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NAVY EXPERIMENTAL DIVING UNIT

Report 13-77

DIVERS' HEATING HOSE COMPARISON STUDY

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SUMMARY REPORT

on

**DIVER'S HEATING HOSE
COMPARISON STUDY**

to

**COMMANDING OFFICER
U. S. NAVY
EXPERIMENTAL DIVING UNIT**

under

CONTRACT NO. N61331-77-M-2421

November, 1977

by

**Harold F. Link
Peter S. Riegel**

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Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201**

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December 13, 1977

CDR C. A. Bartholomew, USN
Commanding Officer
Navy Experimental Diving Unit
Panama City, Florida 32407

Dear CDR Bartholomew:

Enclosed are four copies of the report "Diver Heating Hose Comparison Study". The research resulted in successful identification of several hoses suitable for diver heating use.

Submission of this report represents completion of the contract.

In order to pinpoint more accurately the characteristics of the hoses some further research and testing may be desirable. Should you desire, we will be happy to assist in any further extension of the effort.

We have enjoyed working with NEDU on this interesting task, and look forward to working with you again. If you have any questions, comments, or suggestions concerning the report, please call me at (614)424-4009.

Sincerely,



Peter S. Riegel
Research Engineer
Equipment Development
Section

PSR:djs

Enc. (4)

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ABSTRACT

Diver's heating hose is used to transport heated sea water from the surface to a diver to provide him with thermal protection. At present no criteria exist for determining the suitability of a given hose for this application. This report describes how requirements of hot water heating systems were used to define hose evaluation criteria. These criteria were then applied to findings of a comprehensive survey of commercially available hoses. As a result, a number of hoses are identified as suitable for diver heating.

SUMMARY REPORT
on
DIVER'S HEATING HOSE COMPARISON STUDY

to
**U. S. NAVY
EXPERIMENTAL DIVING UNIT**

from
**BATTELLE
Columbus Laboratories**

by
H. F. Link and P. S. Riegel

November, 1977

INTRODUCTION

The use of hot water heating systems for diver thermal protection has increased in recent years. The operation of these systems is quite simple. Sea water is heated at the surface and then pumped through an umbilical hose to the diver. At the diver it is directed through a special unit which distributes the heat to all parts of the body. Finally, the water is exhausted from the suit through a number of "leak" paths. In deep dives, the water may also be directed to a heat exchanger to heat the diver's breathing gas.

Presently the U. S. Navy has no established criteria for determining whether a given hose will be suitable for conveying hot sea water to the diver. This task was initiated to define practical criteria by which hoses could be judged and use these criteria to identify suitable hoses.

SUMMARY

In order to insure that the hoses recommended in this report would meet the operational requirements of present and proposed Navy hot water heating systems, the task consisted of a sequence of five steps. These steps are summarized below while more detailed explanations are included in the later sections of this report.

First, the operational requirements of the hoses were outlined in general form. Review of the ASR-21 and the Mark 1 Mod 0 heating systems revealed general pressure, temperature, and flow requirements for hot water systems.

These requirements were outlined in a letter of inquiry to hose manufacturers listed in the Thomas Register. Limited response to the letter prompted a more direct second effort to obtain information from manufacturers. Telephone calls and a second, simplified, letter resulted in the identification of 22 companies that could provide potentially suitable hoses.

Theoretical analyses were also conducted to correlate heat and pressure loss to hose characteristics and operating conditions. These correlations were then used to examine two of the most severe diver heating scenarios. It was shown that the worst case of application is a deep water dive where hose inlet temperatures and pressures might be as high as 175°F and 185 psi respectively.

With the information gained in these first three steps of the program, Battelle investigators and NEDU personnel were able to make the final definition of hose evaluation criteria. These criteria can be used to judge not only the hoses identified in this survey but also new hoses which will undoubtedly be considered in the future.

Finally, the hoses which had been identified in the market survey were evaluated against the criteria. In addition to manufacturers information, hose samples were obtained for visual examination of quality. Ten hoses were selected as meeting the established criteria.

RESULTS

The results of this task are summarized in the following figures and tables. Table 1 is a matrix of the most suitable hoses found in the survey along with comparative characteristics and prices. All of the hoses included in this list should be suitable for diver hot water heating. Selection of a particular hose may be based on availability, cost, or previous experience.

Figure 1 is a graph of flow-induced pressure loss to be expected for hoses of different inside diameters and lengths. The graph can be used to estimate the required inlet pressure for a particular hose and flow rate. Alternatively, it can be used to select a hose of suitable diameter for an intended flow and inlet pressure.

Table 2 indicates required inlet temperatures for different sized hoses operating in water of various temperatures. It can be used by the dive master to set the heating system controls at the start of a dive. Diver's comments will then be used to adjust inlet temperatures for variations in operating conditions or for his comfort.

It should be noted that these values are derived from theoretical calculations which include a number of assumptions. Actual heat losses will undoubtedly differ from those predicted by theory. Experience in diver heating operations will ultimately prove to be the best guide.

CONCLUSIONS AND RECOMMENDATIONS

In the course of completing the hose survey and theoretical calculations, our research has led us to conclude the following

- (1) Hoses suitable for diver's hot water heating systems are available from many sources. No specific source has been shown to be clearly superior for all applications.

TABLE 1. 1/2-INCH HOSES FOUND TO BE MOST SUITABLE FOR DIVER HEATING UNSILICALS

| Manufacturer | Address | Hose Name | Inlet Temp ⁽¹⁾ , F | Weight in Air, lb/100 ft | Weight in Water, lb/100 ft | Length Available | Cost ⁽²⁾ , \$/100 ft |
|---|---|--------------------------------|----------------------------------|-----------------------------|-------------------------------|---------------------|------------------------------------|
| Aerquip Corp. (Industrial Div) | 1225 W. Main St. Van Wert, OH 45891 | FC-285-08 | 143 | 28 | -3 | 300 ft min | 164 |
| Amazon Hose and Rubber Co. | 130 N. Jefferson St. Chicago, IL 60606 | Deep Sea Diving | 147 | 30 | -2 | Reel ⁽³⁾ | 35 |
| Dayco Corp. (In- dustrial Sales Div) | 333 W. First St. Dayton, OH 45401 | Thoro-Flo All Purpose | 147 | 29 | -3 | 300-600 ft | 37 |
| Diving Unlimited International | 1148 Dalevan Dr. San Diego, CA 92102 | Hot Water Diver | 150 | 19 | -12 | Reel | 160 |
| Diving Unlimited International | 1148 Dalevan Dr. San Diego, CA 92102 | Hot Water Bell | 130 | 61 | +17 | Reel | 197 |
| Electric Hose and Rubber Co. | 12th and Dure Sts. Wilmington, DE 19899 | MultiPurpose | 150 | 26 | -5 | Reel | 43 |
| Gates Rubber Co. | 999 S. Broadway Denver, CO 80217 | Planc Master 119B (315 psi) | 145 | 27 | -4 | Reel | 114 |
| Goodrich, B. F. (Industrial Products) | 500 S. Main St. Akron, OH 44318 | Highflex | 164 | 20 | -7 | Reel | 107 |
| Goodyear (Industrial Product Div) | E. Market St. Akron, OH 44316 | Ortac (350 psi) | 138 | 38 | +2 | Reel | 85 |
| Parler Humifin Corp. (Hose Products Div) | 30240 Lakeland Blvd. Wickliffe, OH 44092 | Parflex 540W | 161 | 12 | -19 | 300 ft | 105 |
| Porter, H. K., Co. (Thermal Div) | Porter Building Pittsburgh, PA 15219 | Versicon | 147 | 29 | -3 | 2/600 ft reel | 51 |
| Uniroyal (Industrial Products) | Middleburg, CT | P-290 | 147 | 29 | -3 | Reel | 111 |
| White, H. S., Co., Inc. | 2056 N. Dixie Hwy. Fort Lauderdale, FL 33305 | Hot Water Hose | 150 | 24 | -7 | Reel | 56 |

(1) Intended to show the effect of hose outside diameter, these numbers are the predicted inlet temperatures required to supply a diver under the following conditions: Flow = 3 gpm, Outlet Temp. = 105 F, Ambient Water Temp. = 40 F, Heat Transfer Characteristic (h) = 0.12 Btu/hr-ft²-F, Length = 600 ft. The hose's outside diameter is the only variable represented in the calculation of these numbers.

(2) Cost based on an order of three lengths of 300 ft. hoses (may require splices).

(3) Reel lengths are industry standards of 300-450 ft. of hose per reel, a maximum of three lengths per reel, the shortest length is at least 10 percent (30 ft.) of total length of hose on the reel.

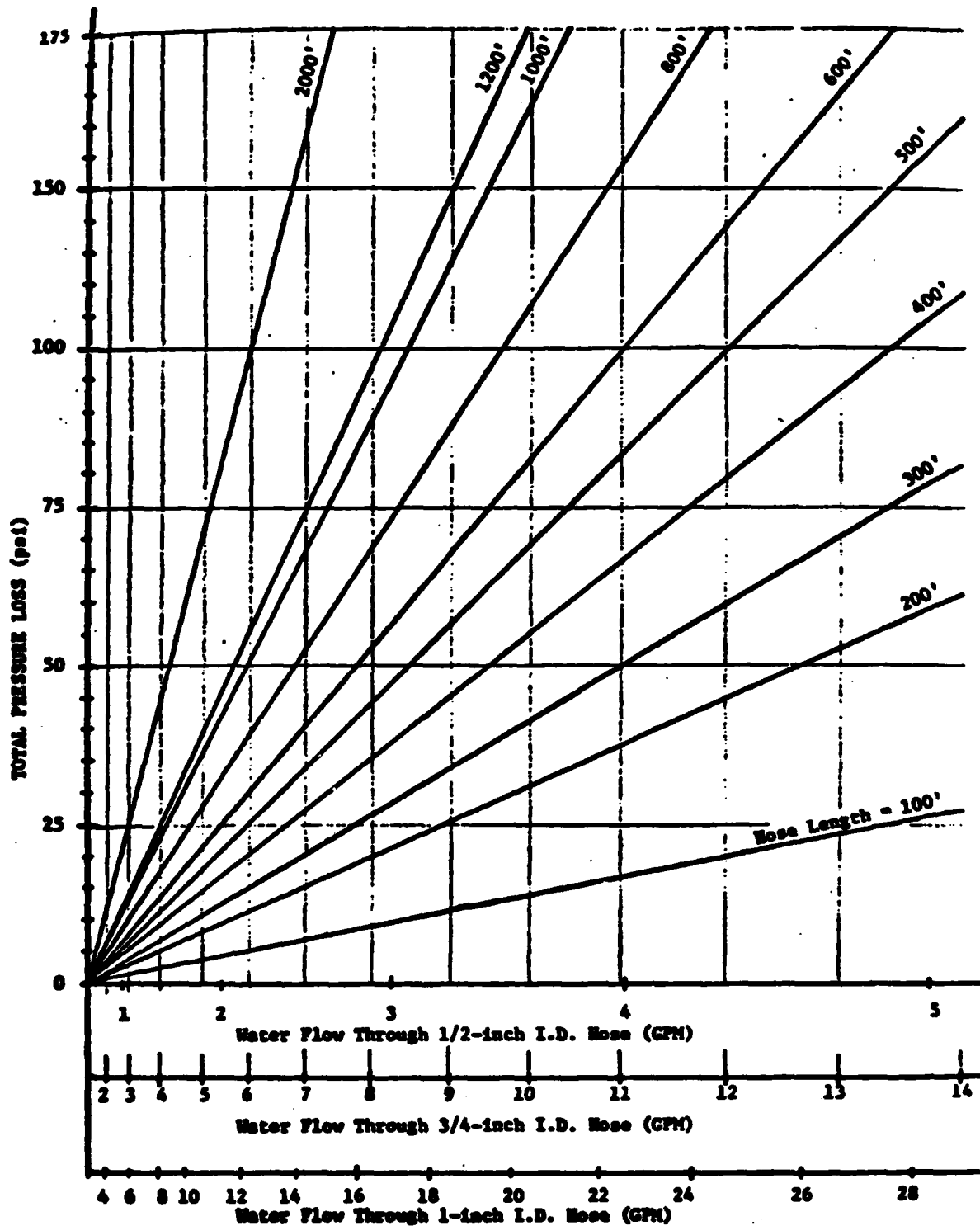


FIGURE 1. CALCULATED PRESSURE LOSS VS. WATER FLOW RATE FOR UMBILICAL HOSES OF VARIOUS DIAMETERS AND LENGTHS

TABLE 2. REQUIRED INLET TEMPERATURES FOR HOT WATER FLOW
THROUGH 1/2-INCH HOSE DISCHARGING AT 105 F

| Umbilical Length, Feet | Ambient Water Temperature, F | | | | | | | |
|------------------------------|------------------------------|-----|-----|-----|-----|-----|-----|-----|
| | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 |
| <u>Water Flow = 2 GPM</u> | | | | | | | | |
| 100 | 114 | 114 | 113 | 112 | 112 | 111 | 110 | 110 |
| 200 | 125 | 123 | 122 | 121 | 119 | 118 | 116 | 115 |
| 300 | 137 | 135 | 132 | 130 | 128 | 125 | 123 | 121 |
| 400 | 150 | 147 | 144 | 141 | 137 | 134 | 131 | 128 |
| 500 | 166 | 161 | 157 | 153 | 148 | 144 | 140 | 135 |
| 600 | 183 | 178 | 172 | 166 | 161 | 155 | 150 | 144 |
| <u>Water Flow = 3 GPM</u> | | | | | | | | |
| 100 | 111 | 111 | 110 | 110 | 109 | 109 | 108 | 108 |
| 200 | 118 | 117 | 116 | 115 | 114 | 113 | 112 | 111 |
| 300 | 125 | 123 | 122 | 121 | 119 | 118 | 116 | 115 |
| 400 | 133 | 131 | 129 | 127 | 125 | 123 | 121 | 119 |
| 500 | 141 | 139 | 136 | 133 | 131 | 128 | 126 | 123 |
| 600 | 150 | 147 | 144 | 141 | 137 | 134 | 131 | 128 |
| <u>Water Flow = 4 GPM</u> | | | | | | | | |
| 100 | 110 | 109 | 109 | 109 | 108 | 108 | 108 | 107 |
| 200 | 114 | 114 | 113 | 112 | 112 | 111 | 110 | 110 |
| 300 | 119 | 118 | 117 | 116 | 115 | 114 | 113 | 112 |
| 400 | 125 | 123 | 122 | 121 | 119 | 118 | 116 | 115 |
| 500 | 131 | 129 | 127 | 125 | 123 | 122 | 120 | 118 |
| 600 | 137 | 135 | 132 | 130 | 128 | 125 | 123 | 121 |

- (2) In general, manufacturers do not have specific data on hose characteristics important for this application, specifically heat insulation properties and life expectancy when flowing hot, possibly oil contaminated, salt water.
- (3) Until results from laboratory testing and/or field evaluations are obtained, it is not possible to define completely the suitability of a particular hose for this application.

Therefore, we recommend that the Navy Experimental Diving Unit or another qualified, diving-oriented group be tasked to test the hoses selected in this report. The review need not comprehensively investigate all aspects of the hoses. However, critical characteristics, such as heat transfer properties and resistance to oil and hot salt water, should be defined as completely as possible.

RESEARCH PROCEDURE

The research efforts of this task were conducted according to the following five steps:

- (1) Preliminary Definition of Hose Requirements
- (2) Market Survey
- (3) Theoretical Analyses
- (4) Final Definition of Hose Evaluation Criteria
- (5) Selection of Suitable Hoses.

These steps are discussed in detail in the following sections of the report.

Preliminary Definition of Hose Characteristics

The first step in the selection of hoses for this application was to review the existing hot water heating systems and to identify some of the critical environment conditions which the heating hose must withstand.

Therefore, Navy representatives were contacted who had experience with hot water systems. In addition, reference was made to a Battelle report "Design Review of Diving Support Systems Aboard ASR-21", SUPDIV Report 1-72 by J. A. Henkener, et al.

From the information gathered from these sources, the following hose characteristics were defined:

- (1) Working Pressure - 200 psig
- (2) Temperature Range - 0°-240°F
- (3) Good Heat Insulation
- (4) Compatibility with Seawater, Petroleum Oil and Mild Cleaning Solvents
- (5) Inside Diameters from 1/2 in. to 1-1/2 in.
- (6) Lengths from 100 to 1000 feet.

It was felt that if hoses of these characteristics were identified they would be able to withstand the most severe conditions likely to be found in a diver's heating system.

Market Survey

Once the preliminary hose requirements were established, a survey of commercially available hoses was conducted. A list of hose manufacturers was compiled from the Thomas Register. Each manufacturer was sent a letter of inquiry containing the hose requirements and asking for technical and price information on hoses which could meet the requirements.

The response to this letter was not good. Many companies wrote back saying that they could not make such a hose -- but not saying why. Most companies did not respond at all. With the benefit of knowledge gained since that letter was written, it became obvious that: (1) The letter was too long and complicated for easy response by manufacturers and (2) the temperature and length requirements were too severe.

When it became obvious that the letter of inquiry was not producing the desired results, a second attempt was made. This time a number of large

companies were contacted by phone. Other companies were sent a short, direct letter asking for information. Some companies were dropped from consideration because their major product line did not include reinforced rubber hose.

The response to this second effort was much more positive. Information was obtained from companies which could provide potentially suitable hoses. This information was compiled into matrix form and is shown in Appendix A. Also included in this appendix is a list of all companies contacted and their responses.

Theoretical Analyses

Concurrent with market survey efforts, a number of theoretical analysis were undertaken. Two factors were investigated, pressure loss and heat loss. Both factors are influenced by and, in turn, influence hose characteristics. The following sections of this report show how these factors are affected by hose characteristics and operating conditions.

Flow-Induced Pressure Loss

The inlet pressure for hot water hoses can be determined by calculating flow induced pressure losses. Other factors such as elevation of the inlet of the hose relative to the diver produce only small effects in comparison*. The pressure loss caused by flow can be calculated from the formula

$$\Delta P = .000216 \frac{fL\rho Q^2}{d^5} \quad (1) **$$

where

ΔP = Pressure loss, psi

L = Hose length, feet

* A static pressure head is produced because of the difference in density of hot sea water vs. cold. However, even in the worst case of an 850' dive the static head will not be more than 5 psi. This error is partially offset by the location of the hot water source above the ocean surface.

** Equation derived from Equation 3-14 in Crane's Flow of fluids Through Valves, Fittings, and Pipe, Crane Co., 1969.

- ρ = Fluid density, lb/ft³
 Q = Flow, gpm
 d = Inside diameter, inches
 f = Friction factor.

Since the density of sea water is about 64 lb/ft³, the friction factor for smooth bore hoses of 1/2 inch to 1 inch I.D. is about 0.24, and the outlet pressure is zero, Equation (1) can be simplified to

$$P_{\text{inlet}} = .033 \frac{LQ^2}{d^5} \quad (2)$$

This relationship is shown graphically as Figure 1 of this report.

Temperature Loss

Because the water inside the hose is hotter than the water surrounding the hose, some heat loss is expected. The question arises: what must the inlet temperature be to insure that the outlet temperature at the diver is adequate? To answer this question we can make use of an equation derived in Reference 1 (Equation 6, Page 42).

$$t_1 = (t_3 - t_2)e^{\frac{2\pi KL}{mC \ln(d_2/d_1)}} + t_2 \quad (3)$$

where:

- t_1 = Temperature of water entering the hose, °F
 t_2 = Temperature of surrounding water, °F
 t_3 = Temperature of water leaving the hose, °F
 K = Thermal conductivity of the hose material, Btu/hr-ft-°F
 L = Length of the hose, feet
 m = Water mass flow rate, lbs/hr
 C = Specific heat of water, Btu/lb-°F
 d_1 = Inside diameter of hose, inches
 d_2 = Outside diameter of hose, inches.

In the derivation of this equation the following assumption is made:

- (1) The inside and outside of the hoses are at the temperature of the water with which they are in contact. The effect of current is therefore accommodated although a slightly reduced heat loss would be expected when diving in still water.

Equation (3) can be simplified if a few additional assumptions are made:

- (2) The thermal insulating properties of common hose materials (EPDM, BUNA N, Neoprene, etc.) are approximated by the factor,

$$K = 0.12 \frac{\text{BTU}}{\text{hr-ft-}^\circ\text{F}}$$

This number will be affected by variances in material formulations and by the number and types of reinforcing braids. However, temperature requirements based on this number correspond closely with curves available from Diving Unlimited International. Actual K factors will probably range from .09 to .18 BTU/hr-ft $^\circ\text{F}$.

- (3) The ratios of hose O.D. to hose I.D. (outside to inside diameters) for the hoses under consideration are 1.81 for 1/2-inch I.D., 1.67 for 3/4-inch I.D., and 1.50 for 1-inch I.D. Again, variation in these ratios can be expected as shown in the hose matrix in Appendix A.

In addition, the following substitutions are made:

$$m = 479 Q \text{ (Q is flow in gals/min)}^*$$

$$C = 1 \text{ BTU/lb-}^\circ\text{F}$$

and

$$K_1 = \frac{2\pi K Q}{mC \ln(d_2/d_1)}$$

$$= \frac{2 \cdot \pi \cdot 0.12 \cdot Q}{479 \cdot 1 \cdot \ln(d_2/d_1)}$$

* $m = Q \cdot (\text{gal/min}) \cdot 64 (\text{lb/ft}^3) \cdot 60 (\text{min/hr}) \cdot 0.13 (\text{ft}^3/\text{gal})$.

Now Equation (3) may be written

$$t_1 = (t_3 - t_2)e^{K_1 \frac{L}{Q}} + t_2 \quad (4)$$

where

- t_1 = Required inlet temperature, °F
- t_2 = Ambient sea water temperature, °F
- t_3 = Desired outlet temperature, °F
- L = Length of hose, feet
- Q = Flow through hose, gpm
- K_1 = $.00250 \frac{\text{GPM}}{\text{ft}}$ for 1/2" I.D. hose
- = $.00286 \frac{\text{GPM}}{\text{ft}}$ for 3/4" I.D. hose
- = $.00362 \frac{\text{GPM}}{\text{ft}}$ for 1" I.D. hose.

Equation (4) was used to generate Table 2 presented on page 6 of this report.

Although assumptions 2 and 3 are useful for generating Table 2, it is desirable to determine the errors in t_1 which might be produced if the thermal insulating properties or O.D. to I.D. ratios of the hoses deviate from the assumed values. Therefore, a few severe cases were considered in which the K values and the O.D./I.D. ratios were varied from their minimum to maximum expected values.

For these cases surrounding water temperature (t_2), desired outlet temperature (t_3) and flow rate (Q) are constant at values of 40°F, 105°F, and 3 gpm respectively.

As seen in Figure 2, neither the K value or the O.D./I.D. ratio affect the required inlet temperature to a great extent with a 300 foot umbilical. However, with a 600 foot umbilical (assuming its entire length is immersed) the effect of a large K value or small O.D./I.D. ratio become significant. It would seem apparent, then, that when a short, 300 ft, umbilical is required, criteria such as price, availability, or proven durability might be the primary criteria to use. Whereas, with longer umbilicals, closer attention must be given to the hose's thermal insulation qualities.

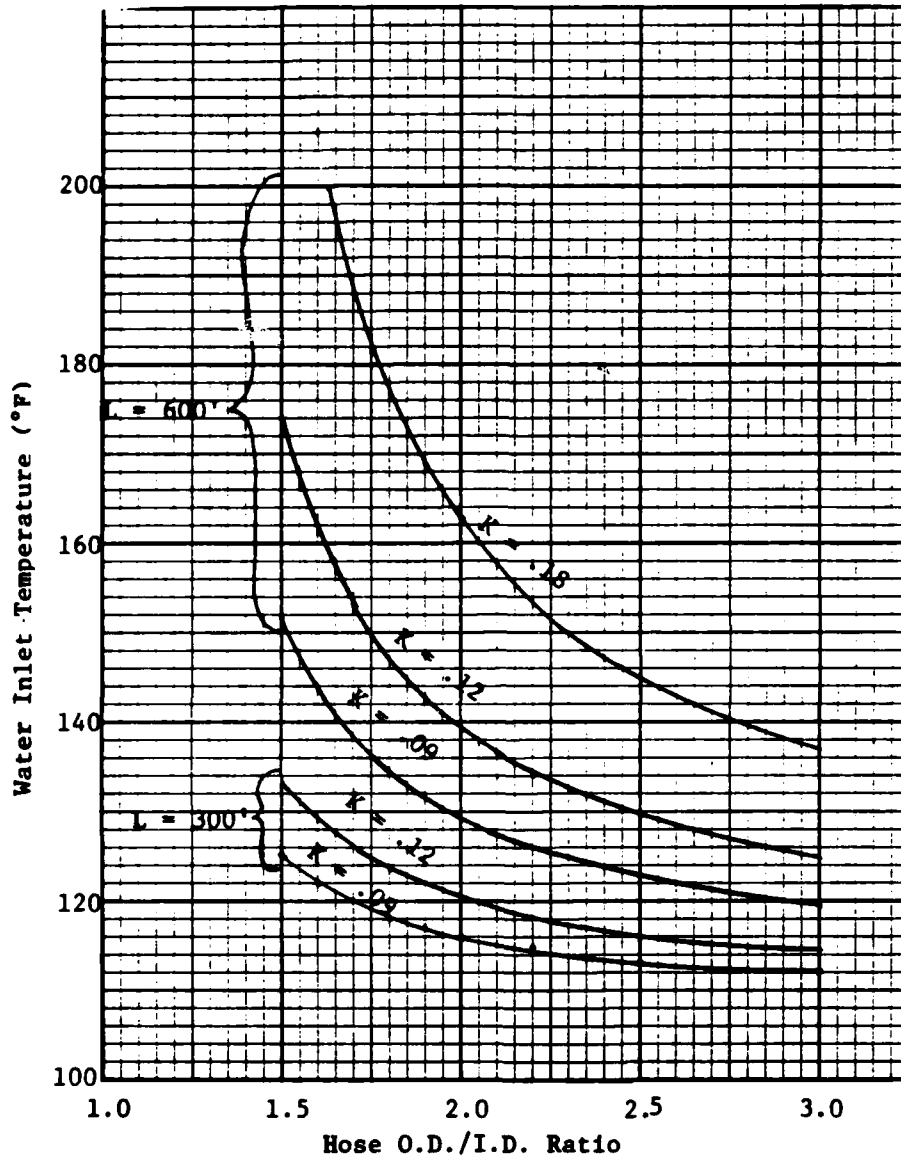


FIGURE 2. EFFECT OF HOSE INSULATION PROPERTIES ON REQUIRED INLET TEMPERATURES FOR 300' AND 600' UMBILICALS

Worst Case Analysis

Using Figure 2 and the heat-loss Equation (4), we can estimate the "worst case" pressure and temperature requirements. With less demanding applications, pressures and temperatures will be significantly less. Two cases were investigated: (1) a deep dive to 850 feet where divers are supported from a PTC and (2) a mixed gas dive to 300 feet where divers are independently supplied from the surface through 600 feet umbilicals.

Case 1--850 Foot Dive With PTC. The conditions for this dive scenario are:

Three divers supported from a PTC at 850 FSW

Length of diver's umbilicals - 300 feet

Length of bell umbilical - 1200 feet

Flow to each diver - 3 GPM

Water temperature required at diver - 105 F

Ambient water temperature - 40 F

Assumptions (2) and (3) valid -- e.g., $K = 0.12 \text{ BTU/hr-ft-}^\circ\text{F}$ and

O.D./I.D. = 1.80 for 1/2" hose

= 1.67 for 3/4" hose

= 1.5 for 1" hose.

Analysis of requirements is completed according to the following procedure:

(a) Size diver and bell umbilicals for flow capability

According to Figure 1, pressure losses through hoses are:

300 feet of 1/2-inch I.D. hose flowing 3 GPM = 3 psi

1200 feet of 3/4-inch I.D. hose flowing 9 GPM = 125 psi

Estimated valve and fittings losses = 30 psi

Total pressure required at source = 183 psi

If 183 psi is too great or if 4 divers will be supplied, then 1-inch I.D. bell umbilical would be recommended:

300 feet of 1/2-inch I.D. hose flowing 3 GPM = 28 psi

1200 feet of 1-inch I.D. hose flowing 12 GPM = 53 psi

Estimated valve and fittings losses = 30 psi

- (b) Estimate water supply temperature. Temperature of water at the bell is determined by estimating the heat losses through the 1/2-inch I.D. hoses using Equation (4) (or Table 1):

$$\begin{aligned} t_{\text{bell}} &= (t_{\text{diver}} - t_{\text{ambient}})e^{K_1 \frac{L}{Q}} + t_{\text{ambient}} \\ &= (105-40)e^{.00250 \cdot \frac{300}{3}} + 40 \\ &= 123^\circ\text{F} \end{aligned}$$

Knowing the required temperature at the bell we can calculate the heat losses through both 3/4-inch and 1-inch I.D. bell umbilicals:

$$\begin{aligned} t_{\text{surface}} &= (t_{\text{bell}} - t_{\text{ambient}})e^{K_1 \frac{L}{Q}} + t_{\text{ambient}} \\ &= (123-40)e^{.00286 \frac{1200}{9}} + 40 \\ &= 162^\circ\text{F for } 3/4\text{-inch I.D. hose @ 9 GPM} \end{aligned}$$

Using the same procedure we can see the effect of substituting 1-inch I.D. hose and different flow rates:

For 1-inch hose @ 9 GPM

$$T_{\text{surface}} = 175 \text{ F}$$

For 1-inch hose @ 12 GPM

$$T_{\text{surface}} = 159 \text{ F}$$

Case 2--300 Foot Dive With Independent Surface Support. The conditions for this dive scenario are:

Each diver individually supplied from the surface to 300 FSW

Length of umbilical - 600 feet

Flow to each diver - 3 GPM

Water temperature required at diver - 105 F

Ambient water temperature - 40 F

Assumptions (2) and (3) valid.

As in Case 1, the umbilicals are first sized for flow capability:

(a) Size umbilicals for flow capability

According to Figure 1, pressure losses are:

| | |
|--|----------|
| 600 feet to 1/2-inch I.D. hose flowing 3 GPM | = 57 psi |
| Estimated valve and fittings losses | = 25 psi |
| Total pressure required at source | = 82 psi |

(b) Estimate water supply temperature

Using Equation 4 (or Table 1):

$$\begin{aligned}
 t_{\text{surface}} &= (t_{\text{diver}} - t_{\text{ambient}}) e^{K_1 \frac{L}{Q}} + t_{\text{ambient}} \\
 &= (105-40) e^{.00250 \frac{600}{3}} + 40 \\
 &= 147^{\circ}\text{F}.
 \end{aligned}$$

Having completed this analysis, we may conclude that the 850-foot dive will make the greatest demands on the supply equipment and the hoses. The maximum pressure in that case could be 183 psi and the maximum temperature could be 175 F. Due to the assumptions made in these analyses, it is reasonable to require hoses to withstand temperatures to 190°F and pressures to 200 psi.

Final Definition of Hose Evaluation Criteria

Once the market survey and the theoretical analyses were completed, a meeting was held with Navy representatives of the Experimental Diving Unit to define the final hose evaluation criteria. These criteria would be used to judge the most suitable hoses for Navy use.

Some of the criteria were easily quantified so that potential hoses could be evaluated purely on manufacturer's information. With other criteria, it was not as easy to determine if a potential hose would be suitable or not. Items on the final list are explained in the following paragraphs.

- Size** -- 1/2-Inch I.D. hoses only would be considered. This size is most suitable for the 2-4 GPM flows required for individual diver umbilicals. Bell umbilicals (3/4-inch and 1-inch I.D.) would be considered on a special basis.
- Pressure** -- 200 Psig working pressure, 800 psi burst pressure minimum. Although pressures this high would probably not be encountered, the extra insulation and factor of safety of this rating justifies any additional weight or cost.
- Temperature** -- 0 to 190°F. Hose should be capable of extended exposure to salt water at 190°F and should remain flexible at 0°F.
- O.D./I.D. Ratio** -- Should be as large as possible for long umbilicals. Smaller ratios for short umbilicals or "whips" are acceptable.
- Flexibility** -- Should be flexible but not liable to collapse during normal handling.
- Weight** -- Weight of hose in sea water should be as close to zero as possible. A negative weight (floater) is less desirable than a positive weight hose. The characteristics of the hot water hose should be considered in respect to the characteristics of the other hoses, cables, etc., in the umbilical assembly however. A heavy hose might serve well when incorporated in an otherwise bouyant umbilical.
- Tube Material** -- Compatible with 190°F sea water and dilute concentrations of oil.
- Braid** -- Synthetic fiber braid or spiral wrap. Natural fiber and carbon steel braids are too susceptible to degradation in a sea water environment.

- Cover Material -- Compatible with sea water, detergents, and strong concentrations of oil. Resistant to ozone, UV radiation and weather checking.
- Color -- Any color is acceptable, however, the carbon black pigment used in black hose is generally considered to provide superior weathering characteristics.
- Length -- Continuous lengths preferable but purchases in reel lengths is acceptable if individual umbilicals can be assembled with no more than two splices.
- Cost -- No maximum costs specified but lower priced hose is preferable if quality is comparable.

Selection of Most Suitable Hoses

After completing the above steps, it was a straightforward procedure to select the most suitable hoses for divers' heating. The hoses which were selected appear to satisfy all of the established requirements. They may, however, vary in durability or heat insulation-characteristics which are difficult to measure without laboratory or field evaluations.

In addition to selecting hoses based on information available from manufacturers, sample lengths of hoses were obtained for visual examination. No discrepancies from manufacturer-provided information were noted with any of the samples. The samples were labeled and delivered to the Navy Experimental Diving Unit.

REFERENCES

1. Crane, "Flow of Fluids Through Valves, Fitting, and Pipe", Crane Co., 1969.
2. Henkener, J. A., "Design Review of Diving Support Systems Aboard ASR-21", SUPDIV Reprot No. 1-72, April, 1972.
3. U. S. Navy Diving Gas Manual, Second Edition, NAVSHIPS 0994-003-7010, June, 1971.
4. "Unlimited Hot Water System", a pamphlet by Diving Unlimited International.

TABLE A-1. MATRIX OF CHARACTERISTICS OF DIVERS BREATHING HOSES
1/2-Inch I.D. Hoses

| Company | Hose Name | OD ID | Number of Braids | Working Pressure (psi) | Minimum Temperature (°F) | Weight (lbs/100') | Tube Material | Cover Material | Color | Length | Cost (1) (\$/100') |
|---------------------------|-------------------------------|-------|------------------|------------------------|--------------------------|-------------------|------------------|----------------|-------|-------------|--------------------|
| Abbot | 6166 | 1.75 | 2 | 250 | 190 | 28 | EPDM | EPDM | Black | Reel | 28 |
| Amann | Deep Sea Diving | 1.81 | 4 | 300 | 240 | 30 | Nycal | Neoprene | Red | Reel(2) | 55 |
| Aerogrip | PC285-08 | 1.88 | 2 | 1000 | 200 | 28 | Synthetic Rubber | Neoprene | Black | 300' Min | 164 |
| Bunker(3) | P979 | 1.75 | 2 | 250 | 200 | 24 | EPDM | EPDM | Red | Reel | 66 |
| Boyd | Gen'l Purpose | 1.75 | 2 | 250 | -- | 18 | EPDM | EPDM | Black | Reel | -- |
| Boyco | Three-Pie All Purpose | 1.81 | 2 | 300 | 240 | 29 | Russ H | Neoprene | Black | 300-600' | 37 |
| Diving Unlimited | Hot Water Diver | 1.75 | 2 | 600 | 200 | -- | Cum Rubber | Cum Rubber | Black | Reel | 160 |
| Diving Unlimited | Hot Water Boil | 2.59 | 2 | 600 | 200 | -- | Cum Rubber | Cum Rubber | Black | Reel | 197 |
| Electric Rubber and Hoses | Multipurpose | 1.75 | 2 | 250 | 200 | 26 | Nitrile | Neoprene | Black | Reel | 43 |
| Gasco | Plumc Master 1198 | 1.60 | 1 | 250 | 212 | 24 | Russ H | Neoprene | Black | Reel | 99 |
| Goodrich, B.F. | Highflex | 1.56 | 1 | 250 | 200 | 20 | Neoprene | Neoprene | Red | Reel | 50 |
| Goodyear(4) | GRTAC | 1.81 | 1 | 300 | 190 | 22 | Chemigum | Chemivc | Red | Reel | 74 |
| Goodyear(4) | GRTAC | 2.06 | 2 | 350 | 190 | 36 | Chemigum | Chemivc | Red | Reel | 85 |
| James Pirall(4) | Pressure 87 2750/L (0.512"ID) | 2.13 | 1 | 206 | 240 | -- | SSR | SSR | Black | 328' | 119 |
| Manhattan | All-Service | 1.81 | 2 | 300 | 200 | 26 | Nitrile | Nitrile/Vinyl | Black | Reel | 75 |
| Parber Emmifin | Perflex 5408 | 1.60 | 1 | 2000 | 200 | 13 | Nylon | Polyurethane | Black | 300' | 165 |
| Porter, R. E. | Versicon | 1.81 | 4 | 300 | 200 | 28.5 | Nitrile | Neoprene | Red | 2/600' Reel | 51 |

Footnotes appear on Page

TABLE A-1. (Continued)
 1/2-Inch I.D. Hose

| Comments | Hose Item | OD ID | Number of Reels | Working Pressure (PSI) | Maximum Temperature (°F) | Weight (lbs/100') | Tube Material | Cover Material | Color | Length | Cost (1) (\$/100') |
|--------------|----------------------------|-------|-----------------|------------------------|--------------------------|-------------------|---------------|---------------------|-------|-----------|--------------------|
| | B-502 | 1.36 | 1 | 200 | 200 | 16 | EPDM | Polyurethane Silver | | 1000' | 793 |
| | Insulated Hot Water Supply | 2.36 | 1 | 200 | 190 | 55 | EPDM | EPDM | Black | 400-600 | 328 |
| | 108578-12-3400 | 1.52 | 1 | 1500 | 500 | 55 | EPDM | Brethman/Silicone | --- | 1000' (6) | 187 (7) |
| | F790 | 1.81 | 2 | 300 | 200 | 29 | NITRILE | OZEK | Green | Reel | 111 |
| White, U. S. | Hot Water Hose | 1.75 | 2 | 250 | 200 | 24 | PARACHIC | OZEK | Red | Reel | 56 |

TABLE A-1. (Continued)

3/4-Inch I.D. Hose

| Company | Hose Name | OD ID | Number of Braids | Working Pressure (psi) | Maximum Temperature (°F) | Weight (lbs/100') | Tube Material | Cover Material | Color | Length | Cost (l) (\$/100') |
|--------------------------|-----------------------------|-------|------------------|------------------------|--------------------------|-------------------|------------------|------------------|--------|-------------|--------------------|
| Abbott | 6208 | 1.54 | 2 | 200 | 190 | 43 | EPDM | EPDM | Black | Reel | 42 |
| Amazon | Deep Sea Diving | 1.67 | 4 | 300 | 240 | 40 | Hycar | Neoprene | Red | Reel | 80 |
| Baldwin | Black Wingfoot | 1.58 | 2 | 300 | 200 | 36 | Synthetic Rubber | Synthetic Rubber | Black | Reel | 111 |
| Baxter (3) | P970 | 1.56 | 2 | 200 | 200 | 37 | EPDM | EPDM | Red | Reel | 89 |
| Boyd | General Purpose | 1.50 | 2 | 200 | -- | 37 | EPDM | EPDM | Black | Reel | -- |
| Boyco | Thoro-Flo All Purpose | 1.67 | 2 | 300 | 240 | 48 | Buna N | Neoprene | Black | 300-600' | 54 |
| Electric Hose and Rubber | Air and Water | 1.56 | 2 | 200 | -- | 40 | EPDM | EPDM | Black | Reel | 70 |
| Gates | Plant Master 19B | 1.09 | 1 | 250 | 212 | 32 | Buna N | Neoprene | Red | Reel | 113 |
| Gates | Plant Master 19B | 1.25 | 2 | 315 | 212 | 51 | Buna N | Neoprene | Red | Reel | -- |
| Goodrich, B.F. | BFG 300 G.S. | 1.67 | 4 | 300 | 200 | 40 | EPDM | EPDM | Black | Reel | 70 |
| Goodyear (4) | ONTAC | 1.58 | 1 | 300 | 190 | 35 | Neoprene | Chemivc | Red | Reel | 99 |
| Goodyear | ONTAC | 1.83 | 2 | 350 | 190 | 54 | Neoprene | Chemivc | Red | Reel | -- |
| Jacon (Firell) | Press. SP 275 N/L .748 I.D. | 1.79 | 1 | 206 | 240 | -- | SBR | SBR | Black | 328 | 151 |
| Manhattan | All-Serve | 1.67 | 2 | 300 | 200 | 40 | Nitrile | Nitrile/Vinyl | Black | Reel | -- |
| Myers-Sherman | Vector Orange | -- | -- | 1250 | 300 | -- | Polyamide | Hytral | Orange | 400-500' | 200 |
| Parber Manufacturing | Parflex 540N | 1.39 | 1 | 1250 | 200 | 17.3 | Nylon | Polyurethane | Black | 300' | 176 |
| Porter, H. K. | G. P. Spiral | 1.58 | 4 | 275 | 200 | 44 | Nitrile | EPDM | Red | 2/600' Reel | -- |
| Swan (5) | Insulated Hot Water Supply | 2.04 | -- | 200 | 200 | 69 | EPDM | EPDM | Black | 200-350' | 414 |
| Uniroyal | F290 | 1.56 | 2 | 200 | 200 | 37 | Nitrile | Oxax | Green | Reel | -- |
| White, H. S. | Hot Water Hose | 1.54 | 2 | 250 | 200 | 44 | Paracrifl | Oxax | Red | Reel | 78 |

TABLE A-1. (Continued)

1-Inch I.D. Hose

| Company | Hose Name | OD ID | Number of Braids | Working Pressure (psi) | Maximum Temperature (°F) | Weight (lbs/100') | Tube Material | Cover Material | Color | Length | Cost (1) (\$/100') |
|--------------------------|-----------------------|-------|------------------|------------------------|--------------------------|-------------------|------------------|------------------|--------|----------|--------------------|
| Abbott | Water Hose (Special) | 1.47 | 2 | 300 | 790 | 50 | EPDM | EPDM | Black | Reel | 94 |
| Amson | Deep Sea Diving | 1.47 | 4 | 300 | 240 | 60 | Hycar | Neoprene | Red | Reel | 106 |
| Baldwin | Black Wingfoot | 1.50 | 2 | 300 | 200 | 55 | Synthetic Rubber | Synthetic Rubber | Black | Reel | 148 |
| Baxter ⁽³⁾ | P970 | 1.47 | 2 | 200 | 200 | 56 | EPDM | EPDM | Red | Reel | 133 |
| Boyd | General Purpose | 1.47 | 2 | 200 | --- | 56 | EPDM | EPDM | Black | Reel | --- |
| Byco | Thoro-Flo All Purpose | 1.53 | 2 | 300 | 240 | 63 | Buna N | Neoprene | Black | 300-500' | --- |
| Electric Hose and Rubber | Air and Water | 1.50 | 2 | 200 | --- | 65 | EPDM | EPDM | Black | Reel | 98 |
| Gates | Plant Master 19B | 1.38 | 1 | 250 | 212 | 47 | Buna N | Neoprene | Red | Reel | --- |
| Gates | Plant Master 19B | 1.50 | 2 | 315 | --- | 64 | Buna N | Neoprene | Red | Reel | --- |
| Goodrich, B.F. | WPC300 G.S. | 1.47 | 4 | 300 | 200 | 50 | EPDM | EPDM | Black | Reel | 90 |
| Goodyear ⁽⁴⁾ | ORDAC | 1.50 | 1 | 300 | 190 | 49 | Chemigum | Chemivic | Red | Reel | 122 |
| Goodyear ⁽⁴⁾ | ORDAC | 1.58 | 2 | 350 | 190 | 57 | Chemigum | Chemivic | Red | Reel | 131 |
| Jason (Firellis) | TK702 .984ID | 1.60 | 2 | 206 | 240 | -- | SBR | SBR | Black | 378 | 161 |
| Manhattan | All-Serve | 1.50 | 2 | 300 | 200 | 53 | Nitrile | Nitrile/Vinyl | Black | Reel | 123 |
| Myers Sherman | Vector Orang | 1.41 | 2 | 1250 | 300 | -- | Polymida | Hytrel | Orange | Reel | 240 |
| Porter, H.S. | G.P. Spiral | 1.44 | 2 | 250 | 200 | 51 | Nitrile | EPDM | Red | Reel | --- |
| Unifroyal | P970 | 1.47 | 2 | 200 | 200 | 56 | EPDM | EPDM | Red | Reel | 133 |
| White, H.S. | Hot Water Hose | 1.47 | 2 | 250 | 200 | 65 | Paracril | Oxoz | Red | Reel | 123 |

Notes:

- (1) Cost based on an order of 3 lengths of 300' hoses (may require splices).
- (2) Reel lengths are industry standards of 350-600 feet of hose per reel. At maximum of 3 lengths per reel, the shortest length is at least 10% (30') of total length of hose on the reel.
- (3) Baxter Rubber and Unifroyal offer identical hoses.
- (4) Goodyear hose is available from both Anchor Rubber and Oberjuege Rubber - prices quoted are Anchor Rubbers.
- (5) Swan hose presently available in minimum orders of 10,000-12,000 feet.
- (6) Titeflex achieves long hose lengths by non-detachable couplings joining 30 foot segments.
- (7) Price includes couplings and end fittings to make a 300' hose assembly.

TABLE A-2. LIST OF COMPANIES CONTACTED IN MARKET SURVEY

| Company | Contacted by | | Response (1) | | Comment |
|--|--------------|-------|---------------|-----|--|
| | Letter | Phone | None Received | Yes | |
| AMB Flex Hose | X | X | | X | Metallic and plastic hose |
| Abbot Rubber Company | X | | | X | EPDM Hose |
| Acco Industrial Rubber Corp. | X | | X | X | Conveyors, belts |
| Ace Hose & Rubber | X | | X | | Not responsive |
| Acme-Hamilton Manufacturing | X | X | | X | Manufacturer does not think their hose is suitable |
| Aero-Motive Manufacturing | X | | | X | Cable & hose handling equipment |
| Aeroquip | X | X | | X | |
| Aero Rubber | X | | X | | Extruded rubber |
| Air Products and Chemicals, Fabricated Products Div. | X | | | X | Plastic hoses |
| American Hose Corporation | | X | | X | Not responsive - EPDM Hose |
| Amazon Hose & Rubber | X | X | | X | |
| American Biltrite Company (Boston Woven Hose) | X | X | | X | Not willing to supply life support systems |
| American Rubber Manufacturing Company | X | X | X | | Not responsive |
| Amelo Products | X | | | X | Do not manufacture hose |
| Alemite and Instrument (Div. of Stewart Warner) | | X | | X | High pressure/high cost |
| Anchor Coupling | | X | | X | Hydraulic hose - not formulated for water |
| Anchor Rubber | X | | X | | Goodyear distributor |

TABLE A-2. LIST OF COMPANIES CONTACTED IN MARKET SURVEY
(Continued)

| Company | Contacted by | | Response (1) | | Comment |
|---|--------------|-------|---------------|-----|---|
| | Letter | Phone | None Received | Yes | |
| Apache Hose and Rubber | X | | X | | Not responsive |
| Armstrong Hose Division, Insu- listed Duct & Cable Co. | X | | | | X Will offer hose in the future |
| Arrowhead Products, Division of Federal-Mobol Corp. | X | | | | X Special aircraft ducting |
| Baldwin Belting | X | X | | X | Goodyear distributor |
| Baxter Rubber Co. | X | X | | X | EPDM Hose |
| Beacon Hose Manufacturing (Cleveland Rubber Prods.) | X | X | | | X Not willing to supply life support systems |
| Boss Manufacturing Co. | X | | | X | Not responsive |
| Boyd Industrial Rubber | X | | | | X EPDM Hose |
| Briggs Rubber Products Co. | X | | | X | Affiliate of Electric Hose & Rubber Special Products |
| Brunswick Rubber Company | X | | | X | |
| Buckeye Rubber Products | X | X | | | X Mandrel made 50' lengths maximum |
| Carlyle Rubber Company (Carlyle Tire & Rubber) | X | | | X | Not responsive |
| Chamberlin Rubber Co. | X | | | X | Molded rubber goods |
| Chase Walton | X | X | | | X 75 psi max. 9' lengths max. |
| Cincinnati Rubber Mfg. Co. (Div. of Stewart-Warner) | X | X | | | X Mandrel made 50' lengths max. |
| Cobon Plastics Corp. | X | | | X | Plastic hose only |
| Conti Rubber Products | X | X | | | X German hose, not applicable |

TABLE A-2. LIST OF COMPANIES CONTACTED IN MARKET SURVEY
(Continued)

| Company | Contacted by | | Response (1) | | Comment |
|---|--------------|-------|---------------|-----|--|
| | Letter | Phone | None Received | Yes | |
| Continental Rubber Works (Sub. of Continental Copper and Steel) | X | X | | X | Length or temperature limitation |
| Controls Southeast, Inc. | X | | X | | Flexible metal hose and rubber jackets |
| Cooper Industrial Products | X | | | X | Mechanical Rubber products |
| Couse and Bolten Co. | X | | X | | Affiliate of Cobon Plastics |
| Darling, R. E. Company | X | | X | | Special hoses (breathing) and rubber products |
| Dayco Rubber Products | X | X | | X | |
| Dearborn Rubber Corp. | X | | X | | Not responsive |
| Delford Industries of Delaware | X | | | X | Rubber extrusions & special products |
| Desco | X | | | X | Diving equipment, but not hose |
| Devisch Company | X | | | X | Stainless steel for aero- space |
| Diving Unlimited International | | X | | X | |
| Durkee-Atwood | X | | | X | V-belts, buck sponge Rubber |
| Empex Industrial Hose Division, Master Processing Corp. | X | | | X | 1-1/4" ID hose and larger |
| Electric Hose & Rubber Company | X | X | | X | |
| Empire State Belting & Hose Co. | X | X | | X | Not responsive |
| Everco Industries | X | | X | | Auto tubing |

TABLE A-2. LIST OF COMPANIES CONTACTED IN MARKET SURVEY
(Continued)

| Company | Contacted by | | Response (1) | | Comment |
|--|--------------|-------|---------------|-----|--|
| | Letter | Phone | None Received | Yes | |
| Firestone Industrial Products | X | | | | X Appliance, auto, special purpose |
| Flexco, Inc. | X | | X | | X Not responsive |
| Flow Products | X | | X | | X Hydraulic hoses and systems |
| Gates Rubber Company | X | X | | X | |
| Goodall Rubber Co. (Manhattan Division) | X | | | | X Not Responsive |
| Goodrich, B. F., Engineered Systems | X | X | | X | |
| Goodyear Tire & Rubber Company Industrial Products Division | X | X | | X | |
| Green Rubber Products | X | | X | | X Not responsive |
| Hancock-Gross | X | | | | X Not interested in diving |
| Hecht Rubber Corporation | X | | X | | X Rubber gasket mats |
| Hewitt Robbins | | X | | | X No longer manufactures hose |
| Hoffman Engineering | X | | | | X Hose couplings |
| Holz Rubber Company | | | | X | X Molded rubber products and hand built hoses |
| Imperial-Eastman | | X | | | X Not for hot water |
| Industrial Tube | X | | X | | X Low pressure tubing & ducting |
| James, E. and Co. | X | | X | | X Not responsive |
| Jarvia Engineering Co. | X | | X | | X Hose assemblies |
| Jason Industrial | X | X | | | X Foreign manufacturer (Pirelli) |
| Jasper Rubber Co. | X | | X | | X Molded & extruded products |

TABLE A-2. LIST OF COMPANIES CONTACTED IN MARKET SURVEY
(Continued)

| Company | Contacted by | | Response (1) | | Comment |
|--|--------------|-------|---------------|-----|------------------------------------|
| | Letter | Phone | None Received | Yes | |
| Kravex Manufacturing Corp. | X | | X | | Plastic hose |
| Manufactured Rubber Products | X | | X | | Extruded & molded products |
| Marshall Brass | X | | X | | LP hose & fittings |
| Maryland Rubber Corporation | X | | | X | Hydraulic hose assembly |
| Mercer Rubber Company | X | | | X | Not responsive |
| Murken, Frank Inc. | X | | X | | Stocking distributors |
| Miller Products Company | X | | X | | Subsidiary of Goodyear |
| Minnesota Flexible Corp. | X | | | X | Distributors |
| Moore Manufacturing | X | | X | | Not responsive |
| Mueller Belting & Supply Co. | X | | X | | Special products |
| Myers Sherman Company | | X | | X | 3/4 & 1" hose only |
| New Jersey Engineering & Supply | X | | X | | Distributors |
| Oberjuege Rubber Company | X | X | | X | Goodyear distributors |
| Ocean Pool Supply Company | X | | X | | Swimming pool accessories |
| Parker Hannifin Corporation Hose Products | X | X | | X | |
| Penntube Plastics Company, Division of Dixon Ind. Corp. | X | | X | | Unreinforced plastic extrusions |
| Plastiflex Company | X | | X | | Plastic only |
| Porter, H.K., Co., Inc., Thermoid Division | X | X | | X | |
| Ramco Industries | X | | X | | Subsidiary of Dayco |
| Renick and Mahoney | X | | X | | Distributors |

TABLE A-2. LIST OF COMPANIES CONTACTED IN MARKET SURVEY
(Continued)

| Company | Contacted by | | Response (1) | | Comment |
|--|--------------|-------|---------------|-----|--|
| | Letter | Phone | None Received | Yes | |
| Reimers Electra Steam, Inc. | X | | X | | Steam generators & accessories |
| Resistoflex Corporaton | X | X | | X | Stainless steel/Teflon hose |
| Robin Industries | X | | X | | Molded rubber products |
| Ronco Corporation | X | | X | | Hose & tube fittings |
| Rubatez Corporation | X | | | X | Insulation materials |
| Rubber Corporation of America | X | | X | | Molded products |
| Schacht Rubber Mfg. Company | X | | | X | Mechanical & household rubber goods |
| Stalwart Rubber Company, Sub. of Blasius Ind. Inc. | X | | | X | Molded & extruded rubber parts |
| Stockwell Rubber Co., Inc. | X | | | X | Molded & extruded rubber parts |
| Stratoflex, Inc. | X | | | X | Stainless steel/Teflon hoses |
| Swan Hose Division, Amerace Corporation | X | X | | X | (2) |
| Tech Aerofoam Products, Inc. | X | | X | | Not responsive |
| Trelleborg Rubber Company | X | X | | X | Foreign manufacturer |
| Tem-Val, Inc. | X | | X | | Not responsive |
| Titeflex Division of Atlas Corporation | X | | X | | Flexible metal and Teflon |
| Tri State Rubber Corporation | X | | X | | Not responsive |
| Unaflex Rubber Corporation | X | | | X | Expansion joints & pump connections, see White |
| United Rubber Products | X | | | X | Not responsive |

TABLE A-2. LIST OF COMPANIES CONTACTED IN MARKET SURVEY
(Continued)

| Company | Contacted by | | Response (1) | | Comment |
|--|--------------|-------|---------------|--------|-------------------------------|
| | Letter | Phone | Mone Received | Yes No | |
| Uniroyal, Inc. Uniroyal Industrial Products Div. | X | X | | X | |
| United Rubber Supply | X | | X | | Not responsive |
| Vibration Mountings & Controls | X | | X | | Not responsive |
| Weatherhead | X | X | | X | Not recommended for hot water |
| White, H.S. & Company | X | X | | X | |
| Zinga Industries | X | | | X | Hydraulic line systems |

Notes: (1) Companies with a "yes" in this column are listed in Table 1.

(2) Swan manufactures an excellent insulated hot water hose, but it is only available in quantities of 10,000 feet or more. Their representatives do not recommend use of their diving air hose for this application.

**DATE
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