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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 12-93

CONTAMINATED WATER DIVING SYSTEM (CWDS) EVALUATION

LT L. J. CREPEAU

DECEMBER 1993

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)
A contaminated water diving system (CWDS) protects a diver from exposure to water-borne toxic, volatile, corrosive, or microbial agents. A CWDS is comprised of a dry suit and a self-contained underwater breathing apparatus (UBA). Currently, the MK 12 surface-supplied diving system is the only UBA currently authorized by the U. S. Navy for contaminated water diving. This report evaluated five commercially-available dry suits equipped with integral neck dams for use with the MK 21 MOD 1 UBA during manned dives conducted in 3.3 degrees C (42 degrees F) water. Dry suit testing was not conducted in contaminated water; rather, this phase of the evaluation addressed suit construction, ease of don and doff, comfort, and human factors considerations.

Testing of the Viking dry suit was secured during initial evaluation because the inflation valve was located under the safety harness, repeatedly triggering accidental suit inflation and one instance of diver blow-up. The manufacturer subsequently relocated the valve to prevent this from occurring in the future. Except for this design deficiency, all the dry suits received favorable reviews and are recommended for ANU listing for contaminated water diving, provided they are furnished with pockets to accommodate additional ankle weight ballast to enhance stability, and the valves are configured to meet the needs of working divers.

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19. ABSTRACT (Continued)

The second phase of testing determined unmanned work of breathing (WOB) performance in two MK 21 MOD 1 UBAs before and after installation of contaminated water kits. These kits were comprised of double flapper exhaust valves and a secondary water dump valve, designed to prevent water aspiration into the UBA. Testing was conducted to a maximum depth of 60.6 msw (198 fsw), with respiratory minute volume (RMV) reaching 90 liters per minute (LPM).

WOB levels were increased by the contaminated water modifications. Still, the overall increase in WOB between the standard and modified UBAs was marginal in terms of absolute pressures.

In the third phase of testing, a marker dye consisting of a dilute base detectable by litmus paper was added to the water ark; the UBA was then tested to determine the RMV required for water aspiration to occur at 60.6 msw. Water aspiration was noted when a RMV of 62.5 LPM was used, but the helmet interior remained dry when a RMV of 40 LPM was used. Thus, the contaminated water kit imparts a negligible WOB increase, while providing protection from water aspiration. NEDU therefore recommends approving the contaminated water kit for the MK 21 MOD 1 UBA for Navy use.

NEDU also recommends including the five commercially-available dry suits tested in this report on the ANU list, as they protect divers working in contaminated water as well as or better than the MK 12 SSDS, provided the conditions detailed in this report are met.

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INTRODUCTION

In the modern world, divers are often confronted with a myriad of new challenges to personal health and safety in the form of water-borne contaminants. Industrial development has led to occasions of accidental and intentional dumping of various industrial wastes into water systems. For example, from 1977 to 1981, the U. S. Coast Guard Marine Environment and Systems office received reports of 64,609 hazardous spills. Medical wastes have recently been washing up on the shores of beaches used by recreational swimmers. Overcrowding of urban areas adjacent to water systems has resulted in elevated levels of microbial infestation. For purposes of definition in the present context, contamination includes any agent, substance, or microorganism that represents a health threat, either short-term or long-term, to the diver following exposure to it. This study will not address protection of combat divers from chemical warfare agents.

A contaminated water diving system (CWDS) includes a dry suit and an underwater breathing apparatus (UBA). Collectively, these components protect the diver from exposure to tainted water by providing complete encapsulation. A CWDS dry suit must provide protection to the diver equivalent to Level A protection provided HAZMAT workers on dry land, which should include a dry suit configured to mate directly to a full coverage helmet, such as the MK 21[1]. The MK 12 surface-supplied diving system (SSDS) is the only UBA currently authoriz·d by the U. S. Navy for contaminated water diving.[2]

The dry suit outer shell should be made of material that resists permeation by various contaminants and is resistant to a variety of corrosive agents possibly encountered while diving in contaminated water. Additionally, it should be easily rinsed off after diving, to prevent direct contact by the diver while doffing the suit. Finally, it should resist abrasion, and be sufficiently thick to resist incidental puncture. The MK 12 UBA dry suit is made of closed-cell neoprene. However, butyl rubber is less permeable to various chemical compounds including acetone, benzene, cyclohexane, gasoline, methanol, methyl chloroform, and methyl ethyl ketone[3], and thus can provide enhanced protection to a diver working in water contaminated with these agents.

Recent modifications available for the MK 21 MOD 1, developed by Diving Systems International (DSI; Santa Barbara, CA), include double flapper exhaust valves and a secondary water dump valve. These components comprise the contaminated water kit, designed to provide an additional barrier to prevent water from leaking into the helmet along the exhaust gas train. A schematic diagram of the double flapper exhaust valves is included in Appendix A.

NEDU was tasked[4,5] to evaluate five commercially-available dry suits configured to mate directly with the MK 21 helmet to determine their acceptability for use in contaminated water diving. The dry suits evaluated included: 1) the

Avon 1800 Standard Heavy Duty (High Tech Diving and Supply, Punta Gorda, FL); 2) the Nokia Boss (Amron International, Escondido, CA); 3) the Typhoon Pro Front Entry; 4) the Viking HD Combi (Trelleborg Viking, Inc., Turisburg, OH); and 5) the USIA Model 3651 Combat Swimmer Suit (USIA, St. Helens, OR). In addition, NEDU was tasked to evaluate contaminated water kits installed in MK 21 MOD 1 UBAs, to determine how well they orotect divers from exposure to contaminated water.

The present study was divided into three separate phases. First, five commercially-available dry suits were evaluated for fit and function during simulated working dives. These dry suits mated directly with the MK 21 helmet via an integral neck dam. Second, work of breathing (WOB) levels in MK 21 MOD 1 UBAs equipped with the contaminated water kits were measured during unmanned testing[6] in the NEDU Experimental Diving Facility. Third, the ability of the contaminated water kits to prevent ingestion of water into MK 21 UBAs was determined following WOB testing.

MANNED HUMAN FACTORS EVALUATION OF DRY SUITS

Testing was not conducted in contaminated water. The focus of the present study was to determine how well these dry suits met human factors needs to be operationally valuable. The variables that were measured during the first phase of this study entailed: ease of don and doff; suit comfort; buoyancy control; location and operation of the inflation and exhaust valves; apparent suit durability; and ease of cleaning the suit post-dive. Dry suit evaluation was conducted during dives requiring mission-emulating maneuvers, including bottom search, ballast tank maintenance, salvage, and underwater ship husbandry and repair. All diver-subjects were military divers familiar with the operation of dry suits. At least five diver-subjects evaluated each dry suit, to determine consistency of evaluations among people of different body builds.

UNMANNED EVALUATION OF WORK OF BREATHING

Unmanned evaluation determined WOB levels from two modified[7] Navy 350 regulators. We selected the best and worst performing regulators from an original sample of five, to characterize the range of WOB levels that may be expected from regulators currently used in the fleet. Work of breathing levels were obtained from the two regulators after being set up in the standard configuration, and after being equipped with the DSI contaminated water kits. WOB levels were also compared to Performance Goal Standards[8] for umbilical-supplied, open circuit demand regulator (Category II) UBAs. This comparison, which represents an optimal level of performance, was made at a depth of 40.4 msw (132 fsw) using a respiratory minute volume (RMV) of 62.5 liters per minute (LPM). Testing was conducted using facility source air, using 931 kPa (135 psi) volume tank overbottom pressure at all test depths. This pressure was closely monitored and maintained, to ensure uniform work of breathing levels. A breathing machine (Reimers Consultants, Falls Church, VA) provided various RMVs between 22.5 to 90 LPM sinusoidal breathing loops to emulate resting to heavy work rates. Test depths varied from 10.1 to 60.6 msw (33 to 198 fsw). Water temperature remained at ambient, approximately 21.1 °C (70°F).

Separate testing was conducted to determine whether water aspiration would occur at 60.6 msw. The UBA was secured to a blanking plate which was connected to the breathing machine with RTV sealant. Baking soda was added to the water in the chamber test ark to determine if water aspiration occurred, using litmus paper for base pH detection.

RESULTS OF MANNED HUMAN FACTORS DRY SUIT EVALUATION

In general, the diver-subjects rated most design features, comfort, and operation of all candidate dry suits as *adequate* to *excellent* i.e., they received a rating of 4 to 6. In fact, for a majority of the questions, ratings were exclusively *good* or *excellent*. At the same time, there were 13 items on the questionnaire that elicited at least one unsatisfactory rating i.e., they received a rating of 3 or lower. Frequency distributions of diver-subject responses for those cases are graphically depicted in Figures 1-13. For each feature considered, this section will present results for each dry suit that elicited at least one rating below *adequate*. For purposes of comparison, the number of responses from *adequate* to *excellent* for each dry suit is provided in parentheses.

DONNING THE SUIT WITH ASSISTANCE FROM A TENDER (Figure 1): The Nokia suit received one *extremely poor*, one *poor*, and one *not quite adequate* rating (2). The Typhoon suit received one *extremely poor* and one *poor* rating (3). The USIA suit received one *not quite adequate* rating (4).

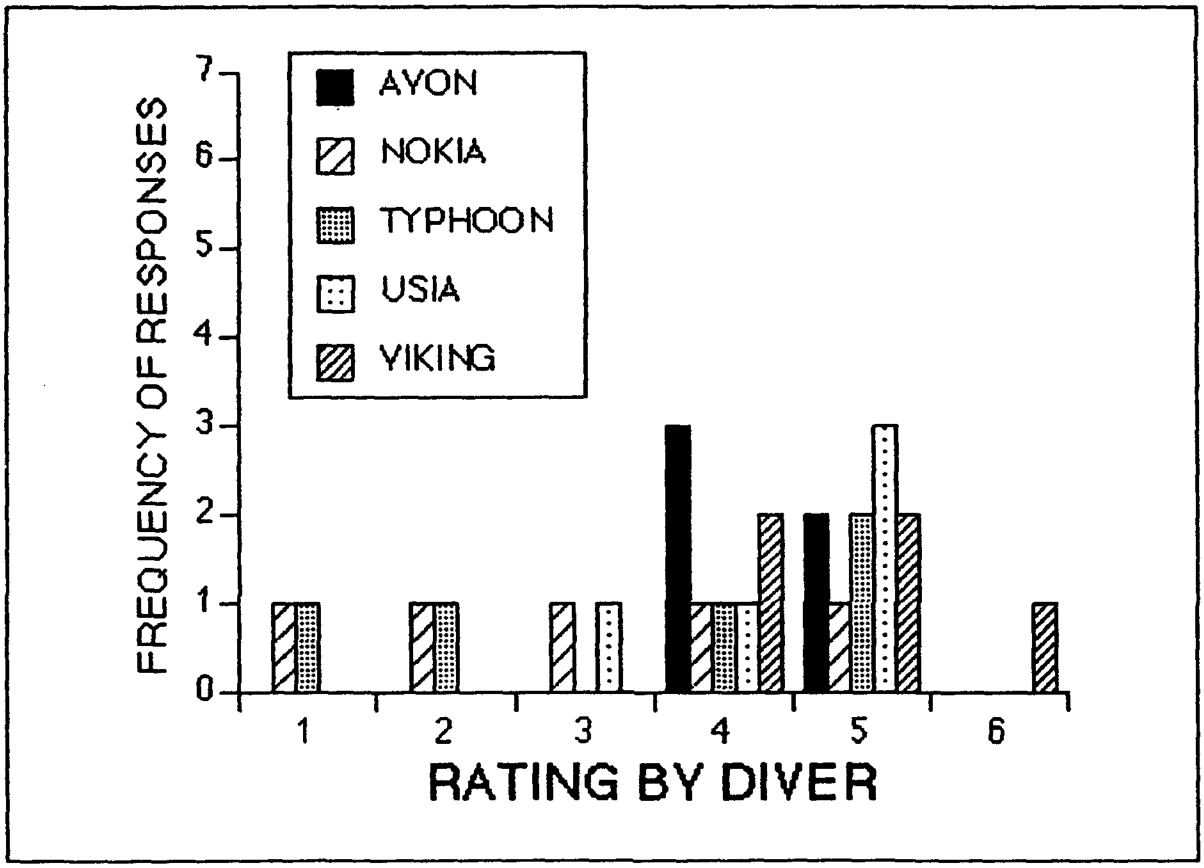

Figure 1

RATING SCALE: 1 = extremely poor 2 = poor 3 = not quite adequate
4 = adequate 5 = good 6 = excellent

DONNING THE SUIT UNASSISTED (Figure 2): The Avon suit received one *extremely poor*, one *poor*, and one *not quite adequate* rating (2). The Nokia suit received one *poor* and one *not quite adequate* rating (3). The Typhoon suit received one *extremely poor* and one *poor* rating (5). The USIA suit received one *poor* and one *not quite adequate* rating (3). The Viking suit received one *extremely poor*, three *poor*, and one *not quite adequate* rating (2).

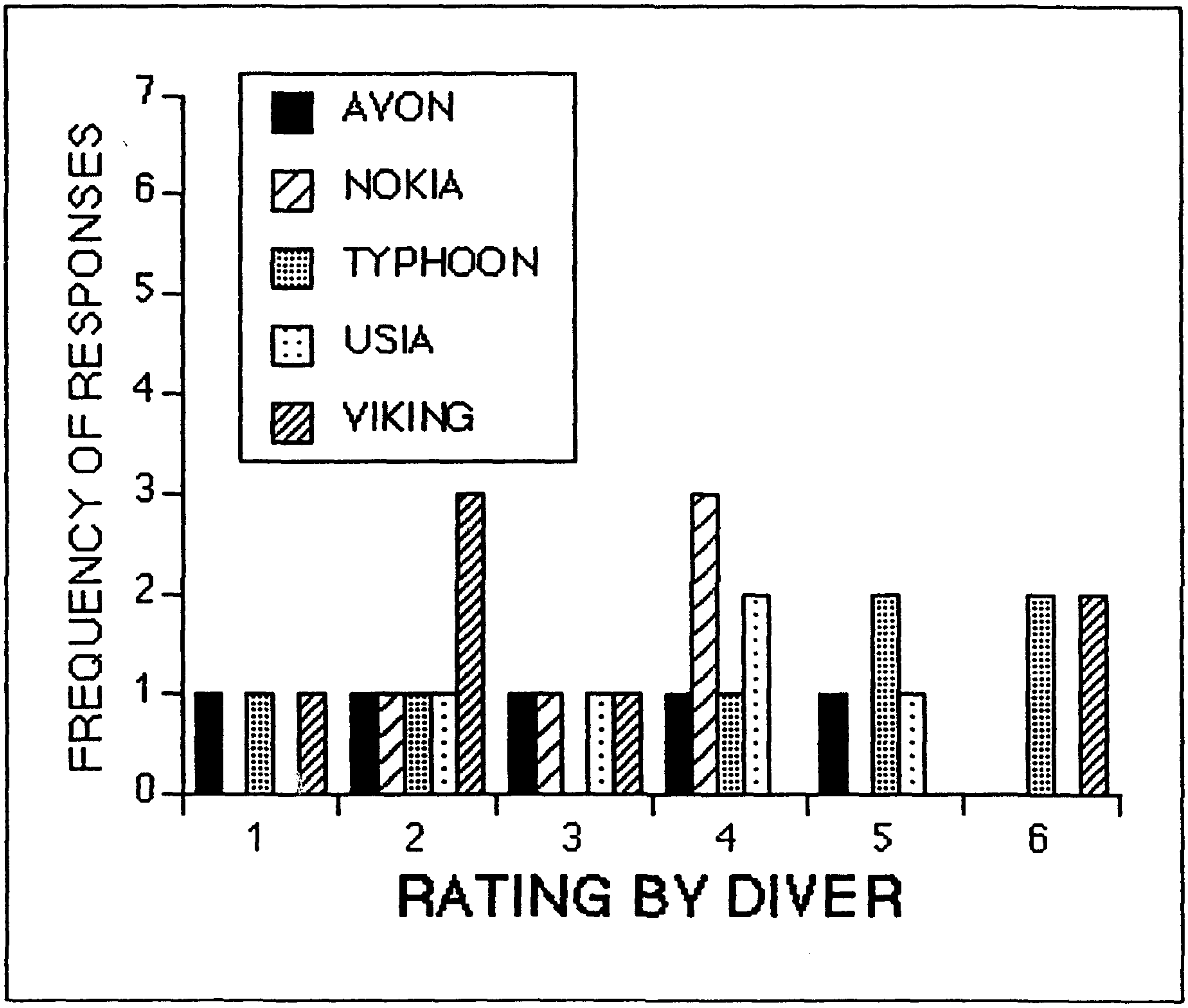

Figure 2

RATING SCALE: 1 = extremely poor 2 = poor 3 = not quite adequate
4 = adequate 5 = good 6 = excellent

DOFFING THE SUIT UNASSISTED (Figure 3): The Avon suit received one *extremely poor* and one *poor* rating (3). The Nokia suit received one *poor* and two *not quite adequate* ratings (2). The Typhoon suit received two *poor* ratings (5). The USIA suit received two *poor* and one *not quite adequate* rating (1). The Viking received one *extremely poor*, two *poor*, and one *not quite adequate* rating (2)

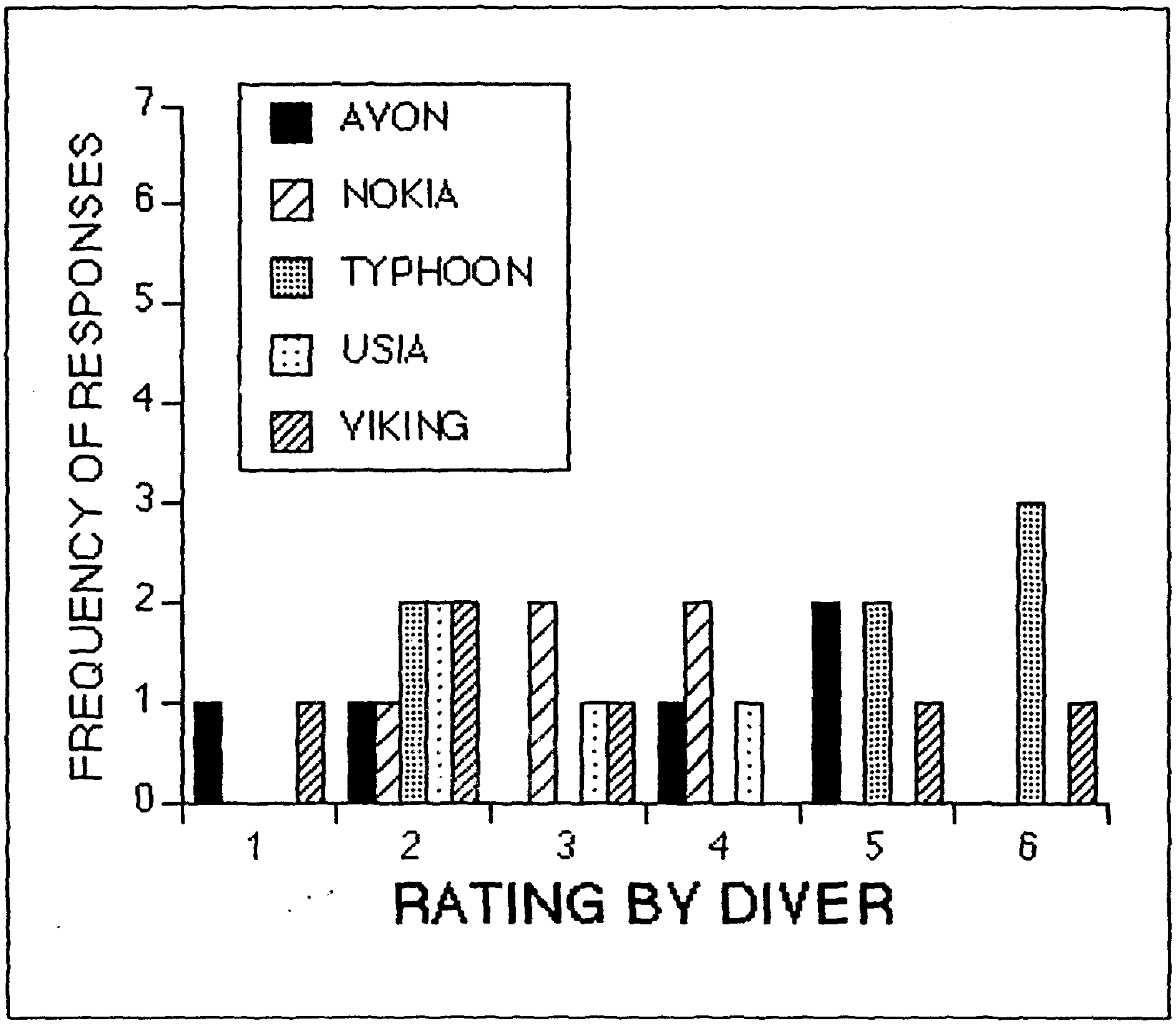

Figure 3

<u>RATING SCALE</u>: 1 = extremely poor 2 = poor 3 = not quite adequate
4 = adequate 5 = good 6 = excellent

OVERALL COMFORT OF THE SUIT (Figure 4): The Avon suit received one *not quite adequate* rating (4). The USIA suit received one *poor* rating (4). The Viking suit received one *not quite adequate* rating (6).

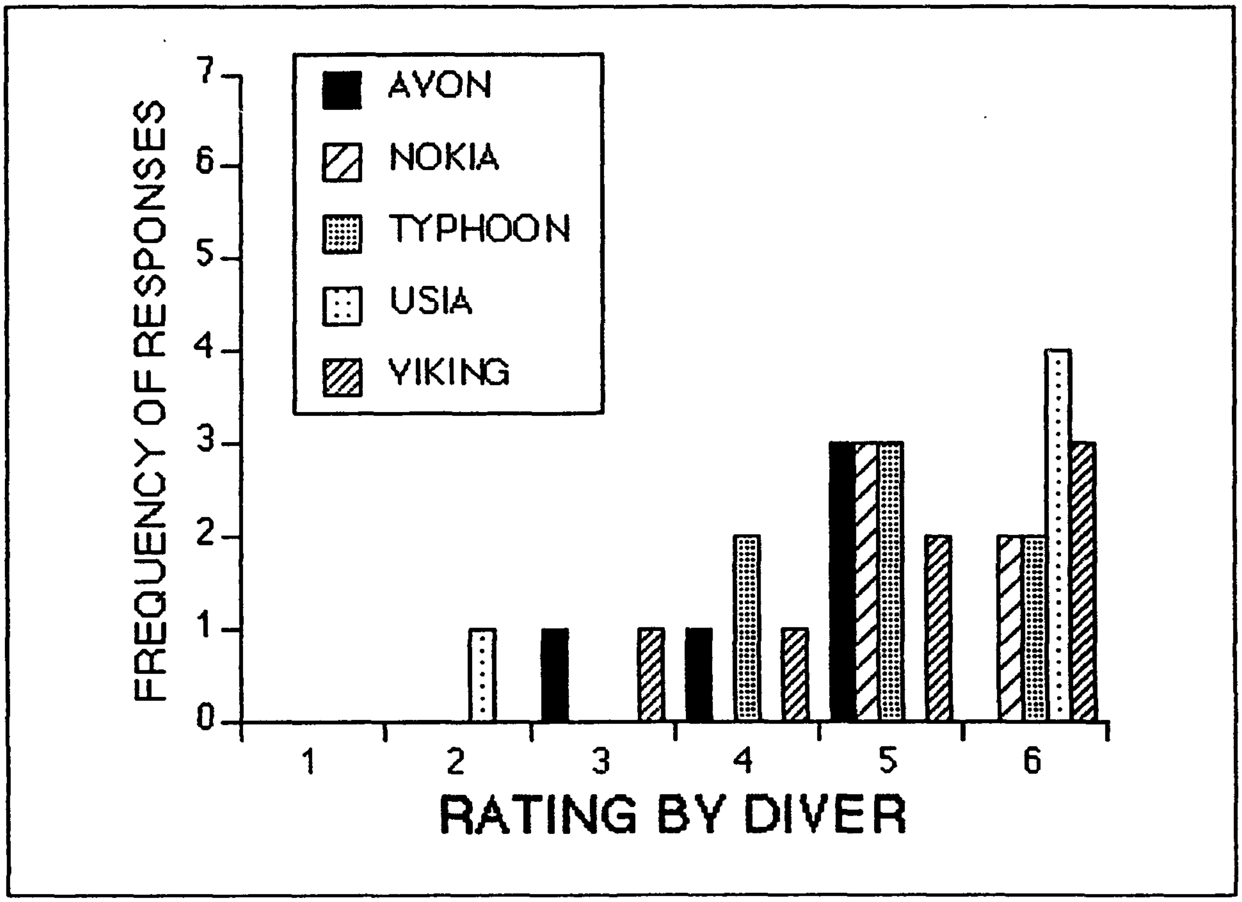

Figure 4

<u>RATING SCALE</u>: 1 = extremely poor   2 = poor   3 = not quite adequate
4 = adequate   5 = good   6 = excellent

COMFORT OF THE SUIT IN TERMS OF BUOYANCY CONTROL (Figure 5): The Avon suit received one *poor* and one *not quite adequate* rating (3). The Typhoon suit received one *not quite adequate* rating (6); and the Viking suit received one *not quite adequate* rating (5).

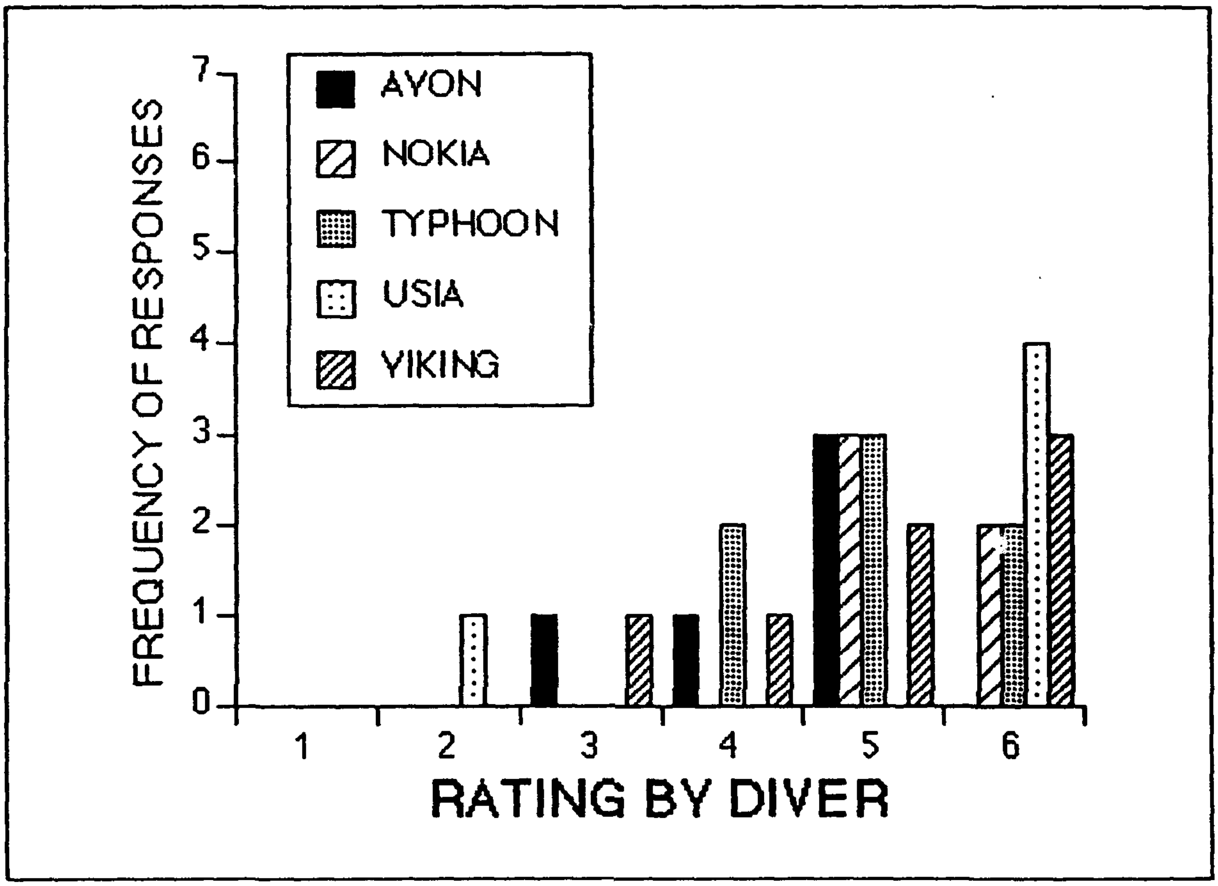

Figure 5

<u>RATING SCALE</u>:	1 = extremely poor	2 = poor	3 = not quite adequate
	4 = adequate	5 = good	6 = excellent

SIZE OF THE SUIT (Figure 6): The Avon suit received one *poor* and one ***not quite adequate*** rating (3). The USIA suit received one ***extremely poor*** rating (4).

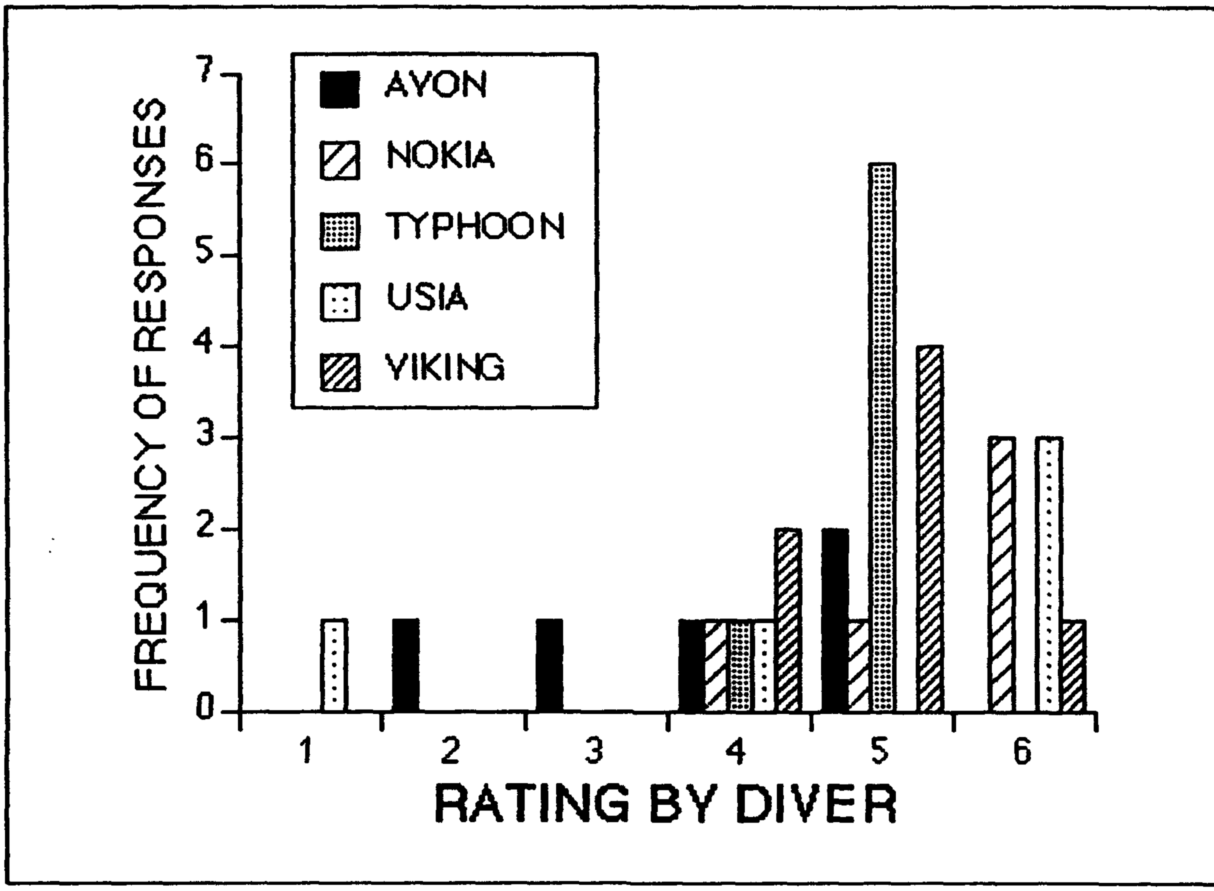

Figure 6

<u>RATING SCALE</u>: 1 = extremely poor 2 = poor 3 = not quite adequate
4 = adequate 5 = good 6 = excellent

LOCATION OF THE INFLATION VALVE (Figure 7): The Avon suit received one *not quite adequate* rating (4). The Viking suit received two *extremely poor*, two *poor*, and one *not quite adequate* rating (2).

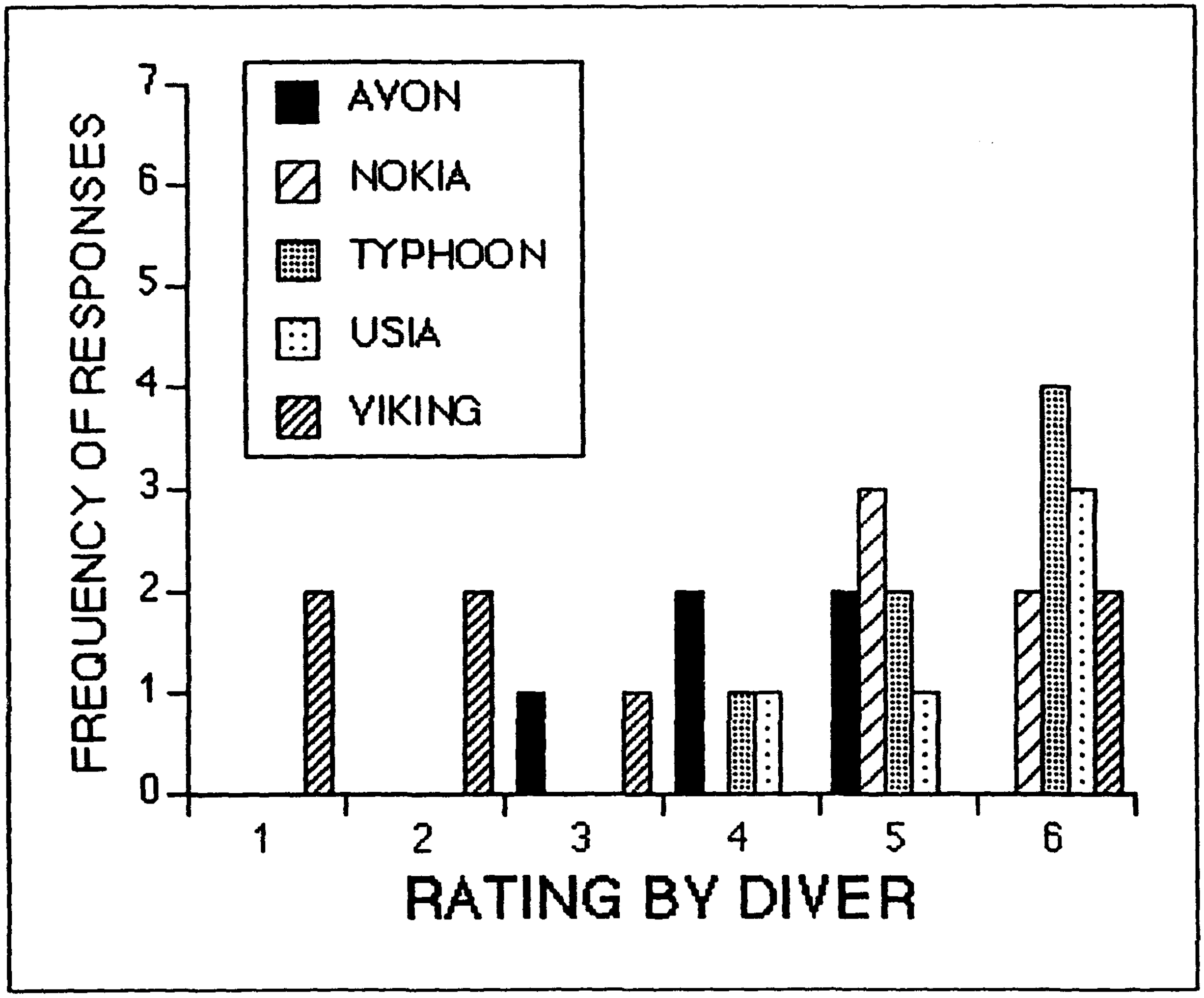

Figure 7

RATING SCALE: 1 = extremely poor 2 = poor 3 = not quite adequate
4 = adequate 5 = good 6 = excellent

OPERATION OF THE INFLATION VALVE (Figure 8): The Avon suit received one *not quite adequate* rating (4). The Viking suit received one *poor* and two *not quite adequate* ratings (4).

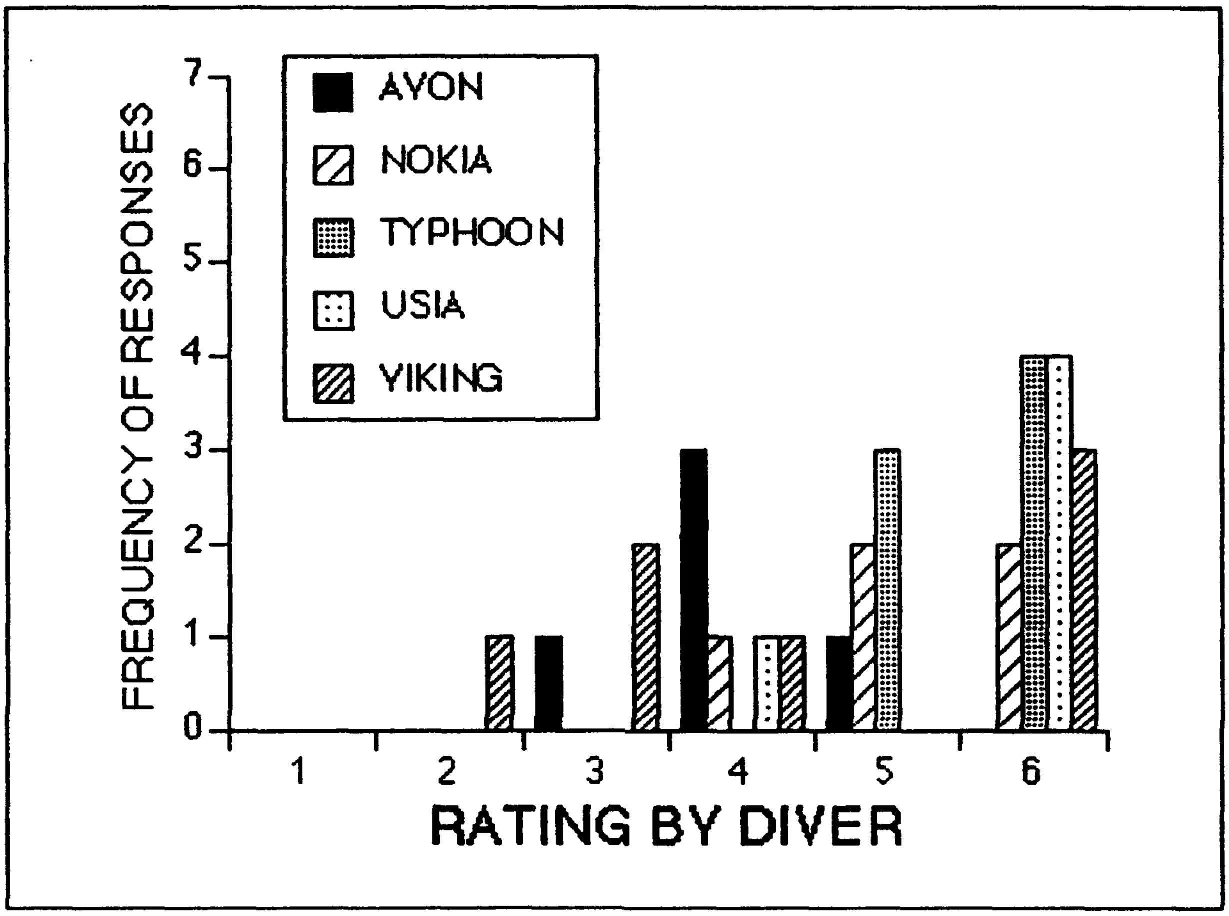

Figure 8

RATING SCALE: 1 = extremely poor   2 = poor   3 = not quite adequate
4 = adequate   5 = good   6 = excellent

LOCATION OF THE EXHAUST VALVE (Figure 9): The Avon suit received two *not quite adequate* ratings (3). The Typhoon suit received three *poor* ratings (4). The Viking suit received one *not quite adequate* rating (6).

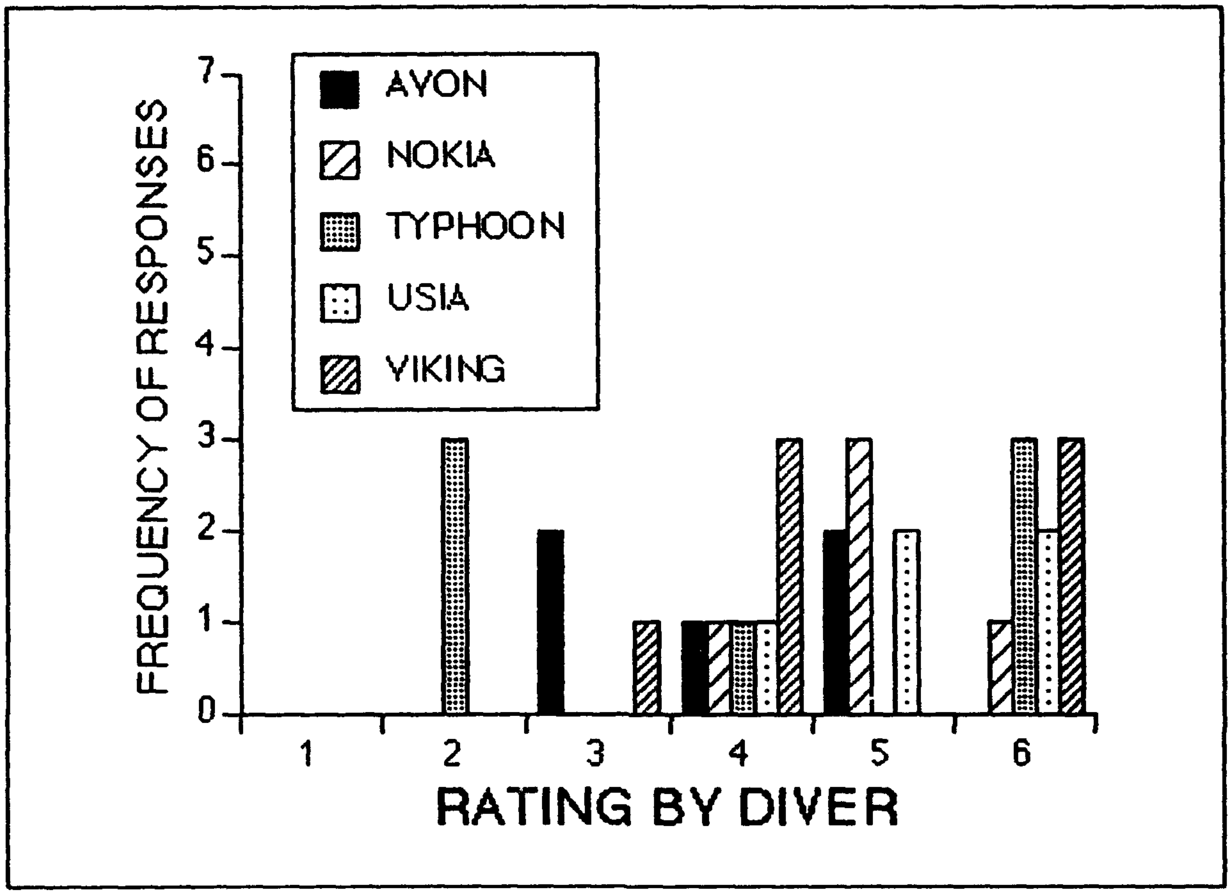

Figure 9

<u>RATING SCALE</u>: 1 = extremely poor 2 = poor 3 = not quite adequate
4 = adequate 5 = good 6 = excellent

OPERATION OF THE EXHAUST VALVE (Figure 10): The Avon suit received one *not quite adequate* rating (4). The Typhoon suit received one *poor* and one *not quite adequate* rating (5).

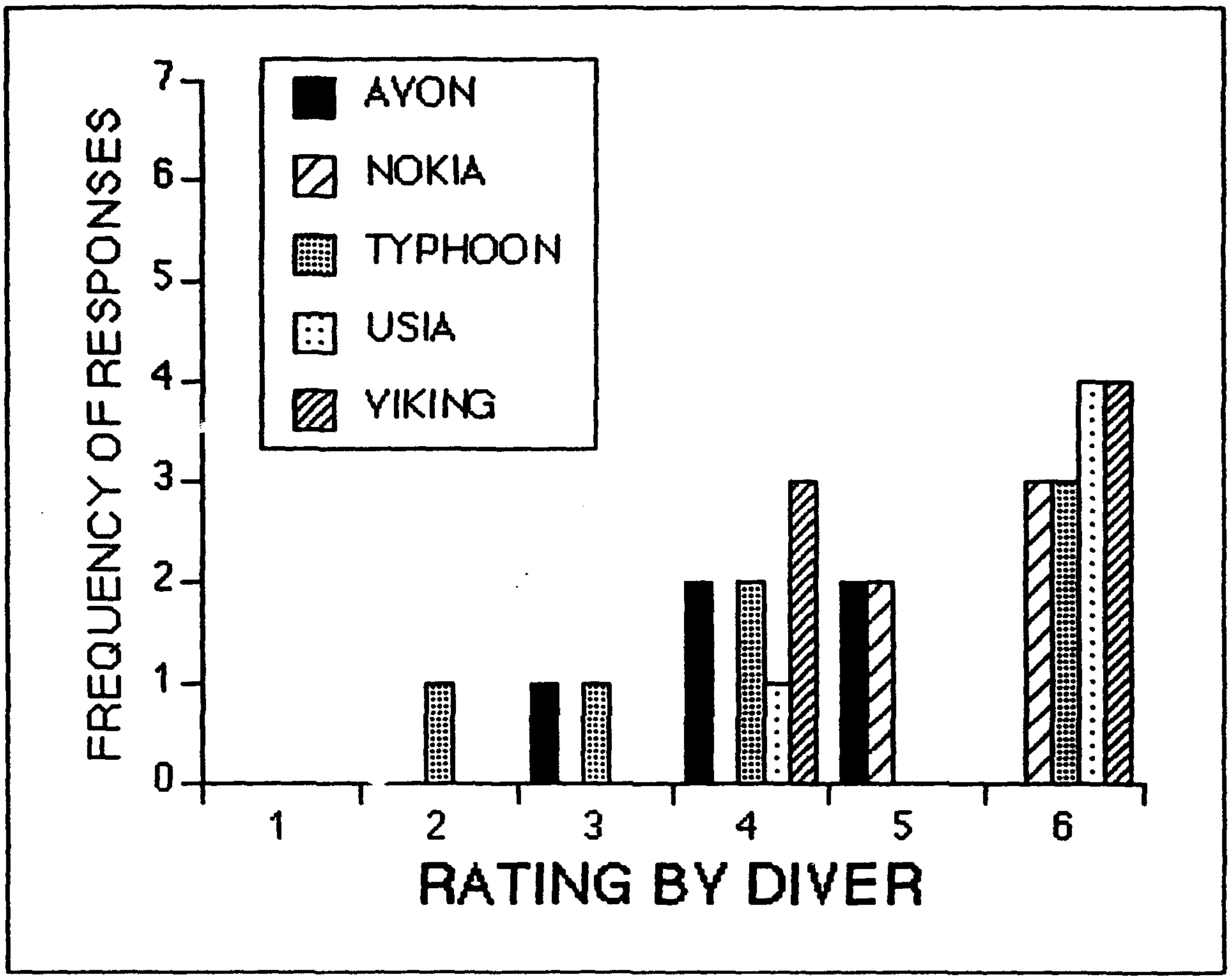

Figure 10

<u>RATING SCALE</u>: 1 = extremely poor 2 = poor 3 = not quite adequate
4 = adequate 5 = good 6 = excellent

ABILITY OF THE SUIT TO KEEP THE DIVER DRY (Figure 11): The Avon suit received one *not quite adequate* rating (4). The Viking suit received one *not quite adequate* rating (6).

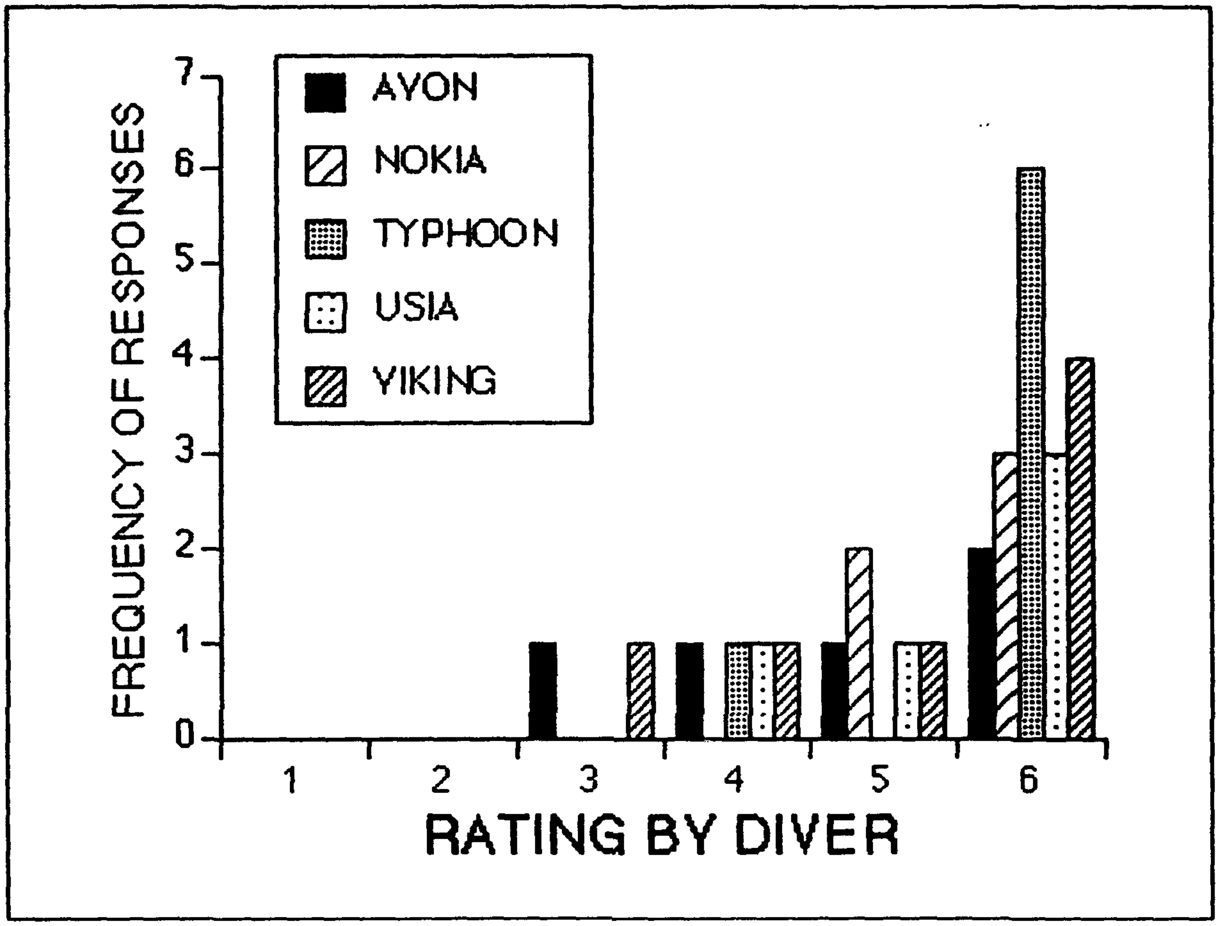

Figure 11

RATING SCALE: 1 = extremely poor, 2 = poor, 3 = not quite adequate, 4 = adequate, 5 = good, 6 = excellent

USE OF THE SUIT FOR CONTAMINATED WATER USE (Figure 12): The Avon suit received one *not quite adequate* rating (4). The Viking suit received one *poor* rating (6).

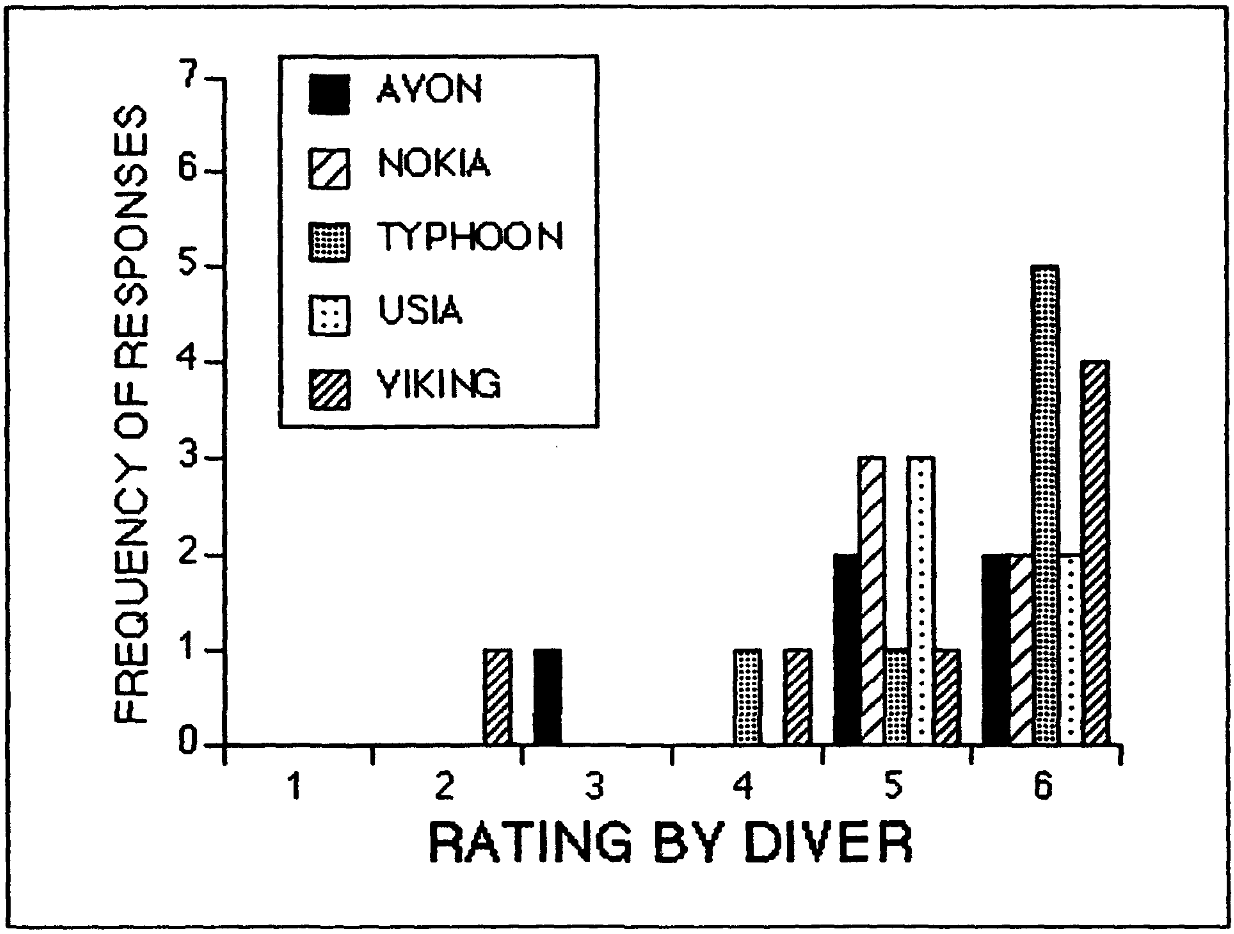

Figure 12

RATING SCALE: 1 = extremely poor 2 = poor 3 = not quite adequate
4 = adequate 5 = good 6 = excellent

USE OF THE SUIT FOR COLD WATER DIVING (Figure 13): The Avon suit received one *not quite adequate* rating (4). The Viking suit received one *poor* rating (6).

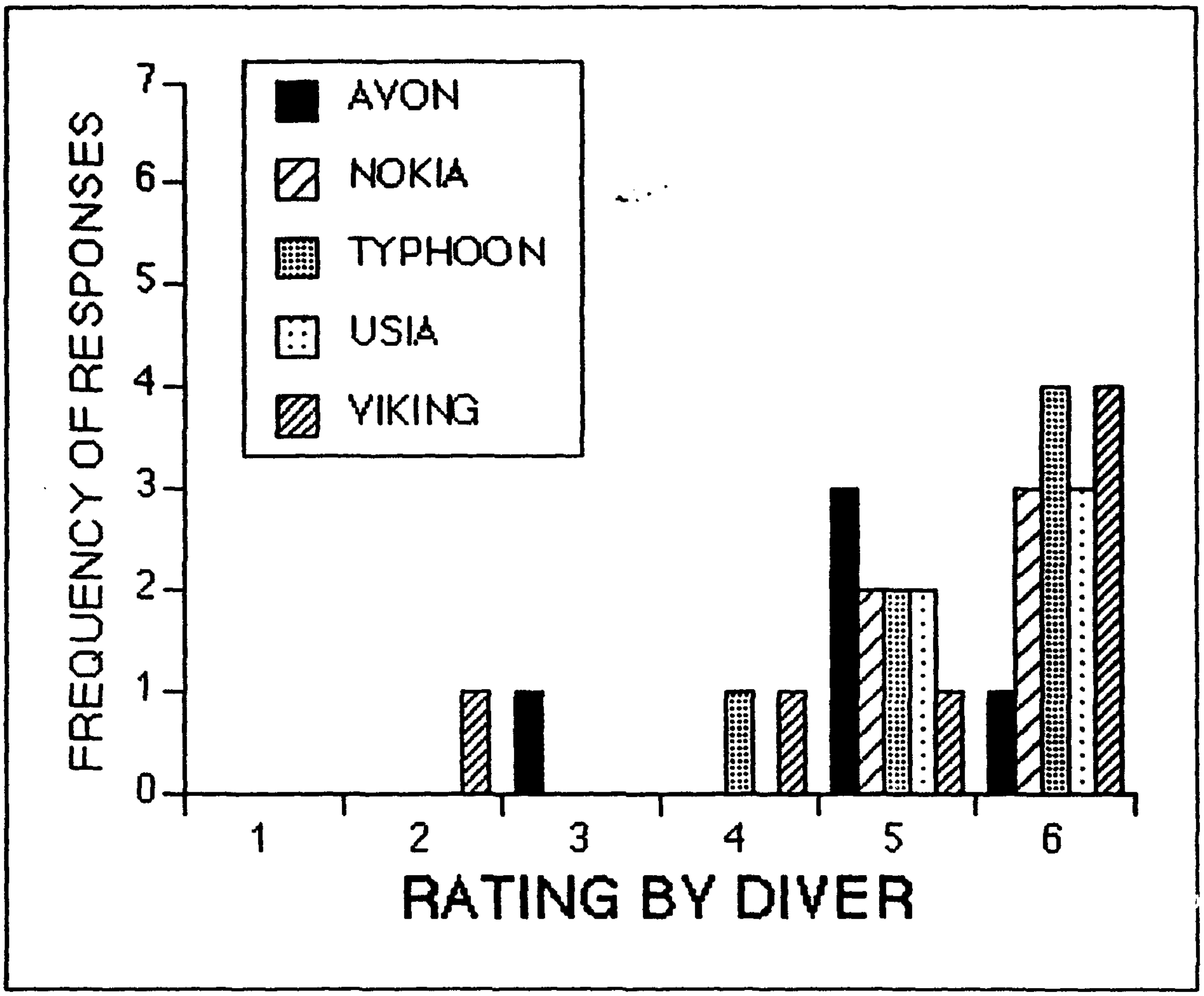

Figure 13

<u>RATING SCALE</u>: 1 = extremely poor 2 = poor 3 = not quite adequate
4 = adequate 5 = good 6 = excellent

In addition, content analysis of written answers was conducted; results are listed in Appendix D. Editorial latitude was taken to make complete sentences of sentence fragments, and to correct blatant grammatical errors. The responses to each question are listed in Appendix D following a roughly ordinal fashion, from most positive to most negative. In addition to covering major concerns, the written answers also provided insight into some of the more incidental concerns of the diver-subjects.

The need for additional weight pockets in the legs to enhance diver stability in the water column was universally noted for all candidate dry suits. Additional points of criticism or concern were obtained from content analysis of the questionnaires, and these are briefly listed below.

AVON:

1) One diver stated that operating the inflation valve was not easy while wearing heavy gloves.

2) Two divers stated that the exhaust valve was accidentally activated by the MK 21 locking device, or was defective and spontaneously released air from the suit

3) One diver stated that the suit leaked at the neck dam ring.

4) One diver recommended adding pockets in the suit for tools.

NOKIA:

1) One diver suggested that thumb rings should be added to facilitate keeping sleeves down when putting on the suit.

2) One diver complained that the inflation valve is difficult to operate with heavy gloves.

3) One diver recommended relocating the dump valve to the wrist and the inflation valve to the middle chest area.

TYPHOON:

1) Excessive air in the legs restricted fin swimming, due to excessive buoyancy.

2) The wrist and neck seals were uncomfortable for one diver.

3) One diver complained that the inner garment was too baggy and bulky.

4) Difficulty encountered trying to purge all the air out of the suit.

5) The feet on the suit made fin use difficult for one diver.

6) The purge button was in an awkward place for one diver, and difficult to reach for two other divers, because range of motion was restricted by the two harnesses worn during the dive, or the tightness in the suit when inflated.

7) The neck dam was too tight and uncomfortable on the surface.

8) Some tenders encountered difficulty mating the neck dam with the MK 21 hat.

9) Bigger boots were needed by one diver.

10) The booties provided with underwear were too bulky for another diver.

11) One diver recommended moving the exhaust valve to the wrist area.

USIA: 1) The suit was too small for one diver.

2) One diver's feet were very cold.

3) One diver recommended booties to keep the feet warm.

VIKING: 1) The steel toe boots were not good for fins.

2) One diver's neck and right foot leaked.

3) One diver's wrist seals were tight, probably because the suit was new.

4) The suit material was described as rigid by one diver, who complained that it bit into his skin.

5) One diver complained that the suit was tight in the groin.

6) One diver experienced excessive leg and groin squeeze that was progressively worse during descent.

7) Three divers complained that the inflator valve was in a very poor position, increasing the possibility of accidental inflation from the weight-bearing harness strap, perhaps causing blow-up.

8) One diver complained that the neck ring was uncomfortable.

9) One diver recommended larger feet for the suit.

RESULTS OF UNMANNED WOB TESTING

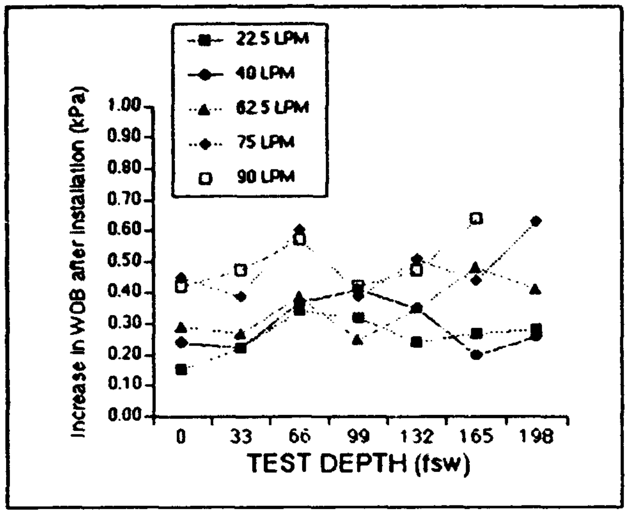

Figure 14

Results of WOB testing in the two MK 21 MOD 1 UBAs are summarized in Figures 14 and 15, and reported in Appendix B. The figures show the difference in WOB levels obtained from the regulators at each depth/RMV after installing the contaminated water kit, compared to levels obtained before the kits were installed.

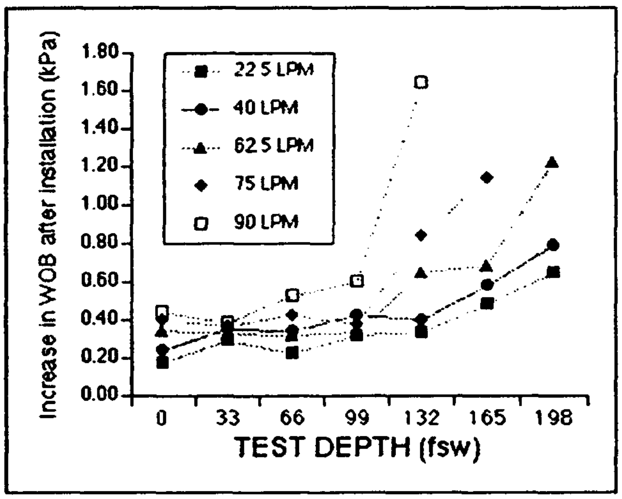

Figure 15

The contaminated water kits magnified WOB levels somewhat in both UBAs, and in the worst-performing regulator WOB levels were elevated above 4 kPa at two depth/RMV combinations where this had not occurred before the contaminated water kit was installed.

RESULTS OF WATER ASPIRATION TESTING

Initial tests for water aspiration using the contaminated water kits resulted in flooded helmets. Closer examination revealed a problem at the proximal end of some of the exhaust valve housings that had been supplied to NEDU for testing. Specifically, with the contaminated water kit installed, the gas train is diverted approximately 45° by the valve housing immediately after passing through the first exhaust valve. Because some valve seats were improperly centered on the angled housing, the mushroom valve could hang up on one side when it opened, which allowed water outside the valve to enter the helmet. It is important to note that this condition only occurred when the distal exhaust valve in the assembly--which should have prevented water from getting as far as the proximal valve--was wedged open by water-borne debris. Subsequent testing revealed the helmet would still aspirate water at 30.3 msw (99 fsw) and 62.5 LPM RMV. However, the interior of the helmet remained dry throughout three successive tests conducted at 30.3 msw and 40 LPM RMV.

DISCUSSION

The chief concern in the present scenario entails isolating the diver from exposure to contaminated water. Therefore, the primary point of failure would be a leak in the dry suit. In the present study, divers reported four neck dam leaks and two foot leaks. However, it was not always obvious whether the neck dam leaks were from a hole in the suit or at the dry suit / helmet interface. Clearly, encountering leaks that originate from perforations in the suit are unlikely if the dry suit has been properly checked before use. Hence, the neck dam leaks appear to be from a deficient dry suit / helmet seal, and it is crucial to make a secure helmet attachment when fitting it on the dry suit.

The second concern entails diving a dry suit that provides sufficient buoyancy control. Divers should not be exposed to conditions leading to uncontrolled blow-up. The data from the present study identify three factors that markedly influence divers' comfort level with dry suit buoyancy control. First, the inflation and deflation valves must be located where they are easily accessed, and where accidental activation is unlikely. Second, the valves should be designed so that they can be operated easily, even while wearing heavy gloves. Third, the suit must accommodate diving weights of sufficient mass and proper distribution to ensure stability in the water column. This does not represent a material modification to the dry suit. Moreover, all the dry suit manufacturers universally indicated that this feature could be provided upon request.

Divers complained about valve placement, particularly in the Viking suit. Nonetheless, valves can be easily relocated on existing suits by a qualified technician, and manufacturers are generally very accommodating when receiving special valve location requests when new suits are being ordered.

Most of the shortcomings in valve design may be circumvented by a more convenient placement of the valve. However, if a manufacturer's valve design continues to elicit complaints from working divers, one should consider not procuring that brand of dry suit, or substituting the valve for one made by another dry suit manufacturer. Still, it appears that valve design and operating ease does not represent a major failing of any of the suits evaluated.

The contaminated water kit did increase WOB levels in this UBA. However, this increase was not of a significant magnitude in terms of the overall respiratory effort needed to operate this UBA. In fact, WOB levels in the best-performing regulator remained well within the Performance Goal Standards[8]. In the worst-performing regulator, WOB levels exceeded the standards, but by no more than 0.2 kPa. Again, these performance goals are not definitive acceptance criteria for UBA approval, and diving equipment that modestly exceeds these goals is not categorically unsatisfactory for diving.

The contaminated water kit performance is considered to be adequate, for two reasons. First, while leakage is clearly possible at higher RMV rates, a RMV of 40 LPM represents a more realistic breathing rate to expect from a working diver. Second, the helmet dial-a-breath knob was only adjusted at the surface, and no subsequent adjustments were made to compensate for increased depth. The exhalation valves could provide water-tight integrity to the helmet following inspiratory pressures of at least -1.8 kPa. Under a normal diving scenario, a working diver would routinely adjust the dial-a-breath to minimize inhalation effort.

CONCLUSIONS

Based on the manned human factors evaluations, the 1) Avon 1800 Standard Heavy Duty, 2) Nokia Boss, 3) Typhoon Pro Front Entry, 4) Viking HD Combi, and 5) USIA Model 3651 Combat Swimmer Suit provide reasonable levels of protection to divers when configured with an integral neck dam for use with the MK 21 UBA, and should be placed on the ANU list for contaminated water use. Prior to suit selection, there are a few features that the diver needs to consider. First, dry suit outer shells should be made of vulcanized or, optimally, butyl rubber, to provide durability, ease of cleaning, and protection from waterborne contaminants. Second, the diver should be able to specify the location of the inflation and deflation valves, as well as pockets for weights and tools. Because all of the candidate dry suits manufacturers indicated their willingness to meet the needs of the customer, this should be easily accomplished. Third, the dry suit must be constructed with an integral neck dam for the MK 21 UBA.

We recommend the use of the MK 21 MOD 1 UBA equipped with the contaminated water kit for Fleet contaminated water diving since it does not markedly elevate WOB levels, while providing protection from water aspiration.

REFERENCES

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4. NAVSEA Task 92-026, *Equipment Changes for Use of UBA MK 21 MOD 1 in Polluted Water*

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6. *Unmanned Evaluation of Double Flapper Exhaust Valve and Secondary Dump Valve in the MK 21 MOD 1 UBA*, NEDU Test Plan Number 93-36, 1993

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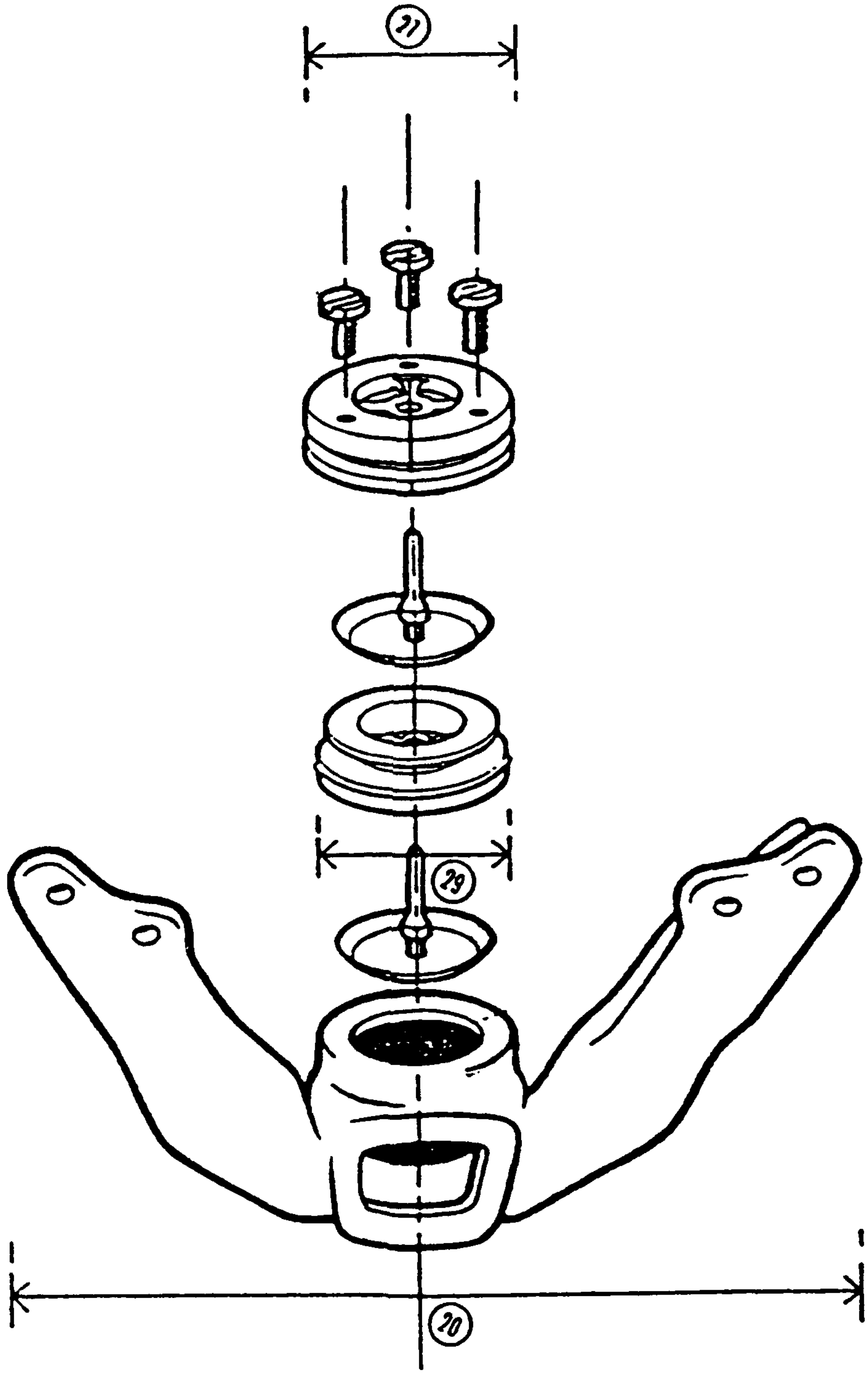
APPENDIX A

DIAGRAM OF DOUBLE FLAPPER EXHAUST VALVE ASSEMBLY



APPENDIX B

Work of breathing levels obtained from MK 21 MOD 1 UBAs (kPa)

HAT #01369 STANDARD EXHAUST VALVE

				DEPTH (f s w)			
RMV	0	33	66	99	132	165	198
22.5	0.57	0.67	0.64	0.69	0.74	0.79	0.84
40	0.66	0.86	0.81	0.85	0.95	1.10	1.14
62.5	0.83	1.09	1.06	1.35	1.33	1.38	1.61
75	0.79	1.14	1.04	1.51	1.53	1.83	2.28
90	0.89	1.18	1.26	1.76	2.09	2.90	*

HAT #01369 DOUBLE EXHAUST VALVE WORK OF BREATHING (WOB) LEVELS

				DEPTH (f s w)			
RMV	0	33	66	99	132	165	198
22.5	0.72	0.89	0.98	1.01	0.98	1.00	1.12
40	0.90	1.08	1.18	1.26	1.30	1.30	1.40
62.5	1.12	1.36	1.45	1.60	1.68	1.86	2.02
75	1.24	1.53	1.64	1.90	2.04	2.27	2.91
90	1.31	1.65	1.83	2.18	2.56	3.54	*

HAT #01399 STANDARD EXHAUST VALVE WORK OF BREATHING LEVELS

				DEPTH (f s w)			
RMV	0	33	66	99	132	165	198
22.5	0.59	0.64	0.80	0.75	0.77	0.71	0.61
40	0.69	0.79	0.90	0.91	0.93	0.88	0.79
62.5	0.78	0.94	1.11	1.37	1.29	1.43	1.26
75	0.84	1.08	1.24	1.68	1.56	1.96	2.05
90	0.89	1.18	1.44	1.85	1.80	3.42	*

HAT #01399 DOUBLE EXHAUST VALVE WORK OF BREATHING LEVELS

				DEPTH (f s w)			
RMV	0	33	66	99	132	165	198
22.5	0.76	0.93	1.02	1.08	1.10	1.19	1.26
40	0.93	1.14	1.24	1.33	1.33	1.46	1.58
62.5	1.12	1.26	1.42	1.70	1.94	2.11	2.48
75	1.24	1.44	1.66	2.05	2.40	3.10	*
90	1.37	1.56	1.96	2.45	3.44	*	*

* Work of breathing exceeded 4 kPa at this depth / RMV combination

APPENDIX C

HUMAN FACTORS EVALUATION QUESTIONNAIRE
(DRY SUIT)

Name of diver ______________ Command ______________ SSN __________

Date of dive ___________ Dry suit brand/model ________________________

Manufacturer and type of undergarment worn __________________________

Diver height (in) ____ Weight (lbs) ____ Chest (in) ____ Shoe size ____

Dive profile: Depth (FSW) ____ Duration (min) ____ Water temp (°F) ____

Brief description of dive

____

____

Were gloves worn during the dive? ____ Type ________________________

RATING SYSTEM:

1 = extremely poor
2 = poor
3 = not quite adequate
4 = adequate
5 = good
6 = excellent

EASE OF DON AND DOFF:

1. How would you rate the ease of putting on this suit with the help of a tender? ____
2. How would you rate the ease of putting on this suit unassisted? ____
3. How would you rate the ease of taking off this suit with the help of a tender? ____
4. How would you rate the ease of taking off this suit unassisted? ____

OVERALL COMFORT OF THE SUIT:

5. How would you rate the overall comfort of this suit? ____
6. How would you rate the suit's comfort in terms of buoyancy control? ____
7. List any points in the suit that were uncomfortable __________________________

7a. How long were you wearing the suit before the discomfort became apparent? __________

8. List any points in the suit that restricted movement, and the specific activities that were restricted by the suit: ____

____

9. How would you rate the size of the suit, if this were the only size available? ____

USE AND OPERATION OF THE SUIT:

10. How would you rate the location of the inflation valve? ____
11. How would you rate the ease of operating the inflation valve? ____
12. How would you rate the location of the exhaust valve? ____
13. How would you rate the ease of operating the exhaust valve? ____

14. How would you rate the <u>ability of the suit to keep you dry</u>? _____
15. Did the suit or neckdam seal leak at any time during the dive? _____
16. How would you rate the <u>overall construction of the suit</u>? _____
17. How would you rate the <u>apparent durability of the suit</u>? _____
18. How would you rate the <u>ease of cleaning the suit</u> after a dive? _____
19. How would you rate the suit <u>for use in polluted water diving</u>? _____
20. How would you rate the suit <u>for use in cold water diving</u>? _____
21. Please provide any additional comments about the construction, design, operation, or performance of the suit that you think are important:

APPENDIX D

CONTENT ANALYSIS OF DRY SUIT EVALUATION

1. AVON:

GENERAL:

Suit had good mobility
Comfortable and warm--good maneuverability

OVERALL COMFORT:

It was a 'squeezy' suit; had to add air to make comfortable
Arm vent was hard to adjust, resulting in suit squeeze
Feet had too much room
Too much garment around legs

INFLATION VALVE:

I think suit should possess a more noticeable inflation valve that is easily operated while wearing heavy gloves

EXHAUST VALVE:

The exhaust valve was purging now and again and the buoyancy of the suit was affected. I may have bumped the valve a few times, but I believe it was defective

Working overhead MK 21 locking device caused exhaust valve to be purged

NECK DAM:

Suit leaked around neck ring

RECOMMENDED IMPROVEMENTS:

Make slots for leg weights
Add tool pockets

2. <u>NOKIA</u>:

GENERAL:

Best suit used so far
Excellent suit
Good suit overall
This suit is good
Suit material too rigid

OVERALL COMFORT:

Undergarment sleeves were source of discomfort; need thumb rings to keep sleeves down when donning suit

INFLATION VALVE:

Inflation valve is difficult to operate with heavy gloves; needs to be more noticeable

EXHAUST VALVE:

NECK DAM:

RECOMMENDED IMPROVEMENTS:

Addition of tool pockets (2) and ankle/calf weight pockets

Locate purge and dump valve somewhere else; possibly locate dump valve on wrist and the inflation valve in the middle chest area a bit higher

3. <u>TYPHOON</u>:

GENERAL:

Air in legs restricted fin swimming

OVERALL COMFORT:

Wrist and neck seals were uncomfortable

Discomfort encountered upon reaching 30 fsw, but minor

Inner garment too baggy and bulky

Hard to get all air out; had to use too many weights

Hard to use fins with the feet on this suit

Ankle weights had to be wrapped around the ankles to prevent the legs from floating up

Swimming with fins was limited due to the need for ankle weights

Legs felt light on the bottom--suit needs leg weights

INFLATION VALVE:

EXHAUST VALVE:

The purge button was in an awkward place

Reaching the purge button was difficult because the two harnesses used with the suit prevent a full range of movement to reach the button

Tight under pressure, making it difficult to reach the dump valve

NECK DAM:

Neck too tight

Moderate degree of difficulty reported by tenders mating the neckdam with the MK 21 hat

Neck seal uncomfortable on surface

RECOMMENDED IMPROVEMENTS:

Need bigger boots!

Need to have metal shanks or ankle weights for buoyancy control

Add some type of weight on the boots

Change the location of the exhaust valve to the wrist area

Ensure ankle weights work in swimmer mode

Booties provided with underwear too bulky once slipped into suit; socks would be preferable

4. <u>USIA</u>:

GENERAL:

This suit is perfect in all aspects aside from donning and tripping out, but it is exceptionally well designed for diving

Excellent suit

Suit too small

OVERALL COMFORT:

Feet were very cold

INFLATION VALVE:

EXHAUST VALVE:

NECK DAM:

RECOMMENDED IMPROVEMENTS:

Needs booties to keep feet warm

Recommend addition of ankle/calf weight pockets

5. <u>VIKING</u>:

GENERAL:

Good suit overall
Steel toe boots, while good for walking on bottom, are not good for fins
The neck and right foot leaked a bit

OVERALL COMFORT:

Fit me perfectly; very comfortable
Wrist seals were tight, probably because the suit was new
The suit has good flexibility but the material is rigid and bites the skin
Tight in the groin
Experienced excessive squeezing around the legs from the groin area to the knees; this became very uncomfortable as I descended deeper

INFLATION VALVE:

Inflator in very poor position (3); possibility of accidental inflation
When wearing a harness bearing weight the harness strap covers the purge valve and causes blow-ups

EXHAUST VALVE:

NECK DAM:

Neck ring source of discomfort

RECOMMENDED IMPROVEMENTS:

Relocate inflation valve as harness restricts access
Put weight pockets on ankles
Larger feet needed!