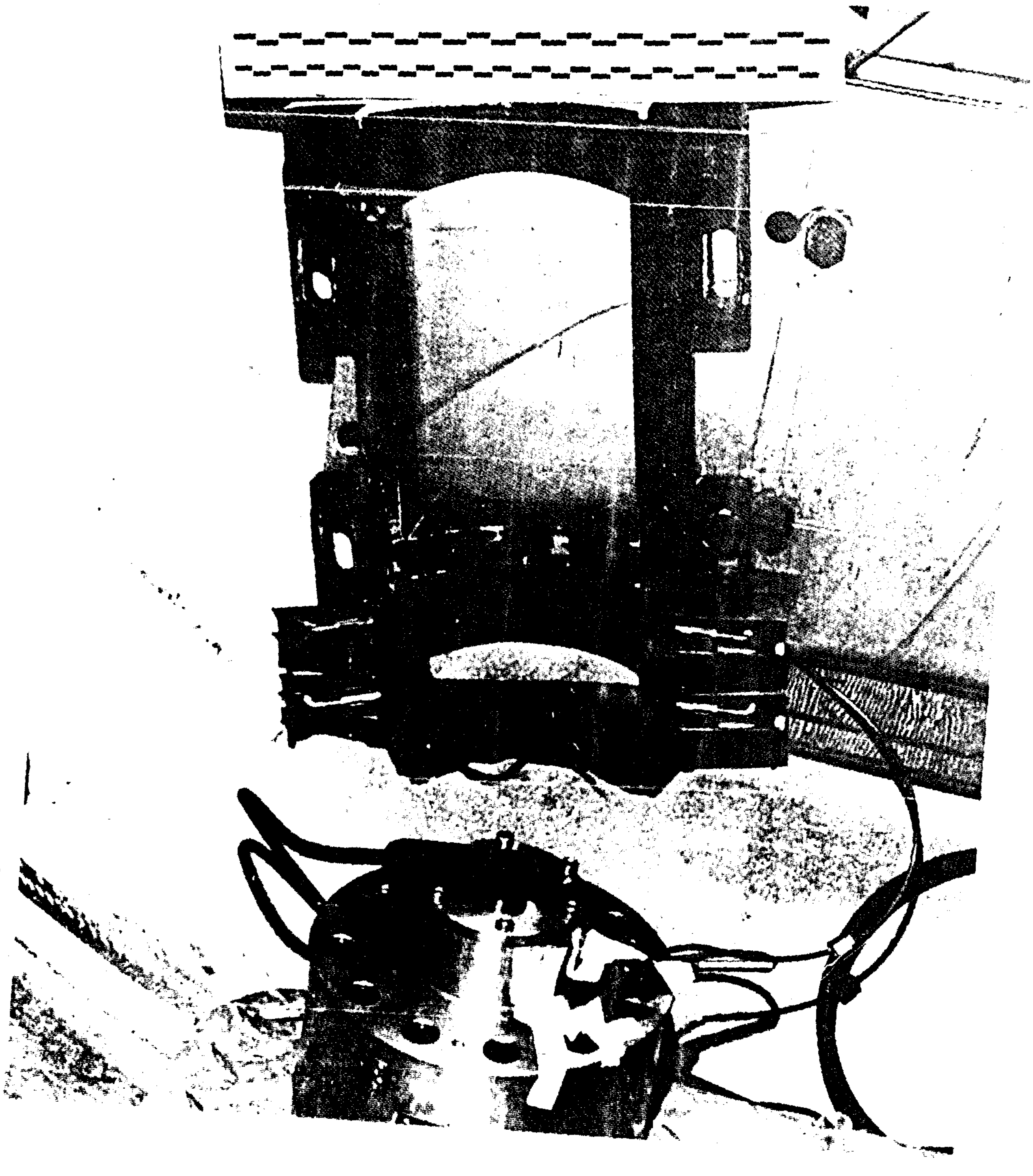

FIGURE 33. MOTOR HOUSING AND ELECTRICAL CONNECTOR FOR AQUA BREEZE II SCRUBBER

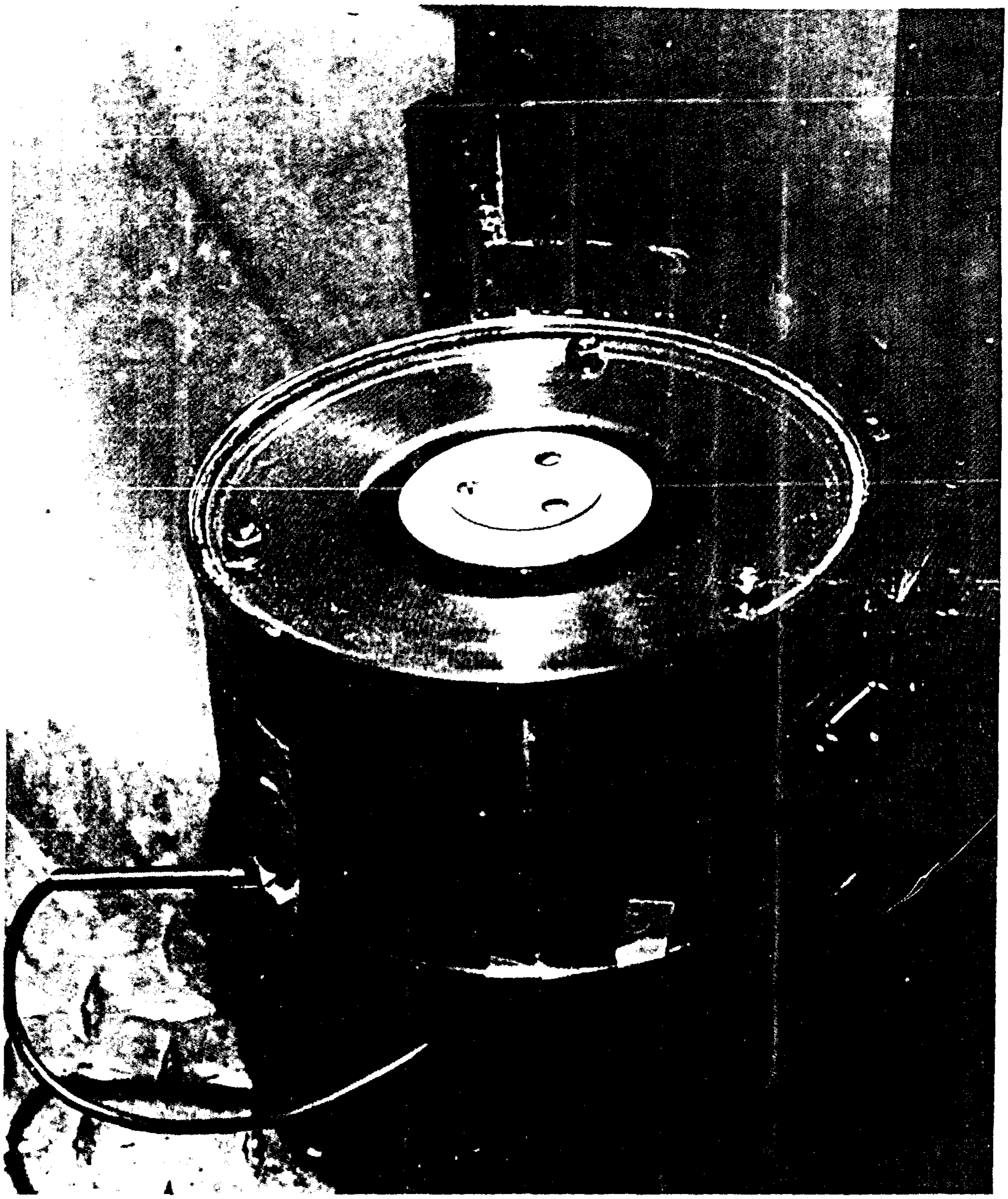

FIGURE 34. TOP OF MOTOR HOUSING OF AQUA BREEZE II SCRUBBER

ANNEX B

ENGINEERING, MEDICAL AND TECHNICAL SUPPORT
Standards Review of Kinergetics DH 21 and Aqua Breeze II
DLRC CO_2 Scrubbers

A. SHIPBOARD EQUIPMENT

1. MIL-STD-454H (Standard General Requirements for Electronic Equipment). Evaluators initial (EV) is next to requirement number. Responsible departments for specific evaluations are M = Medical, E = Engineering, T = Technical Support. This department designation is for planning reasons only and is flexible as deemed appropriate. Evaluators should note if the scrubbers pass standards (YES) or (NO), if the standard is not applicable (N/A) or if follow-on testing is recommended (TEST). Any requirement marked TEST should be commented on.

Requirement # Meets STD's

	#	(EV)	YES/NO N/A TEST		#	(EV)	YES/NO N/A TEST		#	(EV)	YES/NO N/A TEST
(E)	1	P	Yes	(T)	26	P	N/A	(T)	51	P	N/A
(T)	2	P	N/A	(M)	27	Z	N/A	(M)	52	M	Yes
(E)	3	P	Yes	(M)	28	C	Yes	(T)	53	P	N/A
(M)	4	Z	N/A	(T)	29	P	N/A	(T)	54	P&C	Test
(E)	5	M	Yes	(T)	30	P	N/A	(E)	55	M	Yes
(M)	6	M	Yes	(T)	31	P	Test	(M)	56	Z	N/A
(E)	7	M	N/A	(T)	32	P	Test	(T)	57	P	N/A
(T)	8	P	Yes	(T)	33	P	N/A	(T)	58	P	N/A
(T)	9	C	No	(T)	34	P	N/A	(E)	59	M	Yes
(T)	10	P	Yes	(T)	35	P	Test	(T)	60	P	N/A
(T)	11	P	Yes	(T)	36	C	Yes	(T)	61	P	N/A
(T)	12	M	Yes	(T)	37	P	Test	(M)	62	C	Yes
(M)	13	M	Yes	(T)	38	P	N/A	(T)	63	C	Yes
(M)	14	M	Yes	(T)	39	P	Test	(T)	64	P	N/A
(E)	15	E	N/A	(T)	40	P	N/A	(T)	65	P	N/A
(E)	16	M	Yes	(M)	41	Z	N/A	(T)	66	P	Yes
(T)	17	P	N/A	(M)	42	C	Yes	(M)	67	C	No
(T)	18	P	N/A	(E)	43	M	Yes	(M)	68	C	Yes
(T)	19	P	Yes	(M)	44	Z	Yes	(T)	69	P	N/A
(T)	20	P	N/A	(T)	45	P	N/A	(T)	70	P	N/A
(E)	21	M	Yes	(M)	46	M	Yes	(T)	71	P	N/A
(T)	22	P	N/A	(T)	47	P	N/A	(T)	72	P	N/A
(M)	23	Z	N/A	(M)	48	Z	N/A	(T)	73	P	N/A
(T)	24	P	N/A	(M)	49	Z	N/A	(T)	74	P	Yes
(T)	25	P	N/A	(M)	50	Z	N/A				

(T) #1 Both Kinergetics DH 21 and Aqua Breeze II meet Class 1 requirements. (MR. PELTON)

(M) #9, 42, 67 See Annex A. (LCDR CURLEY)

(M) #10, 11, 20, 26, 69 While these requirements are necessary when designing or writing specification on new equipment, not yet built, it is only useful as a reference material when conducting test and evaluation of commercial equipment for ANU status. Therefore, it should be listed as a guide not a requirement. (Mr. PELTON)

(T) #19 This requirement is good reference material to use during the evaluation of equipment to judge quality control. (MR. PELTON)

(T) #32, 32, 35, 37, 39 These requirements are good items to test during test and evaluation. (MR. PELTON)

(T) #66 This requirement is very good reference material, but cable used on commercial equipment may not meet this requirement and still be good for the design use. What needs to be considered is will it work on the equipment where the Navy will use it. (MR. PELTON)

(T) #74 For commercial equipment requirement #1 covers this area. (MR. PELTON)

Individual Requirements:

Requirement 1 - Safety (Personnel Hazard)
Requirement 2 - Capacitors
Requirement 3 - Flammability
Requirement 4 - Fungus-Inert Materials
Requirement 5 - Soldering
Requirement 6 - Bearings
Requirement 7 - Interchangeability
Requirement 8 - Electrical Overload Protection
Requirement 9 - Workmanship
Requirement 10 - Electrical Connectors
Requirement 11 - Insulating Materials, Electrical
Requirement 12 - Fastener Hardware
Requirement 13 - Structural Welding
Requirement 14 - Transformers, Inductors, and Coils
Requirement 15 - Ferrous Alloys, Corrosion Resistance
Requirement 16 - Dissimilar Metals
Requirement 17 - Printed Wiring
Requirement 18 - Derating of Electronic Parts and Materials
Requirement 19 - Terminations
Requirement 20 - Wire, Hookup, Internal
Requirement 21 - Castings
Requirement 22 - Parts Selection and Control
Requirement 23 - Adhesives
Requirement 24 - Welds, Resistance, Electrical Interconnections
Requirement 25 - Electrical Power
Requirement 26 - Arc-Resistant Materials

Requirement 27 - Batteries
Requirement 28 - Controls
Requirement 29 - Electron Tubes
Requirement 30 - Semiconductor Devices
Requirement 31 - Moisture Pockets
Requirement 32 - Test Provisions
Requirement 33 - Resistors
Requirement 34 - Nomenclature
Requirement 35 - Reliability
Requirement 36 - Accessibility
Requirement 37 - Circuit Breakers
Requirement 38 - Quartz Crystals and Oscillator Units
Requirement 39 - Fuses, Fuse Holders, and Associated Hardware
Requirement 40 - Shunts
Requirement 41 - Springs
Requirement 42 - Tuning Dial Mechanisms
Requirement 43 - Lubricants
Requirement 44 - Fibrous Material, Organic
Requirement 45 - Corona and Electrical Breakdown Prevention
Requirement 46 - Motors, Dynamotors, Rotary Power Converters and Motor-Generators
Requirement 47 - Encapsulation and Embedment (Potting)
Requirement 48 - Gears
Requirement 49 - Hydraulics
Requirement 50 - Indicator Lights
Requirement 51 - Meters, Electrical Indicating, and Accessories
Requirement 52 - Thermal Design
Requirement 53 - Waveguides and Related Devices
Requirement 54 - Maintainability
Requirement 55 - Enclosures
Requirement 56 - Rotary Servo Devices
Requirement 57 - Relays
Requirement 58 - Switches
Requirement 59 - Brazing
Requirement 60 - Sockets and Accessories
Requirement 61 - Electromagnetic Interference Control
Requirement 62 - Human Engineering
Requirement 63 - Special Tools
Requirement 64 - Microelectronic Devices
Requirement 65 - Cable, Coaxial (RF)
Requirement 66 - Cable, Multiconductor
Requirement 67 - Marking
Requirement 68 - Readouts and Displays
Requirement 69 - Internal Wiring Practices
Requirement 70 - Electrical Filters
Requirement 71 - Cable and Wire, Interconnection
Requirement 72 - Substitutability
Requirement 73 - Standard Electronic Modules
Requirement 74 - Grounding, Bonding, and Shielding

2. MIL-STD-810C, Environmental Test Methods (Sections). See instructions in paragraph (1).

DEPARTMENT	PARAMETER	STANDARDS	APPROPRIATE LEVEL OF TEST	MEET STANDARDS YES/NO N/A TEST	INL
(T)	Temperature	Section 501.1	Procedure I	Test	P
	(High & Low)	Section 501.2	Procedure I	Test	P
(T)	Water Exposure	Section 506.1		N/A	P
		Section 509.1			
		Also MIL-STD-108E			
(T)	Humidity*	Section 507.1		Test	P
(E)	Vibration	Section 514.2		Test	M
		Also MIL-STD-167			
(E)		Marshall Space		Test	M&P
		Center			
(E)		Document # SE-019-			
		049-2H Rev A			
(E)		Section IX.A.4.			
		Ships			
(E)	Shock**	Section 516.2		Test	M&P
		Also MIL-S-901C			
(E)	Tilt	NEDU Report 3-50	30° Port/Stbd Tilt	Test	M
		(Page 1)			

COMMENTS: *This is a valid test for equipment that should be conducted on all electrical equipment to be used in the diving community. NEDU does not have the facilities to test in manner described (MR. PELTON)

**Procedure V, Bench Handling Test can and should be conducted on equipment undergoing Test and Evaluation at NEDU. MR. PELTON

3. Human Factors Evaluation:
(M)

a. See MIL-STD-454H above requirements 28, 42, 50, 62 and 68.

b. Review of MIL-STD-1472C (Human Engineering Design Criteria for Military Systems, Equipment and Facilities) has been performed and appropriate recommendations are below or on a separate sheet.

c. Human Engineering Guide to Equipment Design, Van Cott, H.P. and Kinkade, R.G. (Eds.), 1972, has been reviewed and appropriate recommendations are blow or on a separate sheet.

COMMENT: See Annex A for complete Human Factors Evaluation. (LCDR CURLEY)

4. MIL-STD-4613, Electromagnetic Emission/Electron Magnetic Interference
(T) (April 1980). Part 1, 5 and 6. N/A MR. PELTON

5. National Fire Protection Association, 99. Health Care Facilities,
(T) 1987 Edition, 12 FEB 1987; Chapter 19.

COMMENT:

Both scrubbers acceptable within constraints of use by U.S. Navy. (MR. PELTON)

B. EQUIPMENT IN CHAMBERS

1. NAVFAC DM-39 July 1982

(M) 1. Chapter 6 Life Support. ACCEPTABLE (Z)
(T) 2. Chapter 9 Elec. (At Sea Hyperbaric Facilities will vary some). ACCEPTABLE (P)

a. Especially Section 3

(1) Grounding or isolation transformer, etc.
(2) AC DC voltage.
(3) Material, gauge, insulation (intrinsic safety) - (incapable of causing spark or ignition).

(M) 3. Chapter 11 Human Factors. ACCEPTABLE (C)
(E) 4. Chapter 12 Lubricant Seals. ACCEPTABLE (M)

a. Especially

(1) Section 1 - Acceptable lubricants and sealants.

2. NASA Environmental Control Guidelines

(E) 1. Flammability, Odor and Offgassing Requirement and Test Procedures for materials in environments that support combustion NHB 8060.1B. ACCEPTABLE (M)

(E) 2. Guidelines for the implementation of required materials control procedures MSFC-PROC-1301, June 1, 1986. ACCEPTABLE (M)

COMMENTS:

1.1 Both the Kinergetics DH-21 and Aqua Breeze II are capable of maintaining chamber CO_2 levels within parameters set by Chapter 6, NAVFAC DM-39. This performance will require simulated operational testing. (LCDR ZWINGELBERG)

1.3 See Annex A. (LCDR CURLEY)

1.4 and 2.1-3. Both scrubbers employ stainless steel and neoprene wire insulation as only components exposed to pressure. These materials have a long safe track record in hyperbaric and hyperoxic environments. (MR. McCARTHY)

Submitted:

(P)
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(C)
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(M)
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(Z)
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