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ADVANCED DEEP SEA DIVING EQUIPMENT

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INTRODUCTION

As a result of recommendations of several committees convened by the U.S. Navy supervisor of diving for the purpose of reviewing conventional Navy diving equipments, General Electric Company proposed a deep sea diving system development program to the Navy. This program, a proposal for the survey and engineering evaluation of deep sea heavy duty diving equipment, was approved by the Navy on February 2, 1970, and the program was initiated.

The overall goal of this program is to equip the Navy salvage diver with equipment and tools that will enable him to perform work of the same quality and in times approaching that done on the surface.

MARK V DIVING SYSTEM

Mark V denotes two distinct deep sea diving systems. The air outfit (fig. 12.1) is for heavy duty diving and is issued to vessels and shore activities whose function is to undertake extensive salvage operations. The helium oxygen outfit is a special system issued only to submarine rescue units. The

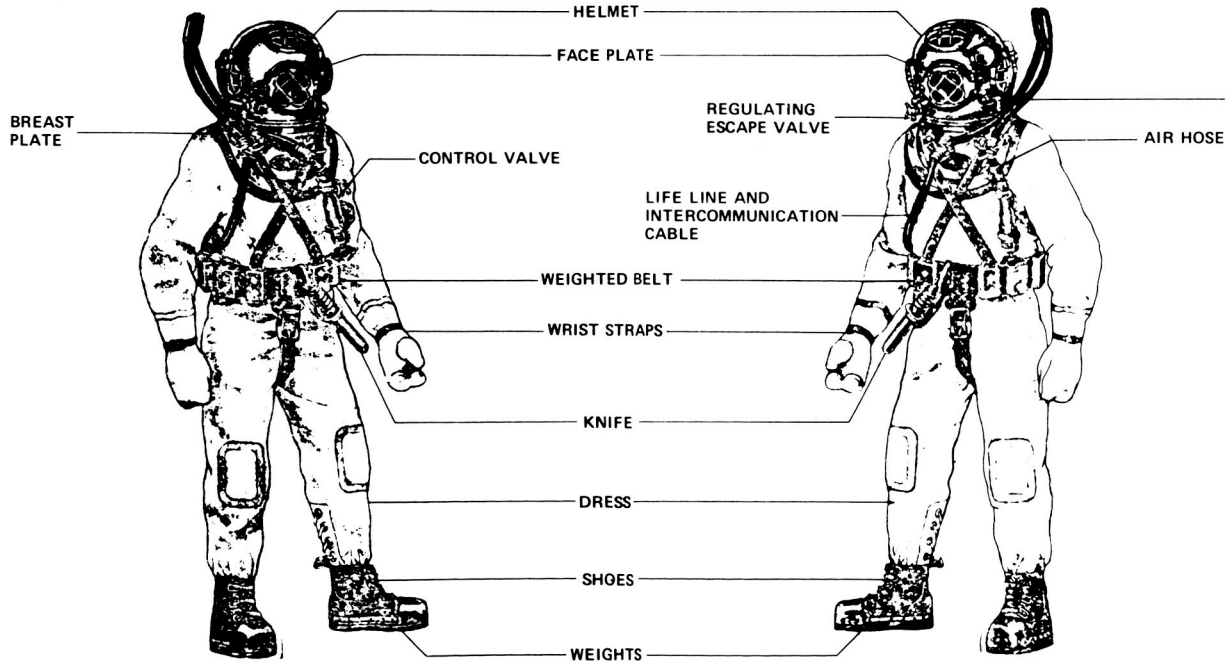


Figure 12.1 Deep-sea diving outfit.

deep sea diving outfit consists of the helmet and the dress, which provide water tightness; weights for overcoming positive buoyancy gained by the volume of the helmet and the inflated dress; hoses and control valves for furnishing air; and a nonreturn valve used to prevent seawater from entering and air from escaping from the dress in the event of accidental rupture of the air hose. This Mark V system has been used for many years with remarkable success. In addition to all submarine rescue and salvage work undertaken in peacetime, practically all salvage work of any extent undertaken during World War II was accomplished with this equipment. The system is designed for extensive, rugged diving work and provides the diver with maximum physical protection. It is now used in general types of work such as submarine salvage, initial inspection, placing moorings, attaching hose for blowing and venting, ship salvage underwater inspection, internal repairs, installation of patches on ship hulls, construction of dams, harbor work, and other standard industrial and commercial forms of diving. There are also many diving operations undertaken with this equipment in shallow depths in which the rugged equipment provides protection for the diver. It is a fact that today, more than 100 years after its basic development, the "hard hat" diving system is essentially unchanged in form; yet it is still the standard for salvage diving throughout the world.

The Navy standard diving helmet consists of a spun copper helmet with its fittings and a breast plate (fig. 12.2). The interface between the helmet and the breast plate is an interrupted thread breech joint. There are four viewports on the helmet. The one directly in front of the divers face is the faceplate. The faceplate is hinged and held in the closed position by a swing bolt and wing nut. All four ports are protected from breakage by metal guards. Inlet air is controlled by a regulating valve attached to the air supply hose and fixed to the breast plate. A regulating exhaust valve controls the internal pressure of the helmet and the flow of gas from the helmet.

The helmet has many good features that account for the high degree of acceptance throughout the world diving community. However, apart from some modifications in response to advances in technology, until now no overall system study had been undertaken to update the equipment in light of new materials and advances in fabrication technologies, and little attention had been given to new requirements for the function of diving.

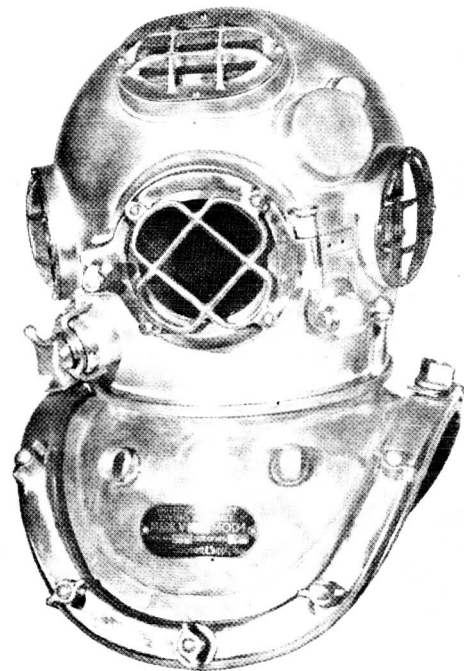


Figure 12.2 *Diving helmet and breast plate.*

PROGRAM TASKS

The overall program was divided into four tasks (fig. 12.3). Initially, a survey was performed to determine the extent of equipment development and the areas where there had been significant improvements in existing equipment. A preliminary system design was evolved with the objective of correcting the deficiencies noted in existing equipment and improving the design to meet the new requirements. In the third task, now in process, sufficient component testing was identified to demonstrate that the system deficiencies could be overcome. This task also includes the final

- TASK 1 – SURVEY AND RECOMMENDATIONS**
- TASK 2 – PRELIMINARY DESIGN**
- TASK 3 – CRITICAL COMPONENT TEST**
- TASK 4 – PROTOTYPE SYSTEM FABRICATION AND TEST**

Figure 12.3 Program plan.

WRITTEN QUESTIONNAIRE – 88 OF 150 REPLIED

- VISITS: 8 U.S. DIVING COMPANIES**
- 8 U.S. EQUIPMENT MFGRS**
- 10 FRENCH DIVING & MFG**
- 4 GERMAN DIVING & MFG**
- 5 ITALIAN DIVING & MFG**
- 8 BRITISH DIVING & MFG**

Figure 12.4 Equipment survey.

definition of the recommended system, by drawings and specifications. Finally, a prototype system is to be fabricated and delivered to the Navy for evaluation in the field.

EQUIPMENT SURVEY

Two basic objectives were established for the survey: to achieve sufficient depth to obtain significant information, and to obtain a proper interpretation of the results. An extensive list of diving companies and equipment manufacturers was generated, which included as wide a range of types of diving as possible. This was quite difficult in the United States, since more than 90 percent of the major diving companies are engaged almost exclusively in oil and offshore support diving. To ensure that the information would be meaningful, the survey was divided into phases and activities. Initially, selected diving firms were visited to obtain the information required. The remaining diving firms were sent a questionnaire. Of 150 companies queries, 88 responded to the

questionnaire (fig. 12.4). Of the total number of commercial divers in the United States, the survey records pertinent diver equipment information from more than 1000 active commercial divers. The second part of the survey entailed questioning the equipment manufacturers. Their design rationales were referenced to divers requirements to determine the appropriateness of the design features. The survey also included a survey of the European diving community. Because of timing and geographical limitations, the overseas survey was less detailed than the domestic portion, but the data were essentially complete.

The survey concluded that the most significant and varied developments in heavy duty diving breathing equipment have occurred in the United States. The advances have been achieved by a small group of low volume equipment manufacturers at their own initiative and expense. Little testing of these devices has been done and it is difficult to compare their performance since all have resulted from different interpretations of the requirements for the designs.

Significant improvements have been made in diver dress in the European diving community particularly in the area of heating and in general diver comfort.

The present Mark V diving system, or a modification of it, is the standard equipment for heavy duty salvage operations throughout the world. There is considerable area for improvement of the many features of this equipment, however, this improvement must be based on the operational parameters of the Mark V system.

SURVEY RESULTS

The results of the survey are published in reference 1. Since the survey was conducted on a subjective basis, and since divers, justifiably, have very strong opinions regarding the attributes of their equipment, the survey sometimes resulted in widely divergent opinions on some features. However, a number of inadequacies in present equipment were identified and efforts were initiated to correct these situations (fig. 12.5).

- **NOISE REDUCTION**
- **IMPROVE RECIRCULATION**
- **SELF DONNING**
- **POSITIVE RESERVE GAS**
- **BETTER MATERIALS**
- **LINEAR CONTROL VALVES**
- **AIR OR MIXED GAS**
- **IMPROVED WEIGHT MATRICES**

Figure 12.5 *Areas of improvement.*

Nearly all divers complained about excessive noise within their helmet and gas system. This did not imply that they desired all noise eliminated. The psychological and safety aspects of hearing gas flowing are quite important. However, a number of divers found it necessary, when using certain equipment, to turn the gas supply off to permit communication—a very dangerous practice.

The process of gas circulation and recirculation varied widely in all of the systems studied. The flow of gas within the helmet performs two functions. One is the removal of carbon dioxide and replenishment of oxygen, and the second is clearing the window ports of moisture to permit visibility. In the recirculation mode of operation described later, the ratio of recirculated gas to inlet gas must be maintained as high as possible, over a range of inlet flows.

The Mark V and many commercial systems are of such weight and complexity that they require the assistance of a tender to dress the diver. As diving from habitats increases, the diver must be able to dress in cramped, confined spaces.

The divers prefer the large volume common to the Mark V helmet because it provides a reserve should the gas supply be cut off. Almost all divers tell of ration-breathing gas from the helmet in emergency conditions—a capability unavailable in a mask. However, it takes an exceptionally trained person to take maximum advantage of this reserve gas.

New materials and material fabrication techniques have generally been ignored in most designs of the diving equipment surveyed. New materials are being used, but they rarely are tailored specifically to the total application.

The control valves were mainly selected from those available at standard valve suppliers. However, very few commercially available valves are required to control precisely over both a wide range of flows and a fairly wide range of inlet pressures.

The Mark V system for air is considerably different, lighter, and much less cumbersome, than the system for mixed gas operation. Most commercially available mixed gas helmets can be used for air operation but not the converse. No single helmet was found that was designed to operate efficiently with both gas combinations.

Significant areas of improvement were identified for the allocation and positioning of weights to control buoyancy and mass properties of the diver in the water and yet allow him mobility on the surface.

From the results of this survey and an assessment of the areas of required improvement a system design requirement was generated (fig. 12.6). The first four parameters delineate the conventional diving environment. The last seven are goals to be achieved in a single diving system design. It was

found that many of the diving systems were designed by divers with a particular mission in mind or a particular improvement desired. Necessary functions of the helmet, such as provisions for communication, were all too often ignored until after the helmet was designed, and then added as an afterthought.

- SINGLE SYSTEM – AIR OR MIXED GAS
- DEPTH – SURFACE TO 1500 FEET
- TEMPERATURE – SURFACE –20° F TO +110° F
– WATER 28° F TO 96° F
- WATER – PURE
– SALT
– POLLUTED
- SIMPLE
- SAFE
- COMFORTABLE
- MOBILE
- MAINTAINABLE
- VERSATILE
- DURABLE

Figure 12.6 System design requirements.

THE DIVING SYSTEM

The system (fig. 12.7) consists of a helmet, a recirculator for removing carbon dioxide and economizing on gas, and the diver's dress. The dress includes a comfortor for distributing the weight of the helmet over the divers shoulders. Over the comfortor is a standard diver's dry suit, which interfaces with the neck ring. Over the dry suit is a nylon coverall with straps and belts to accommodate the weights, which are distributed low on the diver's waist and on his thighs. He also wears molded rubber boots with integral weights.

The combination of the coverall and the comfortor is designed to distribute the weight uniformly over the diver's body for comfort and mobility on the surface, and to minimize weight shift in the water. Each diver can adjust the straps on the coverall to his own stature and minimize the time and adjustments required to dress. The color of the coverall can be changed to permit covert operations, high visibility, etc. The coverall also serves the function formerly performed by chafing gear. The coverall will also contain a pocket for a smaller version of the bailout bottle when the rig is

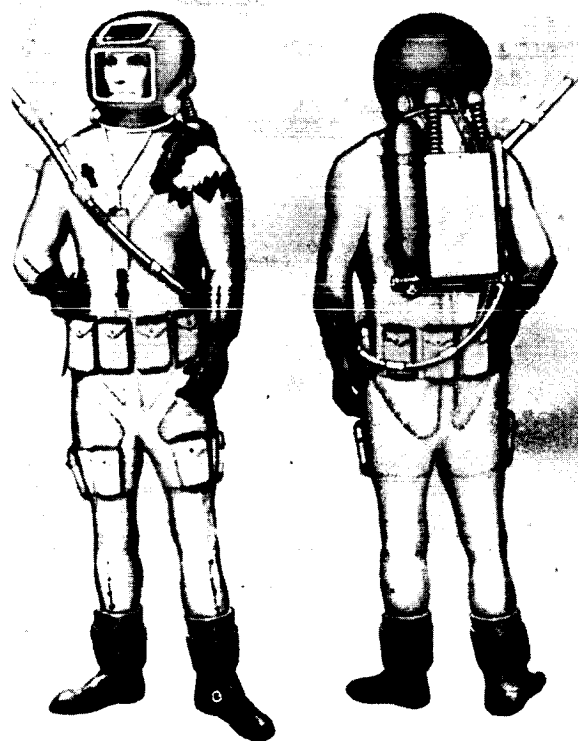


Figure 12.7 Diving system.

used for air diving. Weights are placed in the pocket and can be varied according to the dress and support equipment.

The recirculator is covered by a shroud to minimize hydrodynamic drag if the diver is in strong currents or moving about. It is, however, not a swimmable system as such. The shoes are rubber with steel foot and toe protection. The foot pad is corrugated rubber and has a definite breakpoint to permit foot movement while walking on rough or slippery surfaces.

The diver dons his insulated undergarment and places the comfort ring on his shoulders. He then enters his dry suit with the neck ring already attached. The dry suit has a back entry with a waterproof zipper. The diver then puts on his coveralls and attaches the cinch cables on the neck ring. Finally, he adjusts his cable and belt tensions to the required fit. At this point, he may have his weights in place or not, depending on his desire for mobility. Just before the dive he places his helmet in position, rotates it, and locks. He is ready now to dive.

The system is designed to be compatible with all types of swim dress (fig. 12.8). The interface in all instances is the neck ring. If the user dives without a suit, a conventional neck seal is attached to the neck ring at the same interface.

• DRY SUIT	WEIGHT	26.83 LBS
• CONSTANT VOLUME SUIT	VOLUME (TOTAL)	0.67 FT³
• WET SUIT	VOLUME (FREE)	0.57 FT³
• NO SUIT	BUOYANCY	16 LBS POSITIVE
• ADVANCED SUITS	FLOW – AIR	0–140 ℓ/MIN (5 FT³/MIN)
• HEATED	– MIXED GAS	0–140 ℓ/MIN (5 FT³/MIN)
• SUPER INSULATIVE	CONTROL VALVE	3 TURN-NEEDLE
	SOUND LEVEL	< 90 db
	WINDOWS	3/16" LEXAN
	MATERIALS:	
	SHELL	GLASS EPOXY
	BREECH	316 SS
	VALVES	PLATED BRASS

Figure 12.8 Diver dress compatibility.

Figure 12.9 Helmet.

The design of the helmet (fig. 12.9) and recirculator will be covered in some detail because they are the major factors affecting the ability to provide a system that meets the goals of the program.

The helmet weight selection is based on several factors, particularly the tradeoff of handling and inertia against buoyancy considerations. The center of gravity and center of buoyancy must be maintained at the same point so that when the diver moves his head underwater the helmet will follow his movement, not resist. The volume of the helmet is sufficient to permit head movement, both to reduce fatigue and to take advantage of the window position, particularly that of the top window. Airflows are compatible with the acceptable values for minimizing the collection of carbon dioxide in dead areas. The inlet valve will allow linear control of the flow evenly across the three turns. Sound levels are set by acoustic standards to permit 8 hr of work without fatigue or irritation.

SYSTEM OPERATION

Taking a front view of the helmet (fig. 12.10), the inlet air control is on the left (diver's right) and the exhaust control on the right. The diver has easy access to the valves even when the suit is inflated. The valves are snagproof yet have positive grip profiles. The window is easily removable when scratched or damaged. The communications interface is just below the window in a recess especially provided to keep the pickup out of the air stream.

When operating open cycle (fig. 12.11) the gas flows from the inlet fitting to the control valve in a tube along the inner wall of the helmet. Expansion chambers are provided for muffling and acoustic deadening. A distributor with a sintered metal filter reduces inlet air noise and flows the gas uniformly across the window for moisture removal. All plumbing for the open-cycle operation is easily removable for maintenance and cleaning and is fabricated from standard parts where possible. The sintered filter is removable for easy cleaning and replacement.

When the recirculator is in operation (fig. 12.12), gas is gradually expanded after it enters the helmet. The gas progresses across the window and enters the circulator inlet tube. As this gas leaves the helmet it passes through a venturi, which aspirates gas from the perforated tube in the bottom of the helmet. Thus, any carbon dioxide accumulating near the neck ring is swept out into the scrubber.

The comfortor supports the neck ring but is not directly attached (fig. 12.13). When the diver enters the water the helmet is likely to float a fraction of an inch above the comfort ring (fig. 12.14).

The recirculator consists of a scrubber to remove carbon dioxide, an inlet to receive the mix gas supply and trap the excess water, a venturi to recirculate and mix the gas from the scrubber with the inlet gas, and connection fittings to the helmet hoses (fig. 12.15). An expansion chamber above the venturi is designed to minimize noise

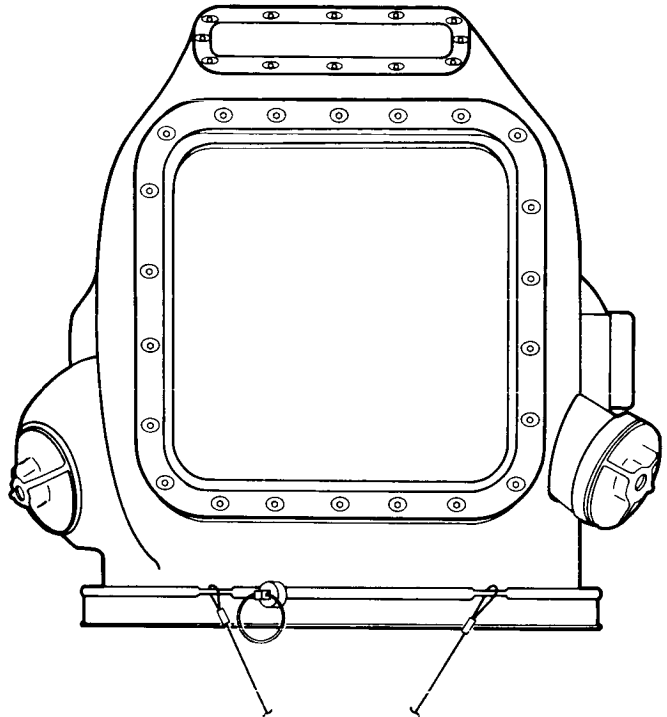


Figure 12.10 *Front view of helmet.*

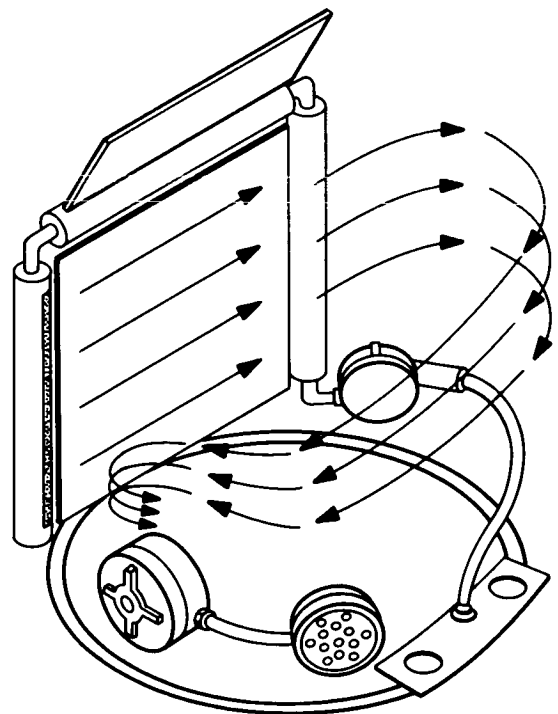


Figure 12.11 *Flow pattern open cycle.*

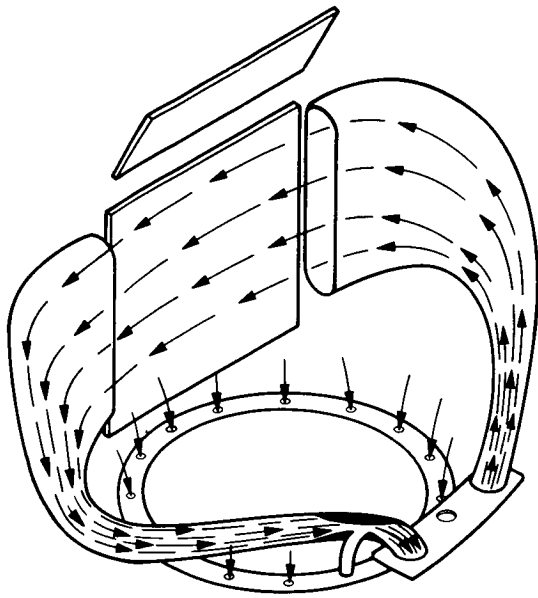


Figure 12.12 *Flow pattern recirculator.*

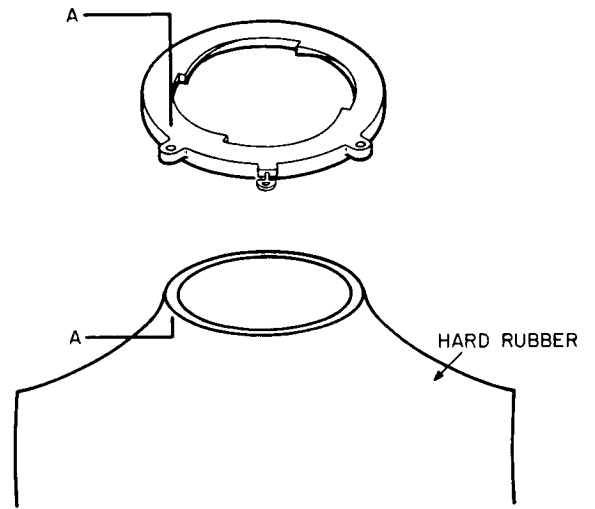


Figure 12.13 *Comfort ring.*

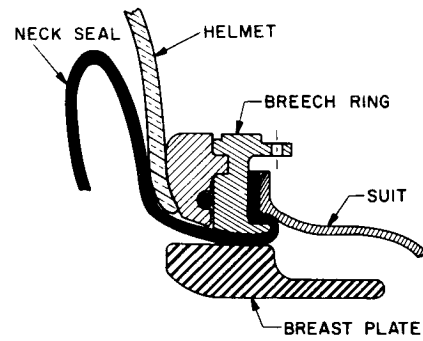
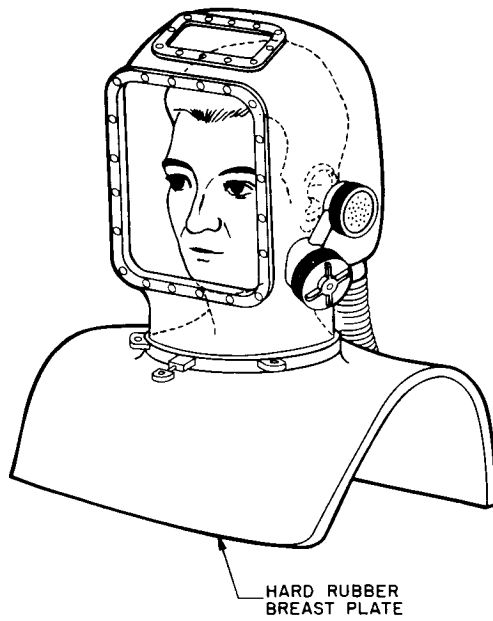


Figure 12.14 *Comfort ring attached.*

VALVES	
RECIRC.	OPEN
GAS INLET	CLOSED
EXHAUST	CRACKED
"K" VALVE	CLOSED

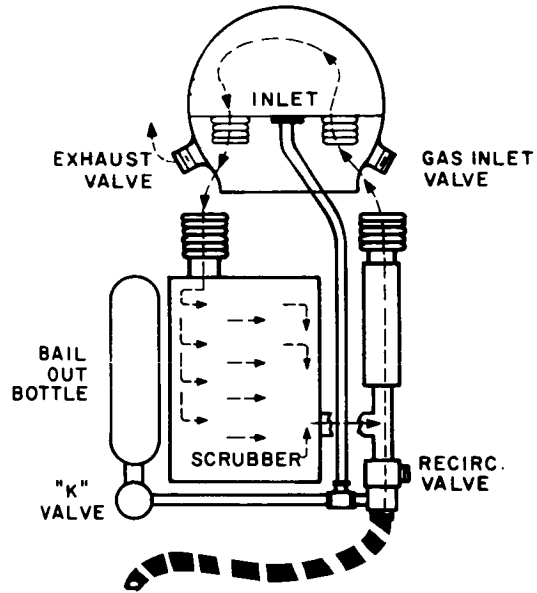


Figure 12.15 Normal recirculator mode.

generation by the aspirator. A bailout bottle is provided to supply emergency breathing gas. A check valve is provided at the air inlet to shut off flow if the pressure drops below ambient. In normal operation, the supply gas enters the venturi and is augmented by a factor of about 10 times by the aspiration action. The gas then enters the helmet, crosses the front of the divers face and across the window, and exits to the recirculator return line. The gas is then drawn into the scrubber by the pressure drop of the venturi and the cycle is continued.

The diver controls his inlet flow by the recirculator control valve. The exhaust valve pressure is then adjusted to vent the excess gas.

Should a malfunction occur in the venturi or in the scrubber, the diver can change to open-cycle operation by opening his air control and exhaust valves, and closing his recirculator valve (fig. 12.16). The gas will then follow the normal air flow for open-cycle operation.

If the air supply is interrupted, the diver can open his bailout bottle valve and continue operation in the normal recirculator mode (fig. 12.17). Should the diver lose his gas supply to both the recirculator and the scrubber, he can change to open-cycle emergency mode and return to the surface or to his habitat (fig. 12.18). In this case, he opens his bailout bottle valve, the gas inlet control, and his exhaust valve.

Recirculator performance is summarized in figure 12.19. Flow rates are compatible with the interface flows in the helmet. The absorbent selected for the design is baralyme. The specification duration is the minimum at -28° F and over 10 hr at normal or higher temperatures. The reserve gas capacity depends on depth: It will allow only two breaths at 1000 ft on open cycle, but should be sufficient to permit the diver to return to his bell or habitat.

The key to recirculator operation is the proper function of the scrubber (fig. 12.20). The scrubber is designed to maximize the dwell time in contact in the absorbent and to minimize temperature and humidity effects. Return gas enters the scrubber inlet and is distributed across the bed by a porous screen. The gas then passes through the bed and traverses the front of the scrubber where it is drawn into the venturi. The low gas velocity in the front and back areas minimize heat transfer from the sea into the absorbent bed and allow the bed to come to, and maintain, an

VALVES	
RECIRC.	CLOSED
GAS INLET	OPEN
EXHAUST	OPEN
"K" VALVE	CLOSED

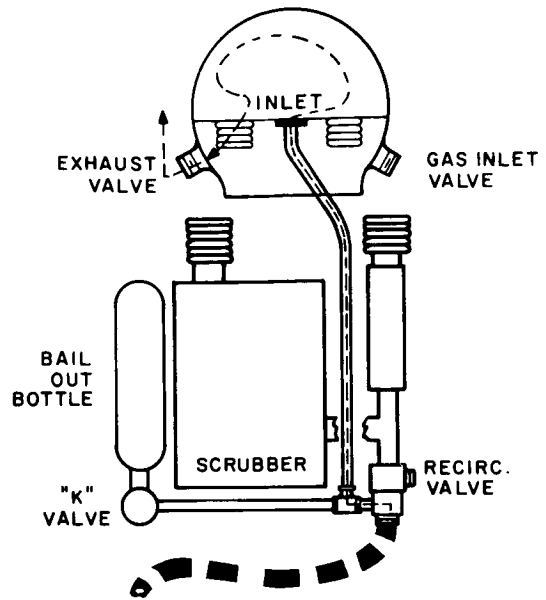


Figure 12.16 *Open cycle (surface).*

VALVES	
RECIRC.	OPEN
GAS INLET	CLOSED
EXHAUST	CRACKED
"K" VALVE	OPEN

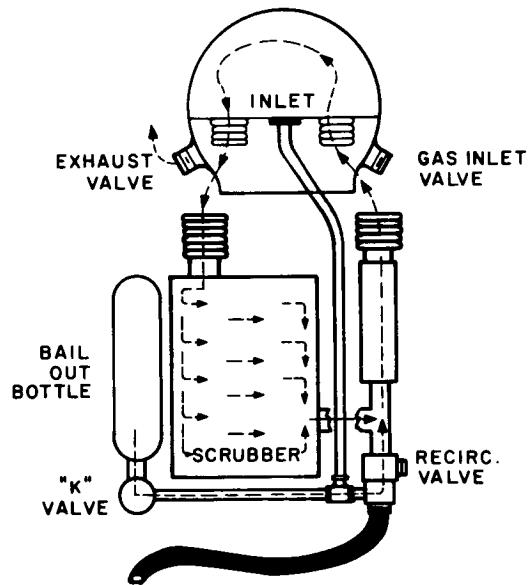


Figure 12.17 *Emergency recirculator.*

VALVES	
RECIRC.	CLOSED
GAS INLET	OPEN
EXHAUST	CRACKED
"K" VALVE	OPEN

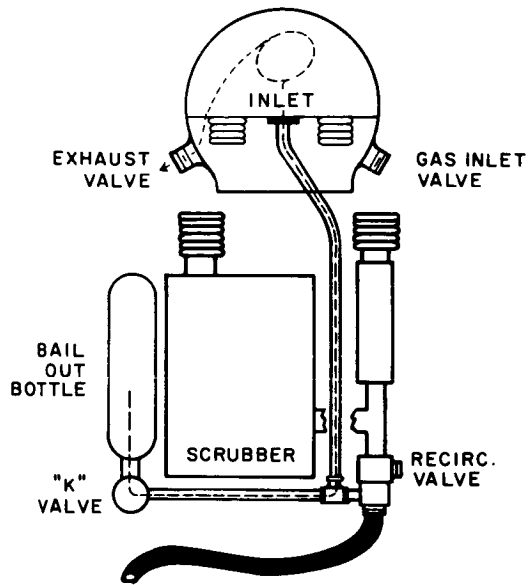


Figure 12.18 Emergency open cycle.

WEIGHT	45 LBS.	RECIRCULATION RATIO	> 10:1
BUOYANCY	NEUTRAL	ABSORBANT	BARALYME
FLOW — INLET	0-14 l/MIN	DURATION	4-6 HOURS
— RECIRCULATION	0-140l/MIN	RESERVE GAS	18 S. CU. FT.

Figure 12.19 Recirculator.

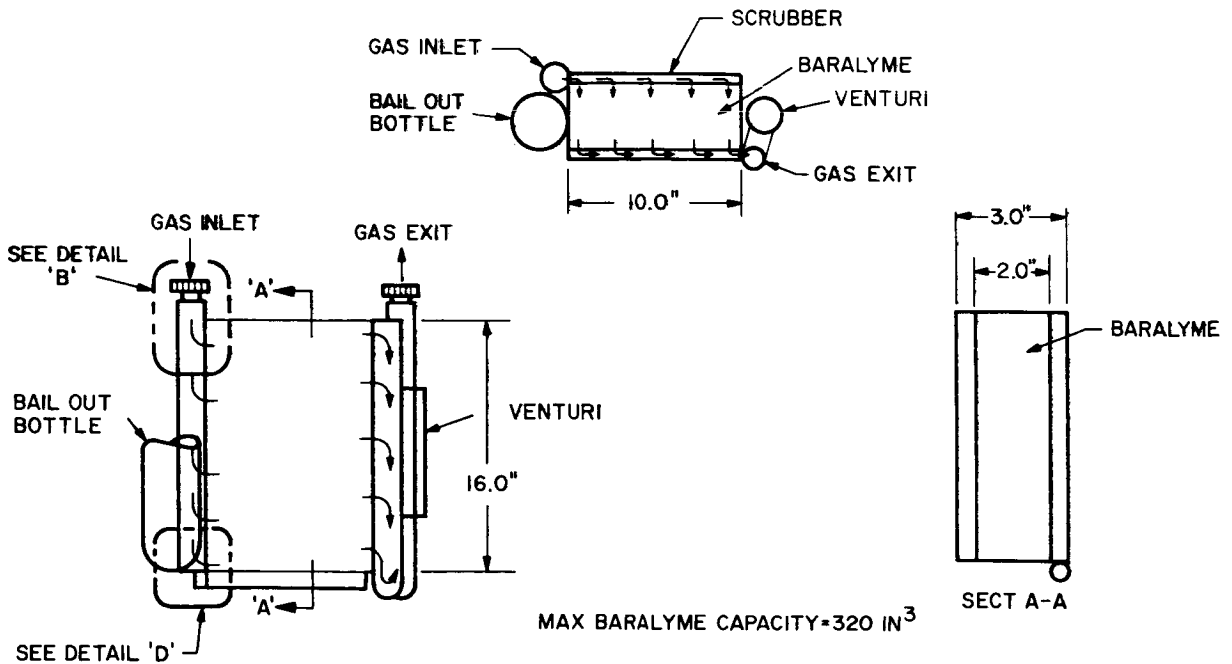


Figure 12.20 Scrubber.

optimum operating temperature. The scrubber inlet has a trap to remove moisture from either the helmet or the breathing gas (fig. 12.21). The trap prevents this moisture from entering the plenum occupied by the porous filter, and prevents clogging of the filter by moisture.

Water is collected in the lower collection tube and kept in place by a simple labyrinth design (fig. 12.22). The accumulated water may be drawn off on the surface by removal of the end cap.

The scrubber is designed to be constructed simply and economically (fig. 12.23). A single multichannel extrusion forms four of the sides providing flanges, holders for the porous plates, and guards to prevent bypass of gases through the bed.

The scrubber shown is a test scrubber to permit sizing of the bed and optimizing operational parameters. Exact dimension and design of this and other parts will be completed when the component test is completed.

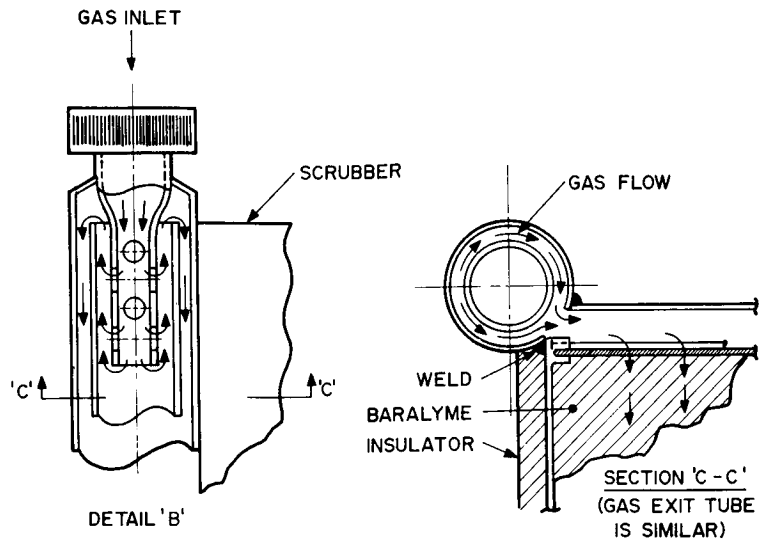


Figure 12.21 Scrubber inlet details.

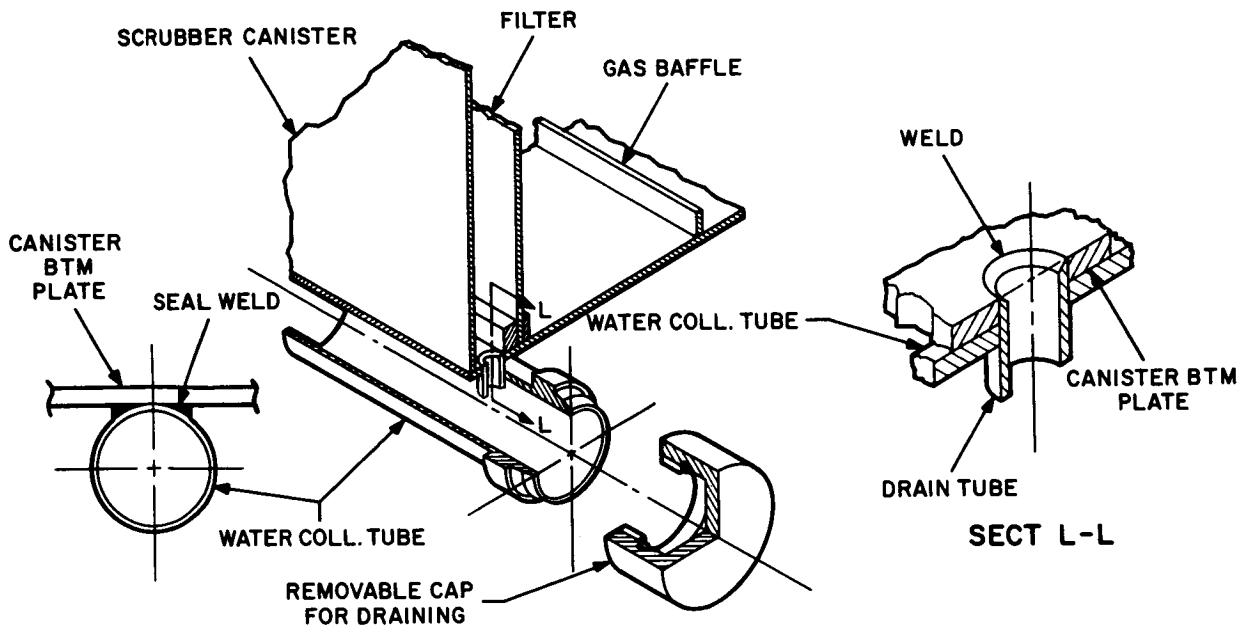


Figure 12.22 Method for water collection.

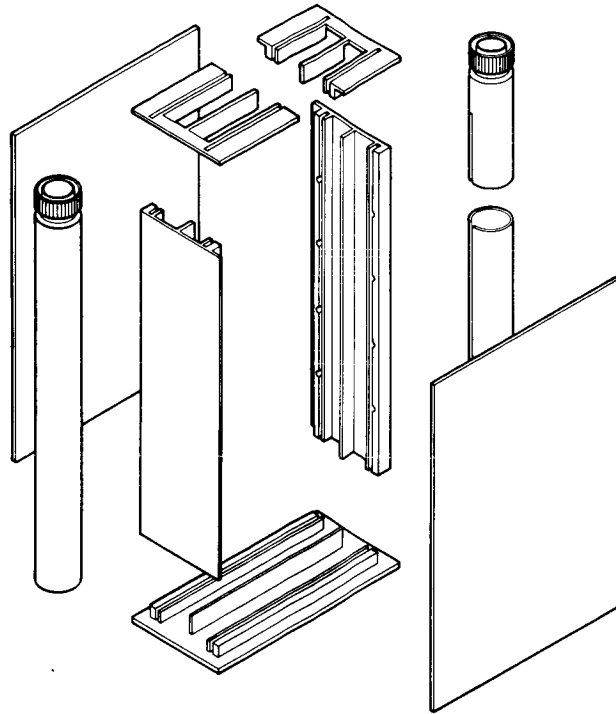


Figure 12.23 *Parts of the scrubber.*

PROGRAM STATUS

The status of the program is shown in figure 12.24. It is expected that the prototype system will be available for swimming in early 1972.

- COMPLETED WORLD-WIDE SURVEY AND REPORT
- STARTING CRITICAL COMPONENT TEST PHASE TO INCLUDE
 - ACOUSTIC TESTING
 - RECIRCULATOR CO₂ SCRUBBING TESTS
 - GAS INLET AND EXHAUST VALVE EVALUATION TESTS
- NEXT PHASE TO BUILD TEST AND DELIVER THREE (3) ENGINEERING PROTOTYPES

Figure 12.24 *Program status.*

REFERENCE

1. Anon: Research Report 12-70. U.S. Navy Supervisor of Diving, Nov. 15, 1970.