NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 19-90

PARACEL, TRANSPORTABLE RECOMPRESSION CHAMBER SYSTEM (TRCS)

K. A. HODINA

OCTOBER 1990

NAVY EXPERIMENTAL DIVING UNIT

2

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407-5001

IN REPLY REFER TO:
NAVSEA TASK 88-023

NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 19-90

PARACEL, TRANSPORTABLE RECOMPRESSION CHAMBER SYSTEM (TRCS)

K. A. HODINA

OCTOBER 1990

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited

Submitted:

K.A. HODINA
LCDR, USN
Unmanned Test Director

Reviewed:

B.K. MILLER, JR.
LCDR, USN
Senior Projects Officer

Approved:

JAMES E. HALWACHS
CDR, USN
Commanding Officer

J.B. McDONELL
LCDR, USN
Executive Officer

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
Unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT
Distribution Statement A: Approved for public release; distribution is unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
NEDU Report No. 19-90

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZ.
Navy Experimental Diving Unit

6b. OFFICE SYMBOL (If applicable)
03F

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS (City, State, and ZIP Code)
Panama City, Florida 32407-5001

7b. ADDRESS (City, State, and ZIP Code)

8a. NAME OF FUNDING/SPONSORING ORGANIZATION
Naval Sea Systems Command

8b. OFFICE SYMBOL (If applicable)
00C

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State, and ZIP Code)
Department of the Navy
Washington, DC 20362-5101

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
		NAVSEA 88-023	

11. TITLE (Include Security Classification)
(Unclassified) Paracel, Transportable Recompression Chamber System (TRCS)

12. PERSONAL AUTHOR(S)
K. A. Hodina, LCDR, USN

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year,Month,Day)	15. PAGE COUNT
Test Report	FROM ______ TO ______	October 1990	36

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
TRCS, TC, TL, DTC, Portable Recompression Chamber System, CO2 Scrubber System, Paracel

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The Paracel, Transportable Recompression Chamber System (TRCS) is a reduced volume, semi-closed, dual place, dual detachable lock recompression chamber system which features light overall weight and efficient use of compressed air. The treatment chamber is designed to facilitate hyperbaric oxygen therapy to a diving casualty tended by another diver or corpsman. Air BIBS is also available as an emergency breathing gas supply for both occupants in the model under evaluation. In production models, nitrox will be available through its own pressure reducing system. Unique to the TRCS is the ability to detach the outer transfer lock (TL) in order to facilitate a transport of patient and tender while under pressure to the site of a hospital or Definitive Treatment Chamber (DTC). In order (CONTINUED)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
[ ] UNCLASSIFIED/UNLIMITED [X] SAME AS RPT. [ ] DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
NEDU Librarian

22b. TELEPHONE (Include Area Code)
904-234-4351

22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

BLOCK 19. ABSTRACT (CONTINUED)

to accommodate a transfer of occupants while the treatment chamber (TC) is still under pressure, the DTC will have to be equipped with the NATO standard receiver.

In this report, design changes to the original chamber system are evaluated and another CO2 scrubber performance study is accomplished. The requirement for chamber cooling is also emphasized through the results of an external cooling study that was conducted. The chamber performed adequately in all respects, and design change recommendations for production models of the TRCS are documented. The TRCS will fulfill the mission requirement of numerous DOD diving activities and is therefore recommended for fleet use.

CONTENTS

		Page No.
I.	INTRODUCTION	1
II.	FUNCTIONAL DESCRIPTION OF DESIGN CHANGES IN THE MODEL III TRCS	1
III.	EVALUATION PROCEDURES, RESULTS AND CONCLUSIONS	10
IV.	RECOMMENDATIONS	12
REFERENCES		15
APPENDIX A - LIFE SUPPORT SYSTEM EVALUATION METHOD AND RESULTS		A-1 thru A-16

Appendix A Figures:
A1 Scrubber Jet and Bed Flow Rates - 0 FSW
A2 Scrubber Jet and Bed Flow Rates - 30 FSW
A3 Scrubber Jet and Bed Flow Rates - 60 FSW
A4 Scrubber Jet and Bed Flow Rates - 165 FSW
A5 Chamber CO_2 at Three Jet Pressures - 30 FSW
A6 Chamber CO_2 at Four Jet Pressures - 60 FSW
A7 Chamber CO_2 at Four Jet Pressures - 165 FSW
A8 Cannister Duration - 30 FSW, Jet Pressure = 50 PSIG
A9 Cannister Duration - 60 FSW, Jet Pressure = 100 PSIG
A10 Cannister Duration - 165 FSW, Jet Pressure = 170 PSIG

Appendix A Tables:
1 Gas Consumption Measurements
2 CO_2 Scrubber Operating Parameters

ILLUSTRATIONS

Figure No.		Page No.
1	TC Piping Schematic	7
2	TL Piping Schematic	8
3	Chamber Temperature Study - 30 FSW, Ambient Temp: 92-96°F(db)	13

PHOTOGRAPHS

Photo No.		Page No.
1	TRCS, TL and TC Not Mated	2
2	TRCS, Including One Gas Stowage Rack	3
3	TRCS	4
4	Personnel in TC	5

I. INTRODUCTION

This report is being prepared in order to complete the evaluation of the Paracel, Transportable Recompression Chamber System (TRCS) project (reference 1). Work on the project was begun in late 1988 and final data acquisition and testing of the most recent version of the equipment was completed at Navy Experimental Diving Unit (NEDU) on 7 August 1990. This report is structured as a continuation of NEDU Report No. 7-90 (reference 2), and will concentrate on the impact of design changes in the model III, corrections of deficiencies outlined in reference 2, results of a field trial with the model III, and the performance of the life support system in the model III.

Significant changes to the design were made in the model III. The litter assembly, the piping arrangement, the mating assembly, and selection of components are entirely different from the model II, and reflect nearly all of the concerns and suggestions for improvement that have been relayed to the manufacturer.

Additionally, the CO_2 scrubber jet pressurization configuration and the cannister design have been improved in the model III. Consequently, a performance evaluation of the CO_2 scrubbing system has been checked by using the methods set forth in reference 3. Refer to photographs 1 through 4.

II. FUNCTIONAL DESCRIPTION OF DESIGN CHANGES IN THE MODEL III TRCS

A. NATO STANDARD MATING ASSEMBLY

The rotating collar has been greatly simplified in its overall design. In the model III, the rotating collar portion of the mating adaptor has been placed on the Transfer Lock (TL) thus reducing the weight of the transportable treatment lock and simplifying its maintenance requirements. This change in the design also makes it immediately compatible with the Canadian Forces chambers that are equipped with the NATO standard receiver. The weight of the rotating collar is now carried on roller bearings instead of the lip seal and the new design incorporates two lip seals instead of one and

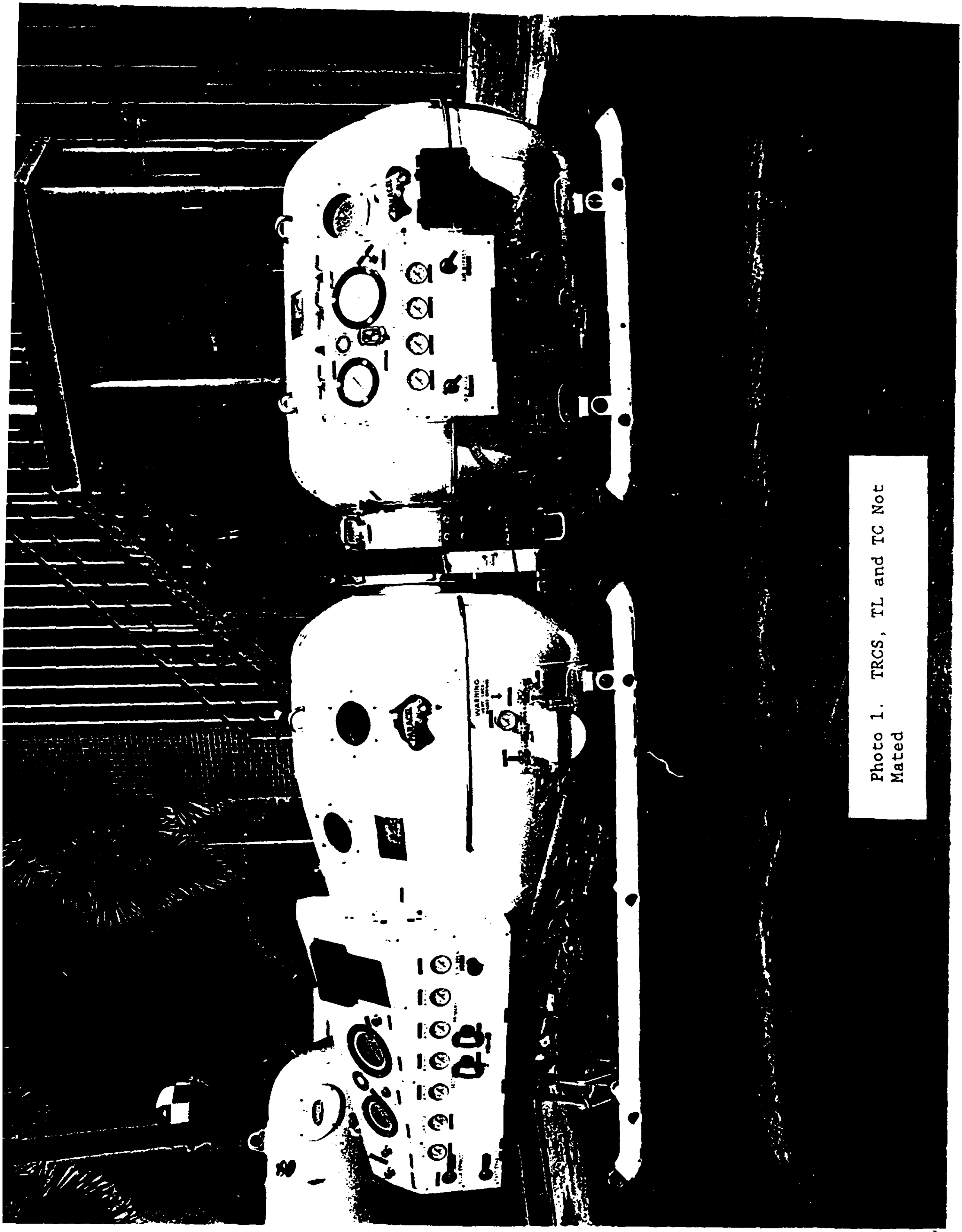


Photo 1. TRCS, TL and TC Not Mated

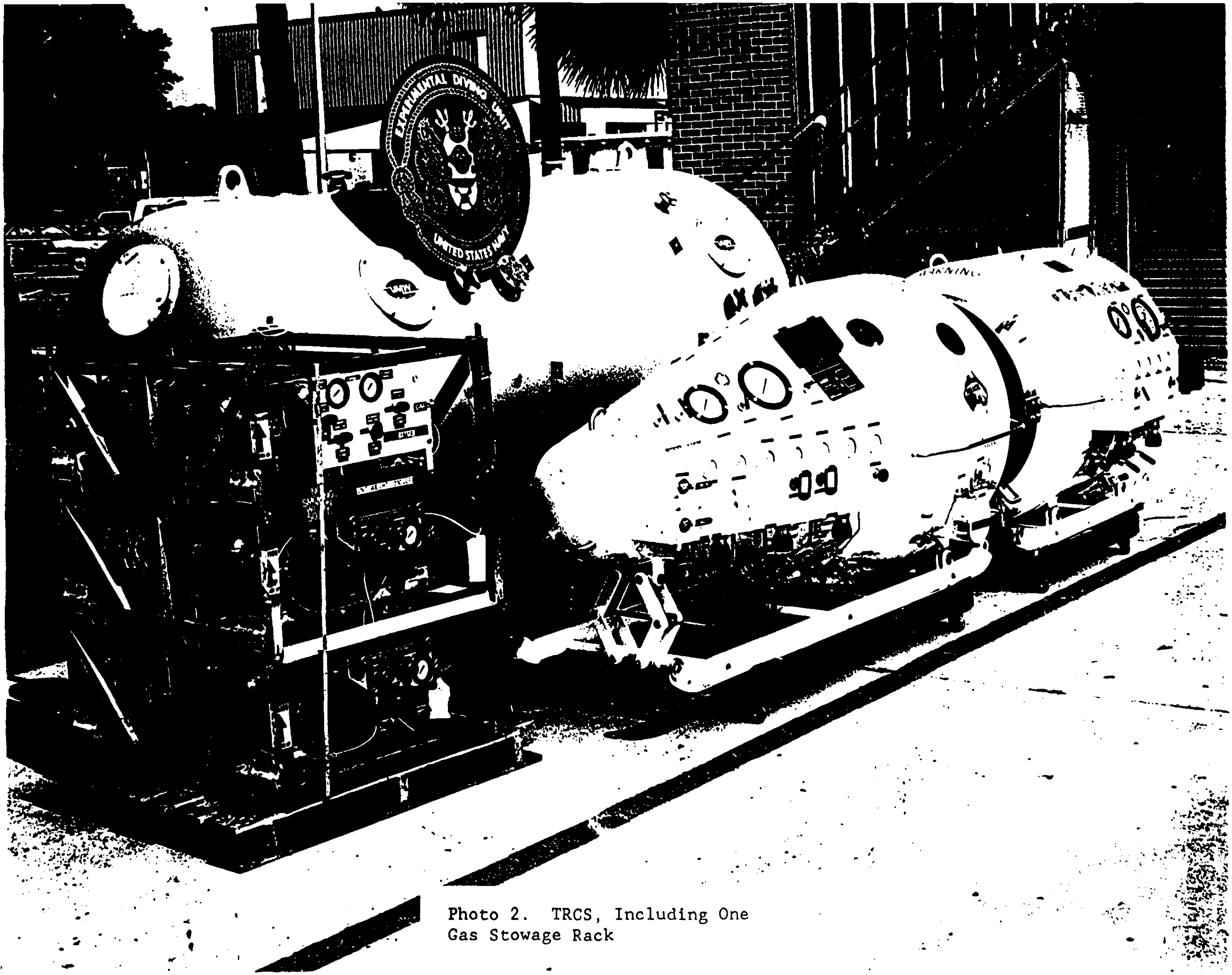


Photo 2. TRCS, Including One Gas Stowage Rack

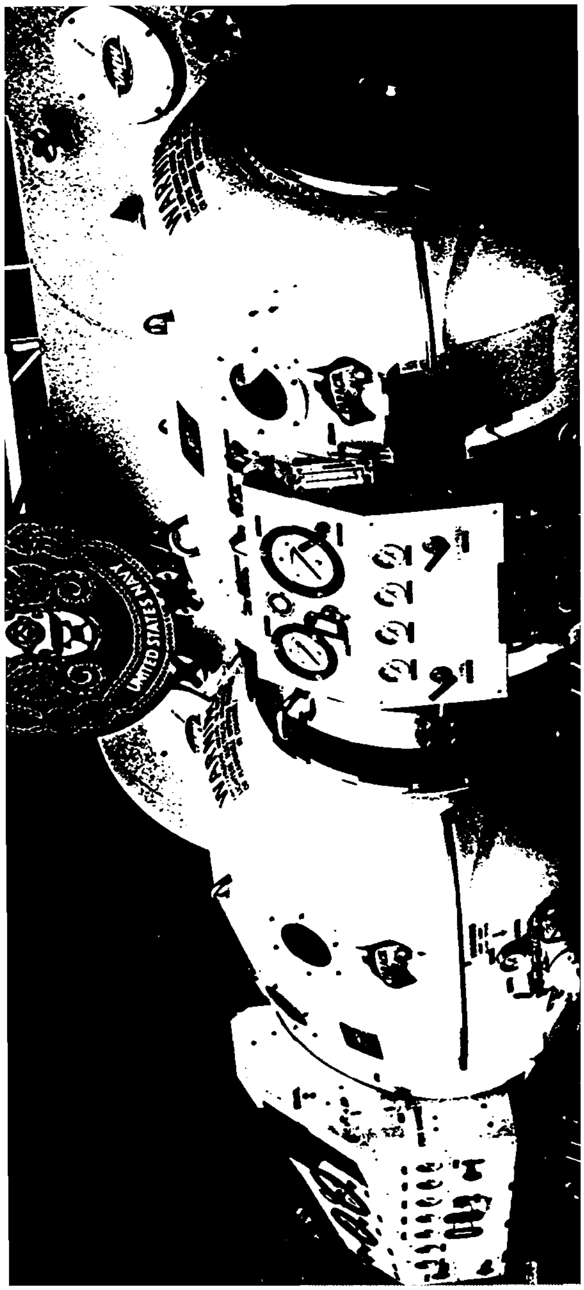

UNITED STATES NAVY

Photo 4. Personnel in TC

b. Operators assigned to the project all commented on the ease of maintaining are constructed of a far more pliable material. The lip seals are a standard Draeger manufactured part rather than specially manufactured for the chamber system as they were in the model II. Furthermore, the mating collar incorporates a poppet valve safety interlock which will prevent pressurization of the collar assembly if a complete seal on both mating surfaces is not achieved. The mating collar can now be rotated by hand with out the use of levers or persuaders.

B. PIPING ARRANGEMENT AND COMPONENTS

In the redesign, all flexible whips have been eliminated. Hull penetrations use CPV fittings with o-ring seats. All piping is 1/2 inch O.D. x 0.035 in wall thickness stainless steel tube with CPV end fittings welded to piping. All grip tight fittings have been eliminated. All valves, regulators and piping are of American origin (Tescom, Whitey, CPV, etc.). Pressurized piping to the hull is backed up with check valves and the exhaust system is protected with a flow fuse. There is complete duplicity in air and O_2 service in both chambers (figures 1 and 2).

C. LITTER ASSEMBLY

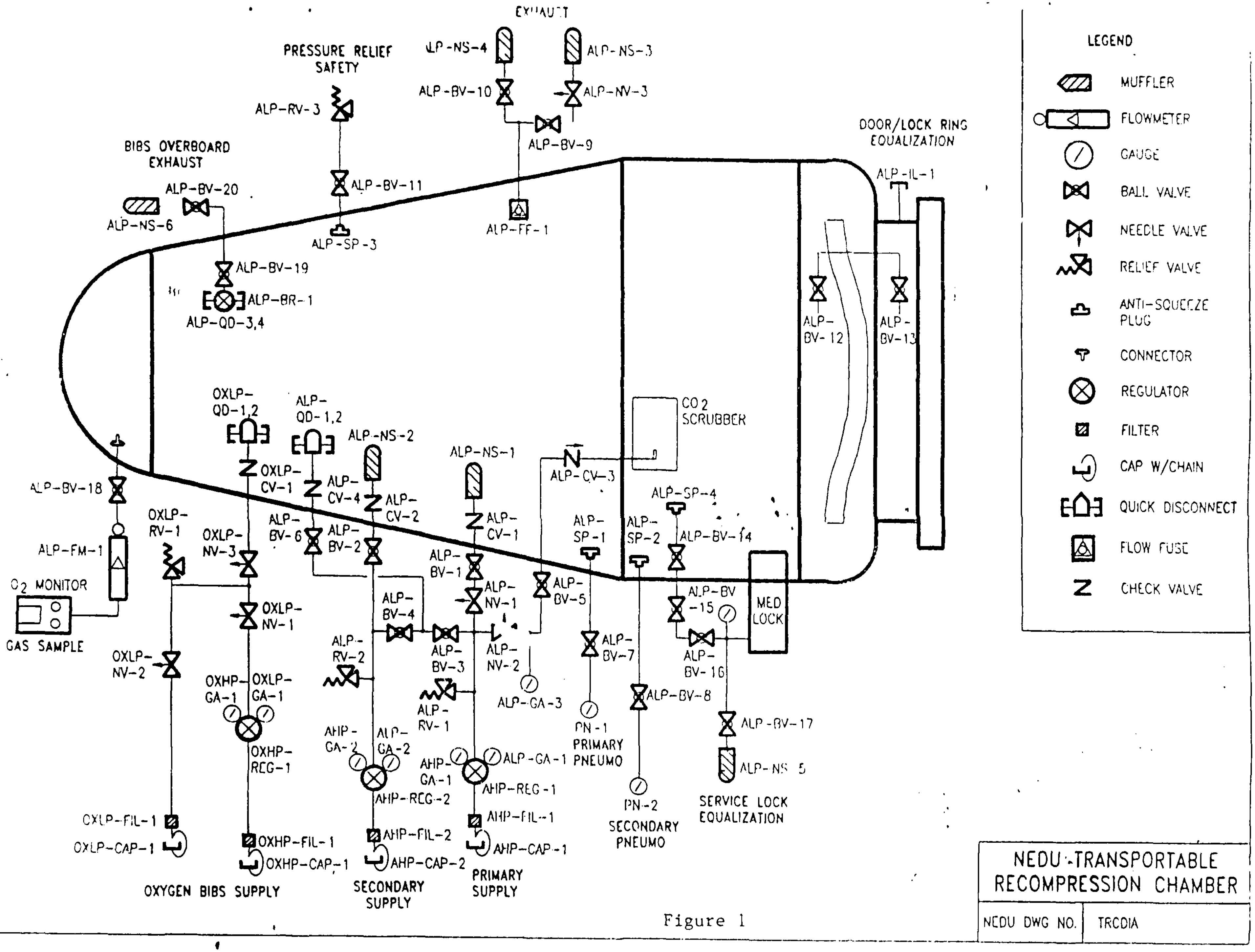
The litter is now mounted on a flat bed plate which uses an engineered plastic low friction bearing surface instead of the rail and rollers of the previous model. The size and shape of the litter is unchanged. When in the stowed position, the model III litter is secure in the longitudinal and lateral directions.

D. LIFTING PADEYES

Lifting padeyes have been enlarged and re-oriented to facilitate a lift from any direction. They are configured to accept nylon lifting straps directly, without the use of screw pin shackles.

E. CO_2 SCRUBBER SYSTEM

The volume of the cannister bed is the same as in the model II, however the model III cannister bed is made of clear acrylic plastic and is slightly longer and narrower than



LEGEND
MUFFLER
FLOWMETER
GAUGE
BALL VALVE
NEEDLE VALVE
RELIEF VALVE
ANTI-SQUEEZE PLUG
CONNECTOR
REGULATOR
FILTER
CAP W/CHAIN
QUICK DISCONNECT
FLOW FUSE
CHECK VALVE
NEDU-TRANSPORTABLE RECOMPRESSION CHAMBER
NEDU DWG NO.
TRCDIA
EXHAUST
ALP-NS-4
ALP-NS-3
ALP-BV-10
ALP-NV-3
ALP-BV-9
ALP-FF-1
PRESSURE RELIEF SAFETY
ALP-RV-3
ALP-BV-11
ALP-SP-3
BIBS OVERBOARD EXHAUST
ALP-BV-20
ALP-NS-6
ALP-BV-19
ALP-BR-1
ALP-QD-3,4
DOOR/LOCK RING EQUALIZATION
ALP-IL-1
ALP-BV-12
ALP-BV-13
CO2 SCRUBBER
ALP-CV-3
ALP-SP-4
ALP-BV-14
ALP-SP-1
ALP-SP-2
ALP-BV-15
MED LOCK
ALP-BV-16
ALP-BV-17
ALP-NS-5
SERVICE LOCK EQUALIZATION
ALP-BV-5
ALP-BV-7
ALP-BV-8
PN-1
PRIMARY PNEUMO
PN-2
SECONDARY PNEUMO
ALP-GA-3
ALP-NS-1
ALP-CV-1
ALP-BV-1
ALP-NV-1
ALP-NV-2
ALP-BV-3
ALP-RV-1
ALP-GA-1
AHP-GA-1
AHP-REG-1
AHP-FIL-1
AHP-CAP-1
PRIMARY SUPPLY
ALP-NS-2
ALP-CV-2
ALP-BV-2
ALP-BV-4
ALP-RV-2
ALP-GA-2
AHP-GA-2
AHP-REG-2
AHP-FIL-2
AHP-CAP-2
SECONDARY SUPPLY
ALP-QD-1,2
ALP-CV-4
ALP-BV-6
OXLP-QD-1,2
OXLP-CV-1
OXLP-NV-3
OXLP-NV-1
OXLP-GA-1
OXHP-GA-1
OXHP-REG-1
OXHP-FIL-1
OXHP-CAP-1
OXLP-RV-1
OXLP-NV-2
OXLP-FIL-1
OXLP-CAP-1
OXYGEN BIBS SUPPLY
ALP-BV-18
ALP-FM-1
O2 MONITOR
GAS SAMPLE

Figure 1

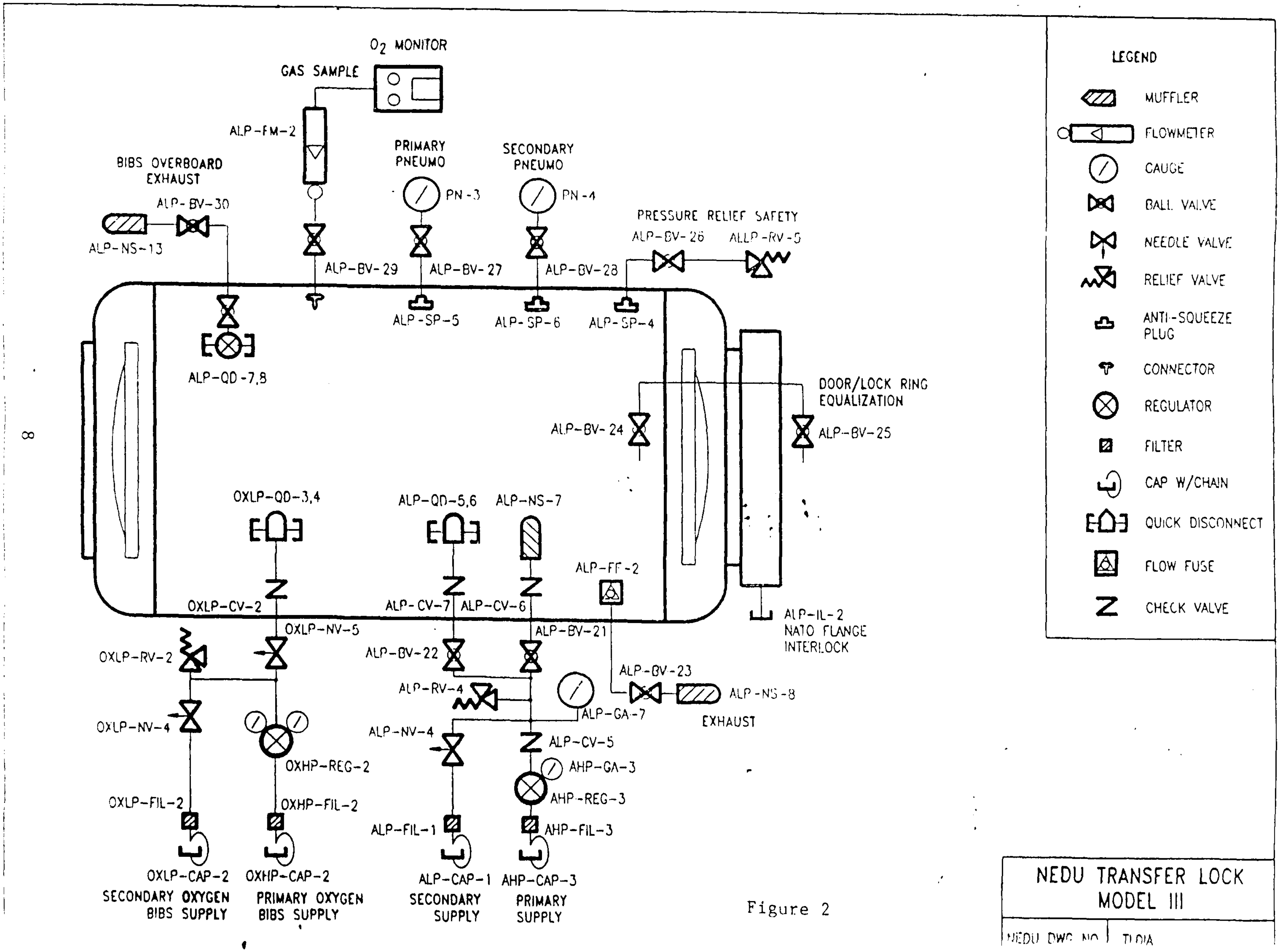

O2 MONITOR
GAS SAMPLE
ALP-FM-2
PRIMARY PNEUMO
SECONDARY PNEUMO
PN-3
PN-4
BIBS OVERBOARD EXHAUST
ALP-BV-30
ALP-NS-13
PRESSURE RELIEF SAFETY
ALP-BV-26
ALLP-RV-5
ALP-BV-29
ALP-BV-27
ALP-BV-28
ALP-SP-5
ALP-SP-6
ALP-SP-4
ALP-QD-7,8
DOOR/LOCK RING EQUALIZATION
ALP-BV-24
ALP-BV-25
OXLP-QD-3,4
ALP-QD-5,6
ALP-NS-7
ALP-FF-2
OXLP-CV-2
ALP-CV-7
ALP-CV-6
ALP-IL-2
NATO FLANGE INTERLOCK
OXLP-NV-5
ALP-BV-21
OXLP-RV-2
ALP-BV-22
ALP-BV-23
ALP-NS-8
ALP-RV-4
ALP-GA-7
EXHAUST
OXLP-NV-4
ALP-NV-4
ALP-CV-5
AHP-GA-3
OXHP-REG-2
AHP-REG-3
OXLP-FIL-2
OXHP-FIL-2
ALP-FIL-1
AHP-FIL-3
OXLP-CAP-2
OXHP-CAP-2
ALP-CAP-1
AHP-CAP-3
SECONDARY OXYGEN BIBS SUPPLY
PRIMARY OXYGEN BIBS SUPPLY
SECONDARY SUPPLY
PRIMARY SUPPLY
LEGEND
MUFFLER
FLOWMETER
GAUGE
BALL VALVE
NEEDLE VALVE
RELIEF VALVE
ANTI-SQUEEZE PLUG
CONNECTOR
REGULATOR
FILTER
CAP W/CHAIN
QUICK DISCONNECT
FLOW FUSE
CHECK VALVE
NEDU TRANSFER LOCK
MODEL III
NEDU DWG NO
TLDIA

Figure 2

the cannister in the model II. The scrubber jet is similar in design to the earlier model except that the jet is socket welded to a threaded fitting. The jet is pressurized from a needle valve now instead of from a hand loaded regulator. The scrubber is physically located before the patient's head instead of over his chest, and this has greatly improved the use of available space around the patient.

F. SERVICE LOCK LOCATION AND CONTROLS

The service lock has been relocated to beneath the litter from over the patient's chest, again, making far better use of usable space. The service lock has it's o-ring on the door this time and the system has a safety interlock which will prevent the inadvertent opening of the service lock door without a seal on the service lock inner door.

G. DOOR SIZES AND HINGE MECHANISMS

Manway doors on the TL and the manway door on the TC are now the same size. This has greatly increased the usable space in the TL. The door to the TC is hung on a bulkhead mounted hinge instead of on a hook and rod as in the model II. The TL has securing points to hold the doors securely against the bulkhead when the chamber is open.

H. BIBS MANIFOLDS

BIBS manifolds and quick disconnect fittings have been relocated to beneath the litter to further improve the use of space above the patient. All piping is now below the litter assembly.

I. TELEDYNE O_2 MONITOR

The model III came equipped with a Teledyne model 354 oxygen analyzer instead of the model 320B.

III. EVALUATION PROCEDURES, RESULTS AND CONCLUSIONS

A. INITIAL EVALUATION OF DESIGN CHANGES

The model III was delivered to Naval Civil Engineering Laboratory (NCEL) in mid June 1990 for initial evaluation. During this period, the system was inspected for compliance with contract specifications, hydrostatic tests on piping and valve seat tightness tests on all valves were accomplished. The chamber was test operated manned and unmanned. The mating assembly was tested repeatedly and leak tested to the working pressure of the chamber. The mating assembly was disassembled and reassembled for familiarization purposes. The deficiencies noted in Appendix B to reference 2 were specifically evaluated on the model III. It was found that either improvements in the design or the manufacturing procedures prevented a repeat of any of the deficiencies listed for model II. All design change recommendations listed in Appendix B to reference 2 were incorporated into the final design of the model III, except:

#2 redesign of the undercarrige,--this was found to be outside of the scope of the contract under which the model III was built. The recommendation remains for procurement models.

#9 control of chamber heat and humidity,--also outside of the scope of the contract. This remains a critical issue in the successful employment of the TRC system, and will be discussed further below. This design change recommendation also remains for procurement models.

#10 BIBS hoses were found to be excessive in length. Since the Scott aviation BIBS mask assemblies are supplied with 72 inch hose lengths, they will have to be shortened by the user commands.

B. FITUP EVALUATION WITH FLEET DIVING UNIT PACIFIC (CANADIAN FORCES) TREATMENT CHAMBER

In order to test the matability of the TRC to a definitive treatment chamber (DTC), the model III was taken to the Fleet Diving Unit Pacific (FDU Pacific) diving center at the

Esquimalt, British Columbia naval station. FDU Pacific (and Atlantic), maintain a large DTC equipped with a female NATO mating adaptor for use with their Draeger Duocom transportable chamber system. It was found at this visit that the lug thickness dimension of the male flange on the TRC was over sized. It was in fact possible to achieve a fitup, but the oversized lug prevented the chamber from being rotated into the fully locked position. A further rotation of 3/4 inch would have allowed the mating assembly to rotate to its fully secured position. Although this lack of full rotation did not produce a safety problem, it was decided to forego a manned transfer at depth until the oversized lug could be corrected.

Prior to testing of the TRCS CO_2 scrubber system at NEDU following the field evaluation at FDU Pacific, the male flange was re-machined to its appropriate thickness, and a successful hydrostatic test of the TRCS in the mated configuration was accomplished. The model III male and female flanges now have lug dimensions that properly conform to the NATO STANAG mating adaptor plan.

This field evaluation pointed out the need for special rigging to be prepared which will be compatible with the chain hoist and available space at the DTC site. Further, the entire evolution of transporting the TC by air with occupants under pressure and hyperbaric oxygen therapy in progress, of making the fitup to the DTC, and finally making the transfer of occupants from the TC to the DTC with the complex at depth all needs to be properly described in a Protocol, and the protocol will need periodic rehearsal by the diving commands using the TRCS in remote locations.

C. PERFORMANCE EVALUATION OF CO_2 SCRUBBER

After the field evaluation at FDU Pacific was finished, the model III was returned to NEDU to conduct a test of the life support system, and to test the effect of external, evaporative cooling (discussed below). The procedures for the scrubber evaluation were exactly those employed in the evaluation of the scrubber for the model II. This included finding the optimal jet pressure settings and their corresponding flow rates (Appendix A, figures A1 through A4), finding the steady state chamber CO_2 that these settings would produce (Appendix A, figures A5 through A7) and determining the duration of a cannister operated at the prescribed setting (Appendix A, figures A8 through A10). This was accomplished for 30, 60 and 165 FSW depths. In general, the scrubber performed well, and gas consumption in the model III was found to be marginally less than in the model II. The results of the life support study are displayed in Appendix A (tables A1 and A2 and figures A1 through A10). A detailed explanation of the methods and results for the conduct of the life support study are contained in Appendix A to this report.

D. EVALUATION OF THE EVAPORATIVE COOLING TECHNIQUE

During the course of the scrubber study, a trial of the effectiveness of external evaporative cooling of the chamber shell was conducted, figure 3. In this trial, the chamber system was placed outside the building, but was shaded from direct sunlight. The chamber was covered with terry cloth towels, and the towels were kept constantly wet with fresh water. The ambient temperature during the trial ranged from 95-99° F, and relative humidity was 80-95%. Temperature probes were mounted inside the chamber, measuring the dry bulb temperature of the chamber air, and outside on the chamber shell. This trial demonstrated that this technique is effective. The chamber shell and internal dry bulb temperatures were maintained approximately 11° below ambient. However, the trial also demonstrated that a heat removal system will be required in extreme climates, since the chamber temperature could not be cooled below 85° F. Internal cooling is a promising method currently in use on newer U.S. Navy recompression chambers.

IV. RECOMMENDATIONS

A. Recommended for fleet use.

B. Recommend a funded research effort to develop a chamber heater/cooler system.

C. Recommend development of a design and procedure for coupling the TC while under pressure, to a non nato ring fitted chamber in order to conduct a transfer of personnel with the chamber at depth.

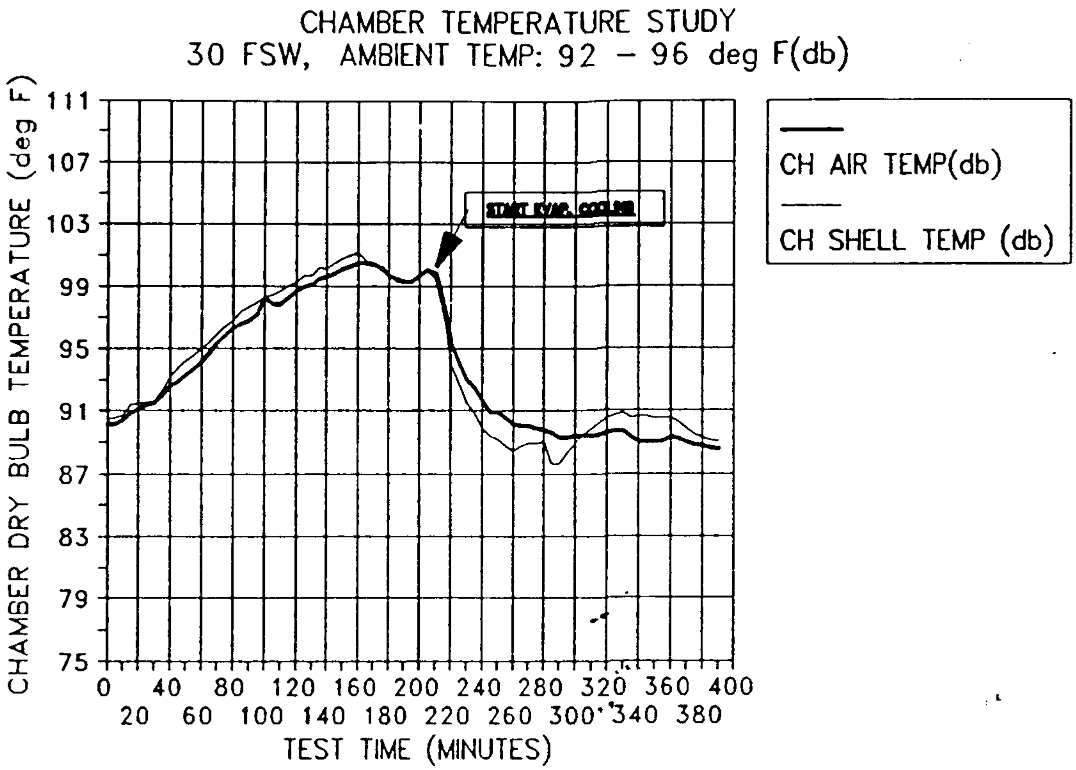

CHAMBER TEMPERATURE STUDY
30 FSW, AMBIENT TEMP: 92 - 96 deg F(db)
CHAMBER DRY BULB TEMPERATURE (deg F)
111
107
103
99
95
91
87
83
79
75
0 40 80 120 160 200 240 280 320 360 400
20 60 100 140 180 220 260 300 340 380
TEST TIME (MINUTES)
CH AIR TEMP(db)
CH SHELL TEMP (db)

Figure 3

D. Recommend including an oxygen and an air storage supply as an integral part of the TC chassis with sufficient storage volume to permit transportation by air to a DTC site.

E. Recommend establishing a formal relationship with Canadian Forces to use their FDU Pacific and Atlantic DTC's on a standby basis during Arctic diving operations, and that this be further supported by:

1. Building appropriate lift and handling adaptors for the TC.

2. Preparing a comprehensive protocol for transport under pressure, fitup to the DTC, and transfer under pressure.

3. Practicing the entire evolution with operational diving commands.

REFERENCES

1. NAVSEA Task 88-023.

2. NEDU Report 7-90, Evaluation of Paracel Transportable Recompression Chamber System.

3. NEDU Report 8-90, Unmanned Testing of the Paracel Transportable Recompression Chamber System Carbon Dioxide Scrubber.

APPENDIX A

TRCS CO_2 SCRUBBER PERFORMANCE TESTS

1. The purpose of the scrubber performance tests conducted were to establish whether or not the Model III scrubber could provide an adequate atmosphere in the TC. The tests conducted were identical to those used to test the Model II TRCS scrubber (reference 3), with the following exceptions:

a. A model treatment table 6A using variable CO_2 injection rates was not considered necessary and not accomplished.

b. To establish CO_2 steady state values at various supply pressure settings, this study started the scrubber after the chamber CO_2 was raised to 1.5% SEV, rather than when the chamber atmosphere was at its natural, ambient value (about 0.03% on the surface). This change to the testing procedure was made because it models the responsiveness of a fresh Sodasorb bed to a chamber atmosphere which has reached the allowable upper limit. A conservative, worst case evaluation is obtained.

2. The following are the questions to be answered by this study.

a. Will the Model III scrubber provide a chamber atmosphere sufficiently below 1.5% SEV CO_2 in order to be considered safe to operate?

b. If so, what is the optimal jet pressure to be set at each depth (30, 60, 165 FSW) (achieves a desirable steady state PCO_2 while minimizing pressurization air consumption)? What are the steady state PCO_2 values to be expected at each depth?

c. Once jet pressure settings at each depth are established, what is the expected rate of pressurization air consumption, and thus, what is the total compressed air requirement for the safe operation of the TC for its intended use (treatment tables 5, 6, 6A)?

d. Finally, what is the safe cannister duration limit to be used by fleet operators?

3. Methods. Similar to the previous study, a CO_2 injection rate of 1 SLPM (dry) was used to model metabolic production. CO_2 was injected continuously using a Matheson mass flow controller. The operation of the controller was secondarily verified by measuring the decreasing CO_2 bottle weight. CO_2 samples were then drawn continuously from the TC centroid and from the inside of the scrubber exhaust tube. During each of the scrubber study protocols, the following data was recorded at five minute intervals: fractional CO_2 in the cannister effluent ($PCO_{2(1)}$) in PPM; fractional CO_2 in the chamber atmosphere ($PCO_{2(2)}$) in PPM, chamber dry bulb temperature, chamber shell temperature, bottle weight. At the beginning of each timed trial, ambient temperature and relative humidity were recorded. The trials seeking a high chamber PCO_2 used a "target" of PCO_2 = 1.5% SEV, which was read in fractional concentration:

DEPTH	TARGET PCO_2
at 30 FSW	= 7857 PPM
at 60 FSW	= 5323 PPM
at 165 FSW	= 2500 PPM

4. The first test protocol was designed to find optimal jet pressurization settings. The goal was to achieve a chamber steady state PCO_2 below the allowable upper limit and to minimize the consumption of the compressed air supply. Air consumption (and, indirectly jet efficiency) was measured at each jet pressure level with a Rotometer and stopwatch. F(1) in table A1 flow (LPM) is the primary flow through the jet nozzle with no cannister in place, and the cannister inlet plugged. F(2) flow (LPM) is the total draw through a filled Sodasorb bed plus the jet pressurization gas. The ratio F2/F1 was computed in order to ensure measured readings were nearly correct. The F2/F1 value as a function of jet pressure is a linear relationship in the range that the scrubber jet acts as a sonic orifice. The jet flow and bed flow rates for 0, 30, 60 and 165 FSW are graphed in figures A1 through A4. In the final part of the protocol, the chamber PCO_2 was raised to 1.5% SEV at each depth before the scrubber with a fresh sodasorb bed in place was started at various jet pressure settings. Data was then recorded for one hour on each trial. The results are plotted in figures A5 through A7. From these trials, the optimal jet pressurization settings were chosen and their corresponding air consumption values and PCO_2 steady state values were noted. These results are displayed in table A2.

A modified steady state test was conducted. In this version the chamber PCO_2 was not initially raised to 1.5% SEV, but left at normal atmospheric air values. It was observed in these one hour trials at the jet pressurization levels considered "optimal," that the steady state PCO_2 value was identical to that found earlier when the trial had chamber PCO_2 starting at the upper limit. It is felt that this demonstrates an important characteristic of the scrubber system, to overcome a high PCO_2 level (such as at the time of a cannister change). Graphs and tables for this trial were not deemed necessary.

5. The final test protocol was designed to determine cannister duration. At each depth, the chamber PCO_2 was initially raised to 1.5% SEV before the scrubber was started with a fresh Sodasorb bed in place. The scrubber was pressurized at the previously determined optimal jet pressure and data was recorded at five minute intervals until chamber atmosphere PCO_2 rose above 1.5% SEV. These results are graphed in figures A8 through A10. The unusual spike noticed in figure A9 occurred when scrubber pressurization air was lost for a period of approximately five minutes due to a mechanical problem outside the experiment. In a real scenario, this represents the time it might take to shift to another air source or to repair a leaky hose fitting. In such a situation, the supervisor could place the divers on air BIBS so that chamber PCO_2 would not rise so dramatically. In the event an alternative air source were not available, the divers could be instructed to inhale chamber atmosphere and exhale into the BIBS in order to prevent a high PCO_2 level. It is instructive to see how, after air pressure to the jet was restored, the scrubber very quickly returned chamber PCO_2 to its previous level. The recommended cannister durations at each depth are also included in table A2.

6. Of the other data recorded, the temperatures measurements showed that chamber temperature will generally rise above ambient temperature initially, then cool to nearly ambient. This is probably due to the semi-closed nature of the system.

7. Other Observations

a. After more than 100 hours of operation, the scrubber system and depth control system of the TC experienced 0 failures.

b. Operators assigned to the project all commented on the ease of maintaining depth control. A treatment could be conducted by one operator and one inside tender on this system.

c. The model III scrubber outperformed the model II in terms of gas consumption and cannister duration.

TABLE A1

GAS CONSUMPTION MEASUREMENTS

Scrubber Jef Efficiency Trials
Date: 30 July 1990 / 7 August 1990

DEPTH	JET PRESS	F(1) FLOW	F(2) FLOW	F2/F1
0	50	11.8	83.0	7
0	70	14.2	104.0	7
0	100	18.0	121.0	7
0	125	22.0	136.0	6
0	150	25.7	145.0	6
0	170	28.6	155.6	5
30	50	5.9	53.5	9
30	70	7.5	68.0	9
30	100	9.8	85.0	9
30	125	11.8	95.0	8
30	150	13.9	105.0	8
30	170	14.5	116.0	8
60	50	3.6	36.8	10
60	70	5.0	49.0	10
60	100	6.7	64.0	10
60	125	8.1	74.0	9
60	150	9.5	82.0	9
60	170	10.3	87.0	8
165	50			
165	70			
165	100	2.4	26.0	11
165	125	3.6	36.0	10
165	150	4.3	45.0	10
165	170	4.8	51.2	11
165	175	5.0	52.0	10
165	200	5.7	57.5	10

TABLE A2

RECOMMENDED CO_2 SCRUBBER OPERATING PARAMETERS AND GAS CONSUMPTION

CHAMBER DEPTH (FSW)	JET PRESSURE (PSIG)	GAS CONSUMPTION (L/MIN)	BED FLOW RATE (L/MIN)	STEADY STATE CO_2 (PPM)	CANISTER DURATION (MINUTES)
30	50	6	52	6900	380
60	100	7	65	3700	440
165	170	5	50	2100	340

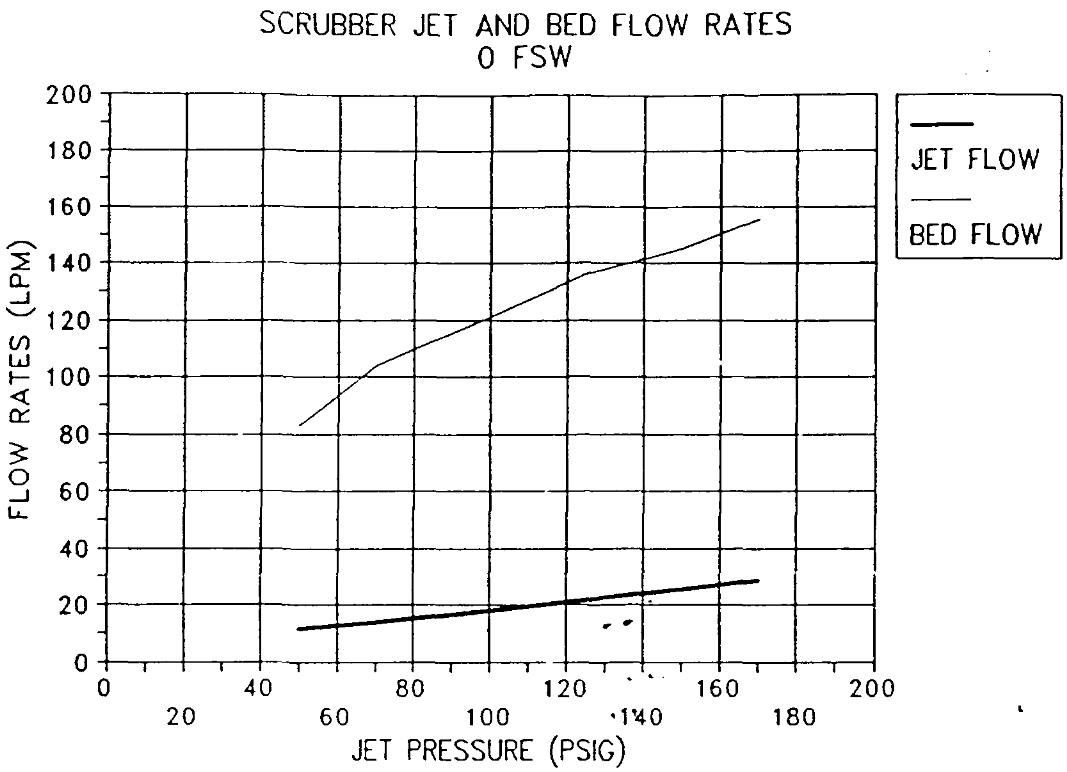

SCRUBBER JET AND BED FLOW RATES
0 FSW
FLOW RATES (LPM)
JET PRESSURE (PSIG)
JET FLOW
BED FLOW
0
20
40
60
80
100
120
140
160
180
200

Figure A1

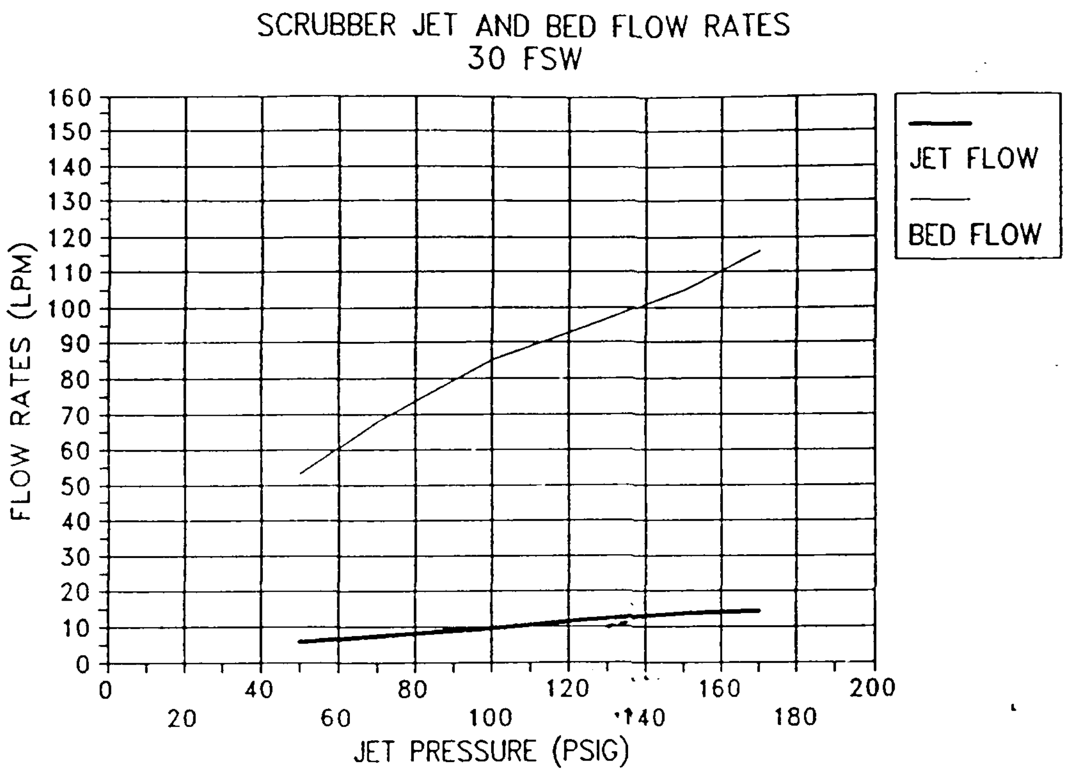

SCRUBBER JET AND BED FLOW RATES
30 FSW
FLOW RATES (LPM)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
JET PRESSURE (PSIG)
JET FLOW
BED FLOW

Figure A2

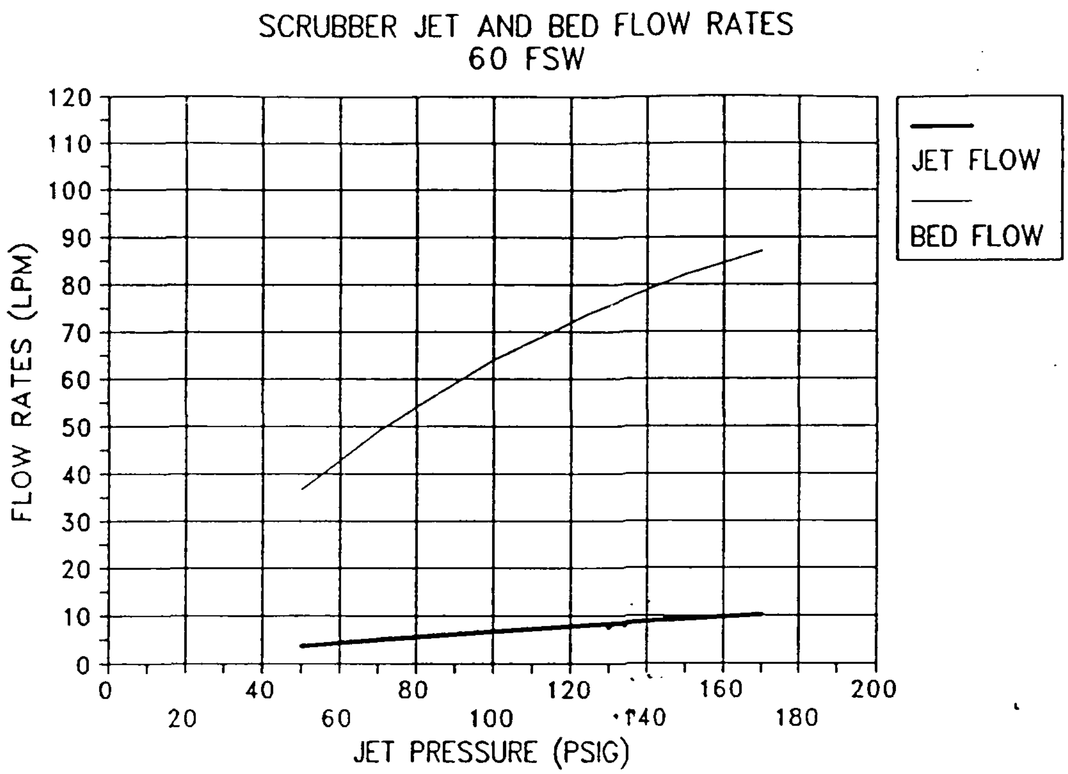

SCRUBBER JET AND BED FLOW RATES
60 FSW
FLOW RATES (LPM)
JET PRESSURE (PSIG)
JET FLOW
BED FLOW
0
10
20
30
40
50
60
70
80
90
100
110
120
0
20
40
60
80
100
120
140
160
180
200

Figure A3

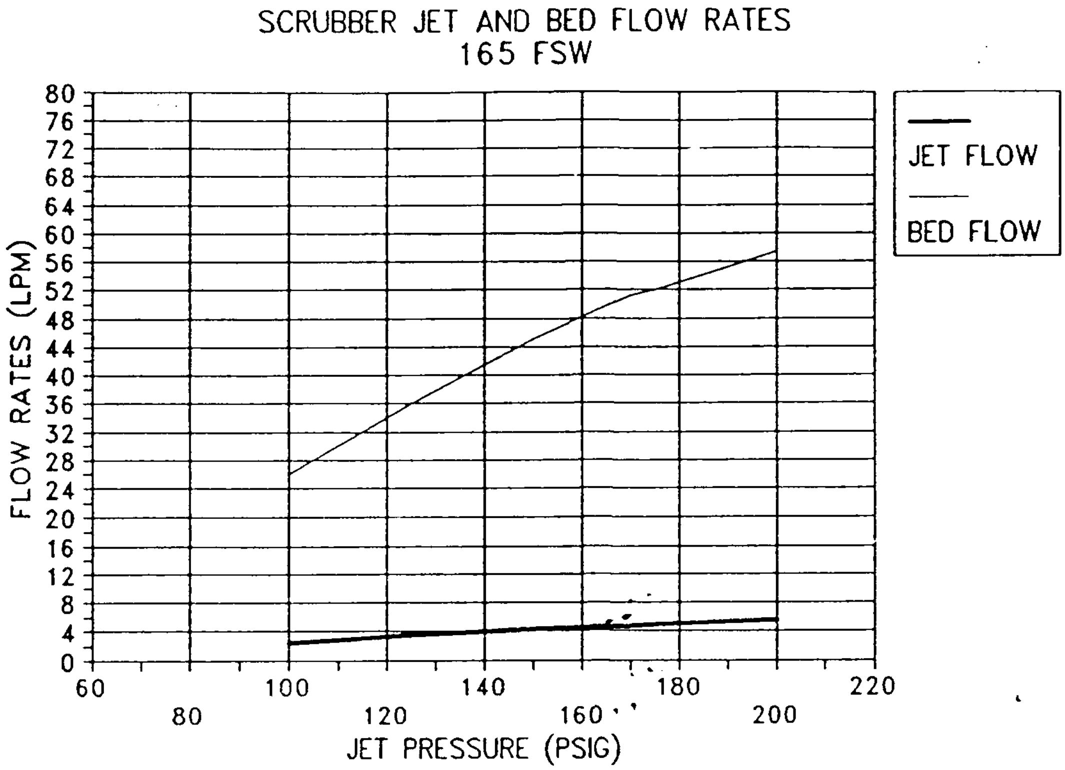

SCRUBBER JET AND BED FLOW RATES
165 FSW
FLOW RATES (LPM)
80
76
72
68
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
60
80
100
120
140
160
180
200
220
JET PRESSURE (PSIG)
JET FLOW
BED FLOW

Figure A4

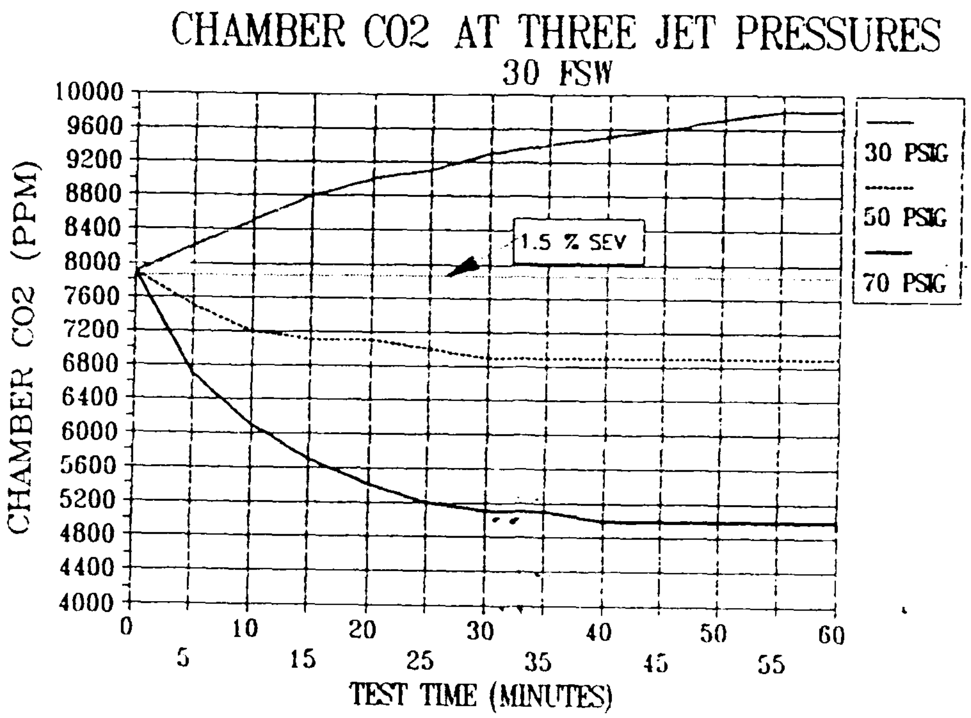
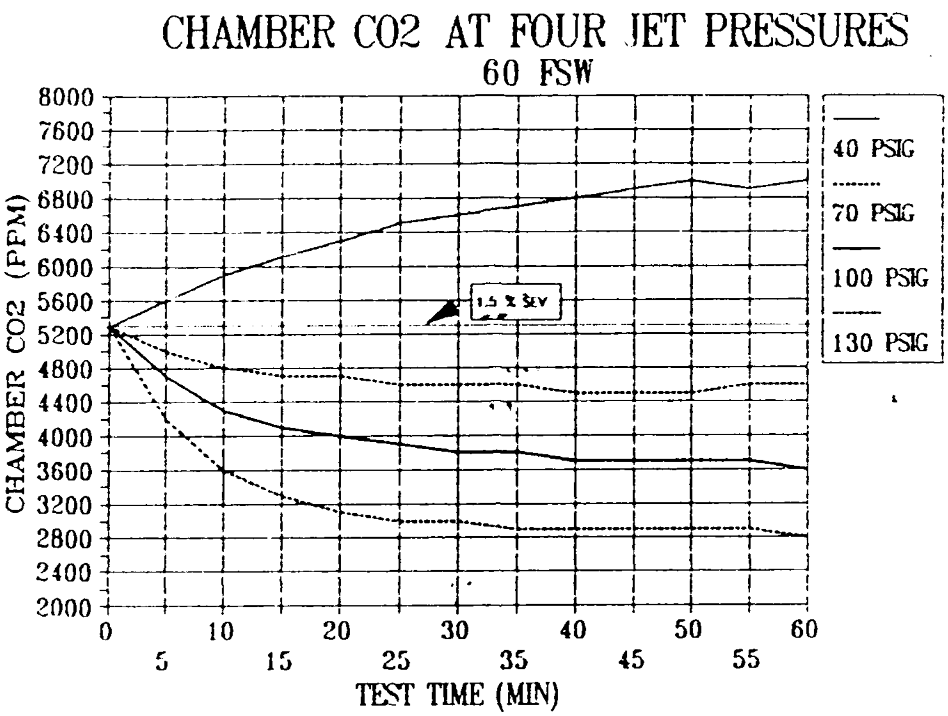

CHAMBER CO2 AT THREE JET PRESSURES
30 FSW
CHAMBER CO2 (PPM)
10000
9600
9200
8800
8400
8000
7600
7200
6800
6400
6000
5600
5200
4800
4400
4000
0
10
20
30
40
50
60
5
15
25
35
45
55
TEST TIME (MINUTES)
1.5 % SEV
30 PSIG
50 PSIG
70 PSIG

Figure A5



CHAMBER CO2 AT FOUR JET PRESSURES
60 FSW
CHAMBER CO2 (PPM)
8000
7600
7200
6800
6400
6000
5600
5200
4800
4400
4000
3600
3200
2800
2400
2000
0
5
10
15
20
25
30
35
40
45
50
55
60
TEST TIME (MIN)
40 PSIG
70 PSIG
100 PSIG
130 PSIG
1.5 % SEV

Figure A6

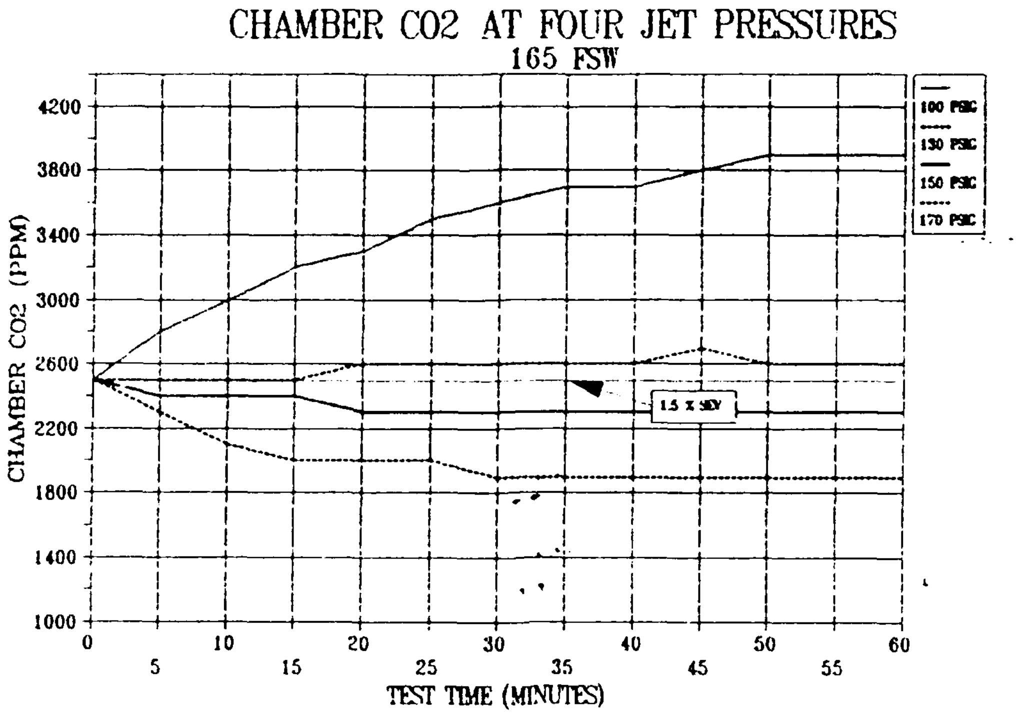
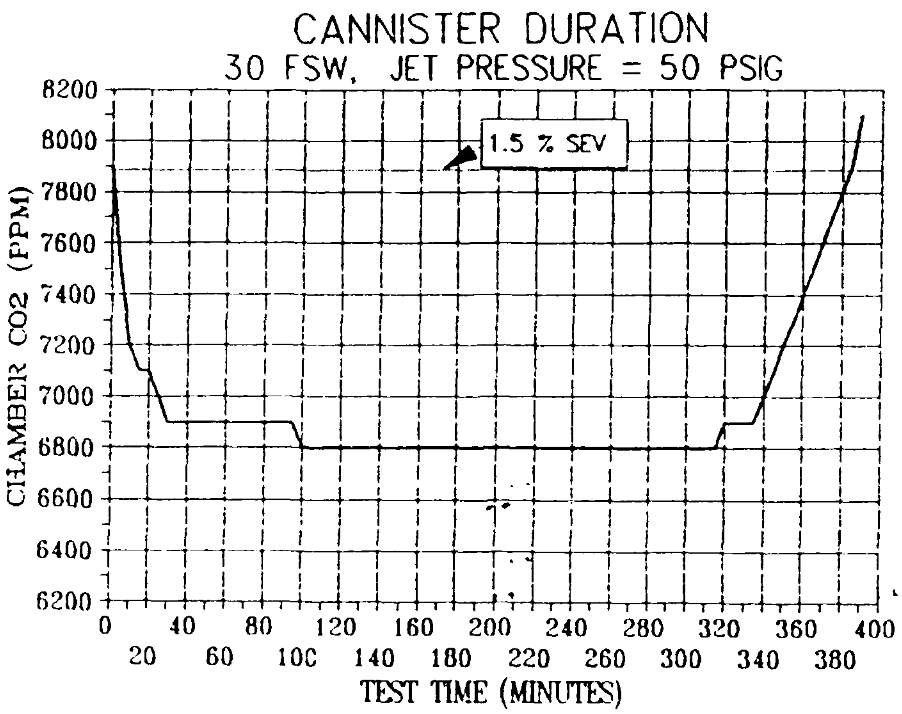

CHAMBER CO2 AT FOUR JET PRESSURES
165 FSW
CHAMBER CO2 (PPM)
4200
3800
3400
3000
2600
2200
1800
1400
1000
0
5
10
15
20
25
30
35
40
45
50
55
60
TEST TIME (MINUTES)
100 PSIG
130 PSIG
150 PSIG
170 PSIG
1.5 X SEV

Figure A7



CANNISTER DURATION
30 FSW, JET PRESSURE = 50 PSIG
CHAMBER CO2 (PPM)
8200
8000
7800
7600
7400
7200
7000
6800
6600
6400
6200
1.5 % SEV
0
40
80
120
160
200
240
280
320
360
400
20
60
100
140
180
220
260
300
340
380
TEST TIME (MINUTES)

Figure A8

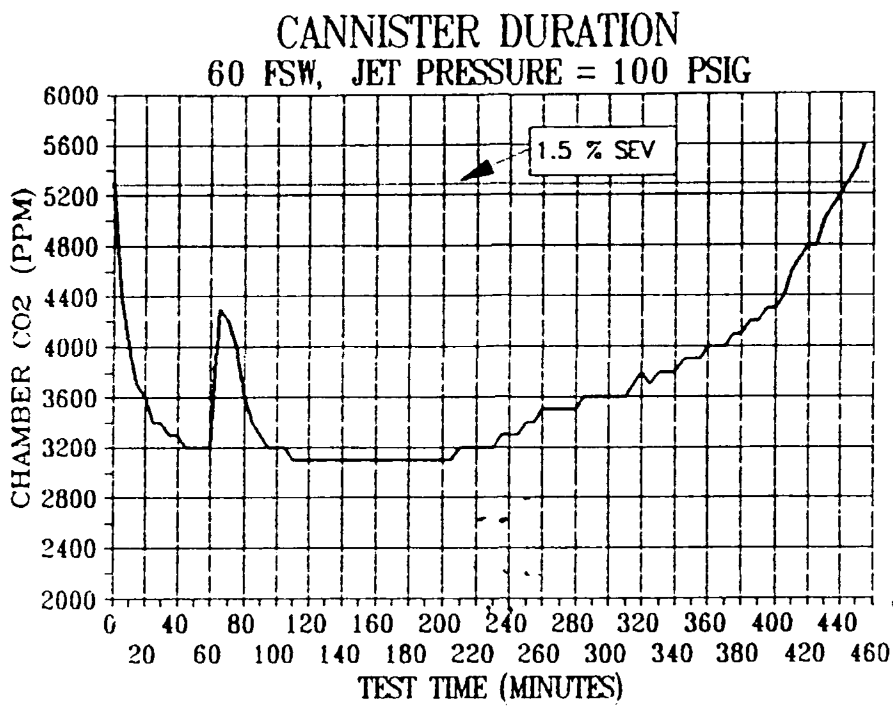

CANNISTER DURATION
60 FSW, JET PRESSURE = 100 PSIG
1.5 % SEV
CHAMBER CO2 (PPM)
6000
5600
5200
4800
4400
4000
3600
3200
2800
2400
2000
0 40 80 120 160 200 240 280 320 360 400 440
20 60 100 140 180 220 260 300 340 380 420 460
TEST TIME (MINUTES)

Figure A9

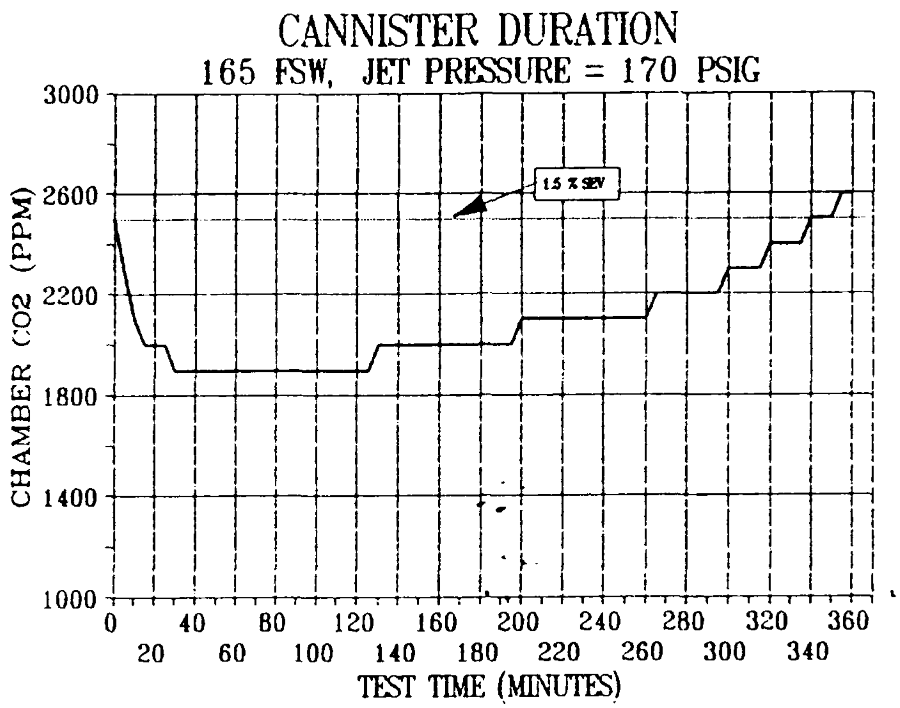

CANNISTER DURATION
165 FSW, JET PRESSURE = 170 PSIG
CHAMBER CO2 (PPM)
3000
2600
2200
1800
1400
1000
1.5 % SEV
0
40
80
120
160
200
240
280
320
360
20
60
100
140
180
220
260
300
340
TEST TIME (MINUTES)

Figure A10