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ABSTRACT

The training requirements associated with equipment and systems utilized in underwater salvage operations and with the diving activities which are a part of underwater salvage operations are examined. The major emphasis of the study was on the training conditions suitable for the diver. It was found that divers are best trained in a tank or in open water. The secondary focus of the study was on the operators of the man/machine underwater systems. The best training procedure for these men was found to be the use of an appropriate simulator. The third major category of persons involved in salvage operations is the topside crew. These men are faced with a problem-solving operation and their training may best be conducted by means of a model, an on-line computer, and scenarios depicting salvage situations. (JY)

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STUDY, FEASIBILITY OF UNDERSEA SALVAGE SIMULATION

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ABSTRACT

The study reviews man's involvement in undersea salvage operations as conducted by the Navy and defines the relevant training requirements.

Naval Salvage Systems are mobilized from specialized and general purpose equipments. The configuration of any salvage system is determined by the salvage task. There are no "standing" salvage systems; rather, there exists a multiplicity of components and personnel of various abilities from which an ad hoc salvage system is mobilized.

Divers represent an important capability. However, the work usefulness of divers is attenuated at deeper depths and by the complexity of the required life support systems and other equipment. One-atmosphere submersibles offer an alternative capability.

A considerable variety of surface ships, submersibles, diving systems and underwater tools is available. A descriptive model of the mobilization of these resources at a salvage site is offered. The following recommendations are derived from this descriptive model.

- Divers must be trained in water; hence, training tanks are required. Suitable facilities are described.
- Underwater systems require the carrying out of complex procedures and skilled tasks; appropriate simulators to train the required skills are necessary.
- Salvage, from the point of view of the on-scene commander and his staff, is a problem-solving operation. Training is necessary and may be conducted by means of a model, an on-line computer, and scenarios depicting salvage situations.

FOREWORD

The original purpose of this study was to assist in the determination of the training device requirements for the Large Object Salvage System. Postponements in several stages of the development cycle of this System made it necessary to change the goal and to consider not one specific System, but the overall problems encountered in salvage operations. The aim was to pinpoint training problem areas that now exist and will probably continue to exist in the foreseeable future and to offer recommendations about the nature of training devices to solve these problems.

Vincent J. Sharkey
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Scientific Officer

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

This study examines the training requirements associated with equipments and systems utilized in underwater salvage operations and the diving activities which are associated with underwater salvage. The major emphasis of the study is on diving; that is, on the human swimmer equipped with a life support system and exposed to the underwater condition. The human swimmer is an important and often an essential component of salvage systems. Secondly, we examine the operator (generally a diver) of man/machine underwater systems. In some cases the person of interest is solely a diver; for instance, a diver using a tool underwater. In other cases the person of interest may be one who controls a system under normal (one atmosphere) conditions during one segment of a mission and in a subsequent mission segment acts as a diver. There are also some personnel, such as pilots of dry submersibles, who are not divers. A third major category of persons involved in salvage operations is the topside crew. These persons include the on-scene commander, various staff personnel and crew members, some of whom may have specialized functions. During the study, we have reviewed the operations of these personnel and the training which the Navy provides at the current time.

Originally this study was intended to be in support of the Large Object Salvage System (LOSS), and to be, primarily, a Training Requirements Study for that system. This intention changed as it became apparent that LOSS, as a specific system, was not going to be developed in the immediate time period. Naval salvage capabilities would depend, rather, on the mobilization of available resources. For underwater salvage the Navy would depend on the underwater capabilities being developed at various other Naval and civilian facilities.

At the maximum, the mission objective of LOSS was the salvaging of a fleet-type submarine, intact, from continental shelf depths. It is appropriate to recognize that the proposed LOSS system was based on the belief that the human diver would be a primary instrument in such salvage operations. As stated by Keays et al. in 1966, "Although there are means of improving the salvage system elements (of the LOSS system) other than the diver subsystem, the greatest gains for a given level of investment will be made by pursuing the improvements in diver technique and equipment. . . ."

Most generally, a considerable reliance has been placed on man as a submarine work resource. For instance, the views expressed by Crispen and Olson (1967) are not untypical:

> "The majority of work tasks are best performed when man can bring his intelligence and skillful use of tools directly to bear on the job to be done.
>
> "The properties of the ocean make man's presence at a work site even more desirable than it would be on land, particularly because visibility is usually low. A man can feel his way, accomplishing useful tasks that cannot be performed by mechanical systems. No manipulator has yet equalled in performance the dexterity of the human arm and hand, or the latter's kinesthetic feedback. There is a formidable problem in all forms of remote devices with communication between the sensor, viewer, etc., at the work site, and the observer at some remote station. This is equally true of command or feedback signals associated with manipulators.
>
> "Man's agility far surpasses that of any manned or remotely controlled vehicle. He can work his way through hatches or around obstacles by accommodating his body to the restrictions encountered.
>
> "Because man is the most efficient means of performing underwater work, it is desirable to extend the scope of his activities while exposed to the ocean environment. Where possible, depth and duration of dives should be increased, and better life sustaining equipment tools should be developed."

The error in their view, it can now be asserted, is that the properties of the ocean are deleterious to man's effectiveness in many and varied manners. Man is affected as soon as he enters the water, and increases in depth serve to increase the impact of the underwater situation on the diver and his support system. Deep diving serves to reduce man's work effectiveness to some fraction of what he enjoys on dry land. The state of affairs has become evident only recently, and will be described and substantiated in a later section of this study. However, in conjunction with other developments, principal among them being the development of small and relatively inexpensive submersibles, there has occurred a marked shift in views concerning the development of underwater resources.

The decade of 1960-70, in the diving world, may be characterized as "let's go deeper for longer." This objective was based on the premise that the utility of the diver would improve with improved equipment, and that the diver's skills when operating at shallow depths could be transferred to deeper depths. There was also a desire to examine the limits of adaptability of human physiological systems to hyperbaric conditions and to the breathing of inert gases other than nitrogen. Thus, the means of achieving the goal of "going deeper for longer" was by means of exploiting the adaptability (equalization potential) of the body tissues to high pressures and the avoidance of the various hazards which are incurred by exposure to hyperbarism and to the cycle of pressurization and depressurization.

There are two major limiting considerations to the acceptability of putting men at depth. The first is the limit of human adaptability to hyperbarism. Currently men have been adapted to a pressure equivalent of 1,500 ft. of water successfully, breathing hydrogen and oxygen. The procedures involved are complex and, it is generally agreed, unforgiving of any errors or equipment malfunctions. As will be described in more detail subsequently, there is a steady increase in diving technique complexity, possible danger, and burden on the diver as depth increases. It is not realistic to identify the maximum depth from which a man can be returned alive using exotic techniques with the depth at which useful work can be done. The maximum "death prevention" depth should not be thought of as the depth at which the diver is a general work resource easily deployed to meet a variety of work requirements. Thus, the second limiting factor is the attenuation of work effectiveness with depth. This factor can be joined to the operational consideration that there is a decrease in the number of work items which a human is required to perform at depths much exceeding 600 to 800 feet. The reason for this limitation is partly due to the much greater engineering activity at the near surface levels and also to the fact that the continental shelf seldom exceeds 800 feet in depth.

There is, relatively, only a very small part of the ocean bottom at approximately 1,000 feet, and much of it is sharply inclined. Thus, it is of limited interest for operational purposes, and for salvage purposes in particular. By 1970, therefore, it has become much more evident that man is a limited submarine work resource, and that his effective working range is primarily in the shallow regions. There has been, it will be generally agreed, some retreat from the position that, simply because techniques could be developed to put man at considerable depths, he <u>should</u>, therefore, be put to work at those depths.

A more balanced view has become possible, due in large part to the successful development of a variety of submersibles, ranging from the DSRV (Deep Submergence Rescue Vehicle) to the one-man Star boats among many others. These boats have been shown to have operational capabilities which can be more work-effective than those of divers. In particular, for instance, the recent successful salvage of a tug from 1,000 feet in Vancouver Sound by the use of a small submersible, equipped with a remote manipulator, demonstrated its capability of rigging lines for hoisting, etc. With a relatively small logistic and personnel complement, the tug was successfully salvaged.

At depths in the first 1,000 feet, except for the very shallow depths, the small submersible offers capabilities which can be used alone or in addition to the diver. Currently, the use of SDVs (Swimmer Delivery Vehicles) is an example of combining a transportation vehicle with a diver; in the SDV case the driver is wet. Other submersibles have lockout capabilities which, perhaps, represent a form of optimum man/machine diving system. The man remains in the one atmosphere environment until it can be seen, on the spot, that man's particular abilities are needed directly on the job. The latest version of this combination is the French boat "Argyronete." The craft is divided into wet and dry compartments. The "wet" compartment is kept at ambient pressure and can house four divers; the wet compartment provides the decompression facility. The dry compartment has a crew of six (Hydrospace Report, 1969).

In this connection it should be mentioned that the DSRV has a lockout capability, and that the system may be used for a variety of missions other than its primary rescue mission. In addition, the Deep Diving Systems (DDS) have the ability to let down the Personnel Transfer Capsule (PTC) at an internal pressure of one atmosphere. The divers can look out of the PTC to inspect the scene and decide on the operational sequence. If it is desired to exit, the PTC can be pressurized and then act as the support locus for the divers. In these and other ways, diving as practiced by the Navy diver is becoming one operational mode among many underwater operational modes.

To conclude this introduction, we foreshadow the findings reached in the study, which are derived from the general considerations set out above. The findings are:

- The underwater environment is a unique and humanly adverse environment. To be "at home" in the water, one has to have the actual, physical experience of being in the water. Furthermore, every human activity is modified or imposed upon by being in the water; hence, all skills are modified when carried out in the water as compared to dry land. "Simulation" of the watery state for the diver is neither sensible nor possible. Rather, the aim should be to develop a training facility which will "replicate" as mucy of the real underwater conditions as possible. The underwater conditions do not only consist of the person being immersed in liquid. In reality, the diver may have to contend with many circumstances, including low temperatures, currents, low light levels, turbidity, management of life support systems, equipment malfunctions, tool deployment, safety measures, etc. The effective diver is the diver who can perform the required work in the context of all underwater conditions.

- The Navy is in the process of developing a number of underwater man/machine combinations, ranging from the simple tool for diver use to complex systems such as the DSRV and the DDS Systems. Diving in itself is an adjunct activity in these systems; it is no more nor no less important than the ability to operate, control, maintain, etc., the systems. To have effective underwater capability, the Navy diver must receive adequate and timely training in the man/machine diving systems. A very considerable portion of the operations in such systems as the DSRV are procedural operations and pilotage operations. These are similar in kind to the training skills for an aircrew in Operational Flight Trainers (OFTs) and in various Part Task Trainers (PTTs). Similar training facilities for diver training are required.

- Salvage is the science and skill of understanding a unique situation and mobilizing existing resources to solve the problem. Salvage is a relatively infrequent occurrence, and relatively few persons have experience in salvage operations of any major character. While actual full-scale practice operations are clearly desirable, probably much greater training effectiveness could be gained by salvage exercises conducted in a training facility. The persons to receive the training would be salvage officers, diving officers, ships' architects, and others in decision roles. A variety of salvage situations would be experienced; the team would be faced with typical contingency conditions (e.g., weather); and the overall operation would be carried out on a computer (in fast time) so that the effectiveness of the salvage methods would be simulated and evaluated.

SECTION II

FACTORS INFLUENCING UNDERWATER PERFORMANCE AND WORK EFFECTIVENESS

INTRODUCTION

Unlike most situations, the underwater operator is not necessarily readily available at the work site nor is he in a normal condition. In considering an underwater operative's work capability (and the necessary prior training to develop his capability), it is necessary to consider how he gets to the work site, what condition he is in while there, and the factors which serve to impede or, sometimes, facilitate his work. In reviewing the material which bears on this topic, evidence which relates to the adaptability or learning capability of the diver is noted. The types of work-tasks, behaviors, and interactions with the environment by the human which have demonstrated improvement over time are candidates for training procedures.

GENERAL AND "SYSTEM" FACTORS

There are two basic cases to consider: the "dry" operator of a submersible vehicle and the "wet" diver.

In this section, the "dry" operator will not be considered further. His case is taken up in the following section as an operator of a vehicle, and particular analysis is afforded the DSRV crew members and their tasks.

The diver is a man entering an environment which is unnatural and adverse. It is unnatural in the senses that man cannot stay there without life support systems, that man is not specifically adapted in a biological sense to be in the water, and that man has not lived in the conditions of the water. In these most elemental respects, man must make up for his "unnaturalness" to the water by use of the adaptability of his body to the liquid surroundings, by use of special equipment and procedures, and by his ability to modify his behavior intelligently and responsively. The water environment is adverse in that it does not naturally support life, and it contains various special features which are a direct threat to man's physiological integrity and/or his ability to maintain responsive and self-preservative behaviors.

The factors which create impositions on the diver include:

- The breathing system and its limitations
- The diving suit or dress and all articles carried on the diver's person
- The modification of the diver's sensing ability (vision, audition, touch)
- The modification of the diver's motor and manipulative abilities
- The modification of the diver's mental abilities, including gas narcosis effects and more generalized stress effects
- The limitations imposed by the decompression schedules and/or saturation conditions of the dive
- Dangers and hazards in the environment
- The handling and control of underwater tools and equipments

It is fair to say that the diver is a "burdened" man. He carries not only a physical burden on his body and the burden of operating in a difficult environment, he also carries the burden of the risk involved. While specific injury and mortality statistics are not available, it is common knowledge among divers, both Navy and commercial, that risk is high. The high wage scales of commercial divers attest to this fact.

The sum of these factors is not easy to determine. Mosby(1967) gave it as his opinion based on work performed in the Gulf of Mexico on submerged oil rigs, that the underwater operative is perhaps 15% as effective as he would be on dry land doing the same kind of work. One must add to this that divers normally are required to undertake only rather simple work. Weltman (1970) has written: "The deep sea diver generally performs quite commonplace work. Jobs such as pipeline inspection, using hand tools to put together or take apart various structures, welding, etc., are no more than expected of most mechanics or technicians. It is the underwater environment which transforms the diver's task to a highly skilled operation."

The experience of men involved in Sea Lab II (Pauli and Clapper, 1967; Bowen et al., 1966) would indicate that while planned jobs can be accomplished eventually, the work effort expended is often much greater than had been expected. Incompletion of task was a common occurrence. Struggles with equipment in the murky, cold environment ate up time and energy. One diver remarked: "It's unbelievable how difficult a minor task is. For example, some of the equipment we were sent to work with--to unwrap it took 20 minutes--to find it might take an hour." However, it was notable that the divers felt that they improved in their performance as they gained in experience of the particular conditions and that, as time went by, the time spent in the water became longer and that more work was accomplished overall.

SENSORY FUNCTIONS

Three types of sensory functions are important to the diver's work performance: vision, audition, and tactile sensitivity.

VISION. Optical properties of water affect the diver's visibility. The following data regarding optical properties of water are taken from Duntley (1967) and Lankes (1970).

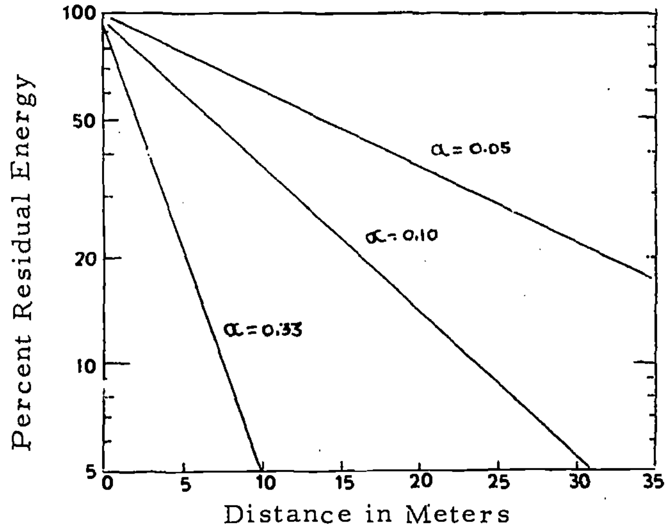

Figure 1. Transmission of non-scattered light through water.

Figure 1 represents typical transmission attenuations of light energy through water. Three types of water are represented. The attenuation coefficient is due to the light absorption of the body of water; an α of 0.05 represents exceptionally clear water; an α of 0.10 is representative of common tap water; an α of 0.33 is representative of bay waters and estuaries.

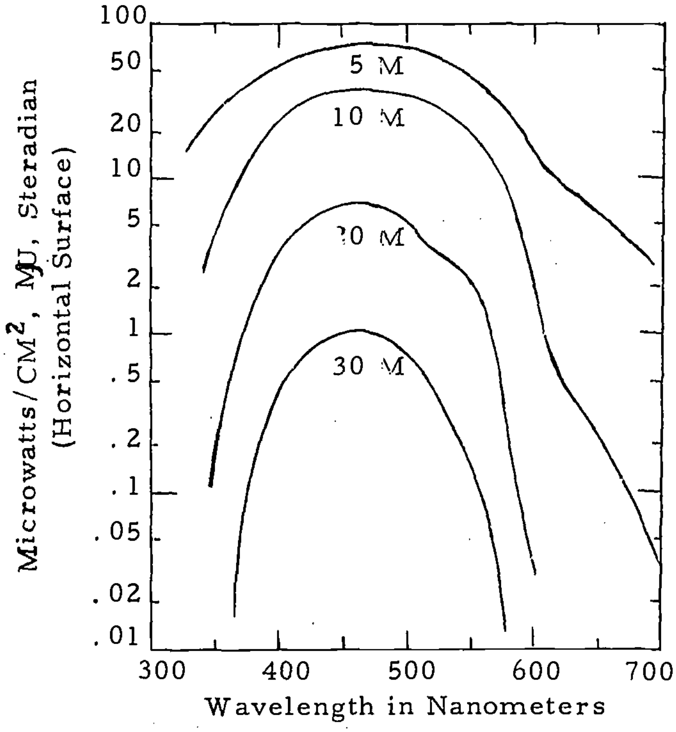

Figure 2. Residual power distribution vs. depth.

Figure 2 presents data for residual power reaching a horizontal surface at increasing depths, starting with sunlight at the surface. The "narrow-band" effect in the blue-green region increasing with depth is readily apparent; the rapid decrease in red components should be noted; the result in practice being that red appears dark gray or black at depth.

The distance at which objects can be seen underwater by a swimmer in a daylighted sea depends primarily upon the contrast transmittance of the underwater path of sight. Recognition of objects can virtually never be expected at a range of over 50 meters, and a much more usual range is less than 15 meters. In conditions where particles are suspended in the water, recognition range may be reduced to zero.

Table I describes data concerning suspended particles. The data suggest that in the worst case one could wait for two months for water to clear, if the water was still.

Kinney et al. (1967) have reported on the visibility of colors underwater. In clear waters, such as are found in the Gulf of Mexico, there is an overall trend for all colors to tend toward being seen in the blue/green/yellow band of the spectrum. In very murky waters, such as occur in the Thames River, Connecticut, an opposite effect occurs, namely, a tendency for all colors to shift toward the red end of the spectrum. The most difficult colors to see under natural illumination are gray and black. Others that have poor visibility are those whose major spectral components are absorbed by the water, namely, orange and red in clear water, and blue and green in murky water.

Under optimum conditions, acuity under water is slightly better than it is in air. Optimum conditions entail extremely clear water (equivalent to distilled water), a clean face mask, and a short viewing distance. Without a face mask, however, the loss of acuity is severe and averages about 90 percent; emmetropes require a target 20 times as large as they could resolve in air; myopes require a target seven times as large as they could see in air.

The ability to judge distance, specifically to equate distances of objects (Luria, 1968) deteriorates underwater. As the clarity of the water decreases, the depth acuity decreases, in terms of both the size of the distance error and in terms of the consistency of the judgment. The loss in depth perception is attributed to the loss of brightness and contrast of the objects, and to the constriction of view and sparsity of visual information in the periphery.

A number of studies have examined the divers' adaptation to the refractive distortion that the air/face plate/water interface imposes. Objects appear to be about one-third closer or larger, or some combination of being closer and larger than they actually are.

TABLE 1. SETTLING VELOCITY FOR SUSPENDED PARTICLES.

Classification	Diameter Microns	Settling Velocity per Stoke's Law	Time to fall 10 cms.				Settling Velocity M/Day
			Days	Hours	Minutes	Seconds	
Very coarse sand	1000	(89.2 cm/sec)				0.6	
Coarse sand	500	(22.3 cm/sec)				1.2	
Medium sand	250	(5.58 cm/sec)				2.7	
Fine sand	125	(1.39 cm/sec)				8.3	1040
Very fine sand	62.5	3482 μ/sec)				29	301
Silt	31.2	870			1	55	75.2
	15.6	218			7	40	18.8
	7.8	54.4			30	38	4.7
	3.9	13.6		2	2	32	1.2
	1.95	3.4		8	10		0.3
	0.98	0.85	1	8	41		0.074
Clay	0.49	0.21	5	10	42		0.018
	0.25	0.052	21	18	50		0.004
	0.12	0.013	87	3	19		0.001

Highly experienced divers, having several years of diving, are able to compensate almost completely for the distortion immediately upon entering the water. Less experienced divers have considerable difficulty in reaching for objects, the degree of competence being related to the amount of underwater experience (Kinney et al., 1970; Ross et al., 1969).

Refraction at the face plate produces not only an increase in apparent size and/or closeness of objects, but various distortions which include the "pincushion" distortion of rectangular objects, curvature imparted to straight lines, the false angling of planes such that, for instance, the bottom, when viewed from above at a slant angle, will appear to slope upwards away from the viewer (Kinney et al., 1970). Of a variety of other visual effects that can occur, an overall shift in color sensitivity is possible. In the Sea Lab I case, the water was exceptionally clear, and at a depth of 200 feet most of the light was filtered out except the blue-green region (Figure 2). A diver regarding this water volume was exposed to a complete field of diffuse, blue-green light. The conditions were appropriate for almost complete color adaptation to take place so that the sea background changed from being blue-green to a colorless appearance. In this condition normally neutral colors appear yellow-red. It was also noticed that divers increased their sensitivity to red colors so that, after a time, they could see red-colored objects not originally visible.

A modification of vision underwater is produced by the restriction of visual angle in the face plate. Average figures are provided by Weltman et al., 1965:

TABLE 2. RESTRICTION OF VISUAL ANGLE IN THE FACE PLATE

	Normal Visual Field	Visual field through typical sport diving face plate
Upward	60° - 70°	60°
Either side	100°	50°
Downward	80°	10°

As Weltman et al. point out, simply replacing the face plate with a larger one has some inherent optical problems. A ray of light at an angle of incidence of 68.2° to an air-water interface is totally reflected. Multiplane masks and contact lenses (Faust and Beckman, 1966) offer some advantages, along with a variety of operational difficulties. Lythgoe and Hemings (1967) have shown that the use of polarizing filters in the face plate can improve detectability by increasing contrast ratios; as much as 15% increase can be obtained. Thus, while vision is restricted and modified considerably for the diver, the evidence suggests that experience in the water enables divers to compensate for the alterations.

AUDITION. Studies by Brandt and Hollien (1967, 1969), Neely and Forshaw (1965), Hamilton (1957), and Wainwright (1958) have indicated that the underwater loudness (SPL) thresholds are from 30 to 60 dB higher than those found in air, the difference increasing with test frequency. Brandt and Hollien (1969) found no effect of depth down to 105 feet.

Unpublished studies have indicated that sound localization is practicable underwater, both for the free swimmer and for the diver-pilot of a SDV (Swimmer Delivery Vehicle).

Tests conducted at the University of Florida, Communication Sciences Laboratory, indicate the generally inadequate quality of underwater speed communication equipment. Intelligibility scores (max. 52.3%) are below that required for normal comprehension requirements.

TACTILE SENSITIVITY. In murky, turbid, or dark waters, the diver may rely considerably on his sense of touch. Bowen (1967) found that 2-point touch sensitivity of the fingertips deteriorated with an ungloved hand as a function of water temperature and period of exposure. After 2-1/2 minutes exposure in 47°F. water, the 2-point threshold increased nearly three times; after 25 minutes, it increased to nearly five times that of dry land values.

WORK PERFORMANCE, STRENGTH, MOBILITY

In this category, underwater behaviors which are energetic and involve muscular effort as a primary parameter are considered.

The mechanical and dynamic conditions which are imposed on the diver as compared to man in the normal, dry terrestrial environment need to be considered. When a man enters water from air, he encounters a physical medium which is approximately seven times more viscous than air, in which he is neutrally buoyant (approximately), has much reduced traction, is partially unstable, and in which he normally needs to swim in order to get around.

The available evidence on human performance underwater and in simulated reduced traction environments indicates that the following decreases in performance occur:

- Overall, there is a reduction in force producing capabilities and work producing characteristics (Pauli and Clapper, 1967; Streimer et al., 1968).
- There are increased energy investments in accomplishing a work unit (Springer et al., 1963; Streimer et al., 1967; Streimer et al., 1969).
- There is an increase in task accomplishment times (Dzendolet, 1966; Streimer and Springer, 1963; Streimer et al., 1968; Bowen, 1967).

In terms of overall work activities, the studies by Andersen (1968) and Andersen et al. (1969) demonstrate the abilities of the diver to transport himself and a payload over a prescribed course of 780 feet. Speed over the course averaged between 1.2 to 1.3 knots, with the divers dressed in wet suits, wearing fins, and breathing on SCUBA. They carried in a sling 3-, 6-, or 9-pound weights in addition to their usual weights worn on the weight belt to provide neutral buoyancy. An older study (Cooperative Underwater Swimmer Project, 1953) found an average speed of 0.96 knots over half-a-mile course.

In terms of manual work, Bowen (1967) tested grip strength, and found very little loss until the diver became cold. On the average, the grip strength on dry land was 55.4 pounds; after 24 1/2 minutes exposure to 47°F. water, grip strength fell to 47.4 pounds.

Streimer et al. (1968) report torque outputs of the diver as a function of wheel diameter. Using 6, 12 and 21 inch wheels, the study found approximately a 25% decrease in torque output for each wheel size where the torque outputs in air were 48, 90, and 167 ft.-lbs. respectively. These decreases in power output seem characteristic of the diver applying force without the benefit of any harness to make up for his loss of traction.

In terms of individual differences, Weltman and Egstrom (1969) found that an individual's ability to exert force underwater is closely related to his ability to exert force on the surface. A relatively strong man on the surface is also relatively strong underwater.

diver teams were compared. Novices were about 60% slower than the experienced teams in a tank. When the experiment was moved to the ocean, the novices' times increased by another 26%. The experts' times did not change.

Activity analysis revealed why the experienced divers were doing better. The most significant finding was that the advantage of the experienced divers was not in working faster but in spending less time doing non-productive activities, such as checking instructions, communications, idle observations, etc.

DIVER RANKING OF WORK FACTORS

In the diver observation program associated with Sea Lab III, divers of the construction team and of the salvage team were asked to rank 10 diving factors in order of importance to successful task completion.

TABLE 4. MEAN RANK OF IMPORTANCE OF DIVING FACTORS (AFTER WELTMAN, 1970)

Diving Factor	Construction Divers	Ranking	Salvage Divers	Ranking
Inter-diver communication	2.3	(1)	6.5	(8)
Special tools or equipment	4.0	(2)	7.1	(10)
Cold protection	4.2	(3)	4.9	(4)
Freedom of movement	4.3	(4)	3.6	(1)
Current, sea state, depth	4.3	(5)	5.7	(6)
Visibility	5.0	(6)	4.8	(3)
Diver strength/endurance	7.0	(7)	4.5	(2)
Diver buoyancy	7.2	(8)	5.9	(7)
Diver stabilization	8.0	(9)	5.2	(5)
Communication to surface	8.7	(10)	6.8	(9)

Weltman comments: "The team members agreed among themselves regarding the rankings, but the two team rankings differed in several respects. The salvage group seemed rather 'diver centered.' Factors dealing with the individual's ability to perform were judged most important; those involving inter-diver or diver-surface communication, or diving aids, were judged least important."

The judgments overall seemed to be task specific and would probably change as a function of the particular requirements of the task and the diving milieu. It may also be thought that the response of the salvage divers reflects the "can-do" and individualistic attitude which may be observed to characterize many Navy divers, and perhaps particularly those engaged in salvage operations.

SUMMARY

In summary, a diver's sensing, responding and overall behavioral capability tends to be reduced in the underwater environment. However, the reduction is minimized when the diver is experienced in the water and has developed the particular work skills required. He adapts himself to the underwater work environment, partly by learning and adaptation and partly by structuring his attitudes toward the task requirements.

In addition to the quantitative literature just reviewed, there is a large body of practical experience and diving lore concerning diver mobility, manipulative skills, and the use of tools.

Sometimes the water is an ally rather than a foe. It is as easy--often easier--to move vertically as it is to move horizontally. This can be a great advantage when working on a large object, such as the hull of a ship. In general, the neutrally buoyant diver finds it as easy to go in one direction as any other. It is a relatively simple matter to worm one's way through a contorted space, performing a feat which might be impossible on dry land.

In using tools, one looks for ways to stabilize oneself or one specifically provides anchor holds. One applies power in short bursts when using a power tool so that one's body mass can absorb the reaction with little motion involved.

An experienced diver moves more expeditiously and more economically than a novice diver. He consumes less gas and is less tired. A typical skill to develop is the control of a "hookak" gas line. A novice diver is very conscious of the line, yet manages to get it tangled on objects or around himself. An experienced diver, it seems, develops an ongoing concept of where the line is in relation to himself and other objects. It is much less of a hindrance to the experienced diver than it is to the novice.

COLD AND WORK PERFORMANCE

Cold has important debilitating effects on the diver and is a most commonly encountered stress. Cold effects on finger sensitivity have been mentioned previously.

A typical performance finding is that reported by Bowen (1967), using a nut-and-bolt manual dexterity test.

TABLE 3. PERFORMANCE ON NUT-AND-BOLT TEST

Condition:	Dry	72°F.	62°F.	47°F.
Completion Time (seconds)	69.44	78.12	84.09	90.36

A variety of types of motion performances are impaired as a function of the cooling of peripheral tissues and muscles (Bowen, 1966, 1967).

Additionally, there are deteriorations in mental performance. Simple, short tasks do not seem to be affected. However, tasks requiring more prolonged attention, the use of memory, and time sharing between task components seem vulnerable to the stress of underwater cold (Bowen, 1967). However, Vaughn (1968) has reported that divers exposed to 60°F. for four to six hours, and with deep body temperatures falling 2°F., were not adversely affected in terms of the control of a wet submersible. It is possible that this task had been sufficiently practiced so that it had become relatively easy, and thus was not affected by the cold state of the divers.

PERFORMANCE AND OTHER STRESSORS

As Weltman (1970) has reported, "A common occurrence in underwater work is mistakes due to oversights, often of the simplest type-- leaving things undone, forgetting equipment, not noticing critical signs, etc."

Some of the effects may have been due to or contributed to by inert gas narcosis. Specific performance decrements due to narcosis have been shown (Kiessling and Maag, 1962; Baddeley, 1966; Adolfson, 1967). In the ocean, as compared to chambers, the effects may be much greater (Baddeley, 1966).

However, performance decrements are not universally found (Baddeley, 1967). Weltman suggests that it may be necessary for the individual to recognize that he is in a high risk situation before performance is affected.

Weltman and Egstrom (1966) suggest that anxiety is the necessary ingredient to precipitate performance deterioration and, possibly, narcosis; and that the anxiety state is accompanied by "perceptual narrowing" (an inattentiveness to peripheral stimulation) which renders the diver less responsive to the environment.

PERFORMANCE IMPROVEMENT

Weltman et al. (1969) report studies of performance improvement of diver teams on a complex assembly task. Experienced and novice

SECTION III

SALVAGE AND DIVING SYSTEMS

In this section of the report, there are described the various ships, submersibles, diving systems, equipments and tools which are representative of the Navy's present-day underwater capability. Where it has seemed appropriate, we have included an analysis of the task functions involved in operating the units. The description and analysis provide an overall coverage of the resources available for a salvage (or similar) operation; however, there is no attempt to provide exhaustive coverage of every unit or system in the Navy's inventory or which may be used in a salvage operation. One of the truisms of salvage is that no two salvage operations are the same. Over the years all manners of ships and equipment have been pressed into service and, not infrequently, special equipment and procedures have had to be fabricated and developed on the spot.

SURFACE SHIPS

At present, surface ships constitute the backbone of any salvage operation; they supply the basic capabilities to effect the salvaging of an object. At the site of a salvage operation, the On-Scene-Commander may have any or all of the following type vessels under his command.

OCEAN SALVAGE TUG (ATS). The ATS is the newest, largest, and most capable USN salvage vessel afloat. The physical characteristics of this ship are as follows:

Length:	282'8"
Beam:	50 feet
Draft (max.):	14'6"
Displacement:	2,929 tons
Speed (cruise):	13 knots
Range:	10,000 miles

For on-board lift capabilities, the ATS has two main bow rollers that can lift 75 tons each (150 tons total). The forward, auxiliary bow rollers will each lift 30 tons. In addition, a variable ballast system can trim the hull fore and aft for tidal lifts. A 10- and 20-ton lift is provided by cranes fore and aft.

An automatic towing machine can handle line pulls from 30,000 to 200,000 pounds.

Ample provisions exist for the support of both SCUBA (air and HeO_2), and tethered diving operations (air and HeO_2). Two high pressure air compressors serve to supply salvage air, and diver's air, and mixed gas breathing requirements. Provisions are being planned for the installation of a deep diving system (Mark I Deep Diving System). Such a deep diving system will substantially enhance the useful bottom time of working divers over that presently afforded by conventional techniques.

SUBMARINE SALVAGE SHIP (ARS). Of wartime construction, these ships have been designed and fitted out for the mission of submarine salvage. A typical vessel of this type has the following characteristics:

Length:	213.5 feet
Beam:	43 feet
Draft (max.):	16 feet
Displacement (max.):	2,000 tons
Speed (max.):	15 knots
Range:	8,000 miles

Regarding the on-board lifting capability, the ARS has two cranes, one in the 8-10 ton range and the other in the 10-20 ton range. In addition, they are port and starboard bow lift rollers, each rated at 75 tons for a total of 150 tons. Two auxiliary bow lift stations are each rated at 50 tons.

The diving capability aboard the vessel is presently limited to air only, in the forms of surface supplied, tethered diving operations, and SCUBA. The maximum safe diving depth is limited currently, therefore, to the limits of air-breathing diving which is 190 feet for hard hat rig and 130 feet for SCUBA. In support of the diver capability is one double recompression chamber, and two diving stations aft.

Other salvage equipments aboard are automatic towing gear (40,000 lbs. rated), heavy duty fire pumps for dewatering compartments, power generators, compressor, welding apparatus, beach gear (for hauling stranded vessels off the beach), and special-purpose rigging for moving the ship.

SUBMARINE RESCUE SHIP (ASR). The primary mission of this ship is that of the rescue of the crew of a disabled, submerged submarine. For at least two reasons, an ASR would have a role in submarine salvage:

- It has a mixed gas (HeO_2) diving capability down to 300 feet; a diving depth limit which exceeds the 190 feet diving capability of the ARS.
- It is quite likely that following a submarine rescue phase, the ASR would be on station available for a salvage role.

The features of this type of ship are as follows:

Length:	251.5 feet
Beam:	42 feet
Draft (max.):	17 feet
Displacement (max.):	2,300 tons
Speed (max.):	14 knots
Range:	9,600 miles

The ASR has five boom lifts with capacities ranging from 2.5 tons to 12.5 tons. Also on board is the McCann Rescue Chamber (850' depth limit), two recompression chambers, surface supplied HeO_2 equipment, HeO_2 and air SCUBA gear, and extensive deep sea mooring gear.

HEAVY, MEDIUM AND LIGHT LIFTING BARGES (YHLC, YMLC, YLLC). Various craft under these categories are often employed for surface lift roles. The lift capabilities range from a few hundred tons to nearly 2,400 tons. A feature found to increase lift capability of the YMLC is capability for deballasting the hull and changing the draft by several feet. These barges usually include provisions for a diving locker, diving compressors, and pumps for deballasting.

ASR-21 CLASS (NEW). This is a new class of submarine rescue ship that incorporates a catamaran-type hull design. There are two ships of this design already under construction and, at the time of this report, one ASR-21 has been launched and is undergoing sea trials. As the designation denotes, this new class ship has been configured for its primary mission of rescuing trapped submariners. However, since it is quite possible that this type of ASR would be on a near-future submarine salvage scene after completing the personnel rescue operations, it is appropriate to consider the application of this ship and her associated subsystems to a salvage operation.

The ship is 251 feet in length, 85 feet overall beam, draws 19 feet, has a cruise speed of 14 knots, a maximum range of 10,000 miles, and can moor in up to 850 feet of water. In addition to two McCann Rescue Chambers, this ASR is configured to carry two primary subsystems with relevance to both rescue and salvage efforts. These equipments are the Deep Submergence Rescue Vehicle (DSRV) and the Deep Diving System (DDS) Mk II. The DSRV is a deep diving submersible designed to mate with the hatch of a distressed submarine and effect the rescue of the trapped crew. The DDS Mk II is a saturation diving system designed to support mixed gas diving operations down to 850' and contains two deck decompression chambers (DDC), two master control consoles (MCC) for diver life support control, and two personnel transfer capsules (PTC) to transport the divers to and from the DDC.

Deck control stations for handling, servicing, launching and recovering the DSRV's and operating the Deep Diving System are provided. A Deck Operations Control Station has control consoles for monitoring and controlling the major handling systems. Television monitors are provided for observing the submerged launch and recovery operations of the DSRV. A space is also provided for men and consoles controlling the conditioned breathing gas for the DDS Mk II; these life support systems include CO_2 scrubbing and temperature and humidity controls. The Rescue Control Center is the nerve center for controlling the operations of the DSRV. It can also serve as a control center for the OIC Submarine Search and Rescue, employing such systems as underwater communications, radio communications, data processing, data recording and sonar display and plotting (including a 3-D sonar to track the DSRV, or to position the ASR relative to deep ocean transponders). There has also been consideration given to providing a portable Salvage Operations Control Center (SOCC) that could be installed aboard an ASR when the need arises. The SOCC would afford salvage command personnel with computer-assisted salvage data acquisition, monitoring, processing (computation) and display capabilities regarding such parameters as breakout force required, lift applied, buoyancy change rate, moor stability, and life support systems status.

It can be expected that an ATS, ARS, or ASR would be the Salvage Operations Control Center from which the On-Scene Commander would make his disposition.

The functions to be performed and/or supervised by SOCC, which have been described briefly in connection with the capability of the ASR-21 Class, cover the following categories of operations:

- Perform status keeping and monitoring operations regarding:

  Weather/sea conditions
  Oceanography information (currents, turbidity, thermoclines)
  Critical salvage parameters (wreck attitude, cable tension), deployment times for submersibles and divers
  Location and status of surface units

- Develop "salvage calculations" with respect to moor design and stability, breakout force required, design of buoyancy package (e.g., number and disposition of dewatering pontoons), buoyancy change rate, etc.

- Monitor all interunit communications (sound power telephones, radio telephones), make situation reports as required to higher command (radio telephones, radio teletype).

- Decide on operational deployment of surface units, buoyancy package, movement of force if successive lifts required, deployment times and tasks for divers and submersibles.

- Operate handling systems for submersibles, diving systems and underwater units (e.g., TV); typical launch and recovery operations involve the use of cranes, booms, cradles, winches, and lines.

- Monitor and control communications links (underwater telephone, hardwire connections) to divers and submersibles. Disseminate status information appropriately.

- Monitor and control life support equipment (breathing gases, heating) to divers, deck decompression chambers, and personnel transfer capsules. Interpret status displays and make required control adjustments.

- Monitor telemetered diver physiological parameters.

- Prepare any necessary rigging operations (cables, fittings) for equipment to be deployed underwater (pontoons, submersibles, tool systems).

SUBMERSIBLES

Submersible vehicles represent a bewildering array of units. We shall consider here only those units which are likely (it is believed) to be manned by Naval personnel and for which training is being or is likely to be afforded.

DSRV: DEEP SUBMERGENCE RESCUE VEHICLE. The DSRV is a deep submergence vehicle 50 feet in length, 8 feet wide and about 68,500 pounds in weight, designed to operate at a maximum depth of 5,000 feet. It has the ability to perform a 3-hour rescue mission, a maximum submerged speed of 4.5 knots, and carries a crew of three: pilot, co-pilot, and crewman. A prominent design feature is the joining together of three steel spheres to form the crewspaces: the control sphere for the pilot and co-pilot, the midsphere attached to the mating shirt for the No. 3 crewman and rescuees, and the aft sphere for rescuees. Each sphere is capable of maintaining its own pressure environment. The primary mission of the DSRV is to descend to and mate with the hatch of a downed submarine to rescue up to 24 trapped crew members at one time. The vehicle can be transported to the site, launched and operationally supported from either the ASR-21 class rescue ship or a specially modified attack-type nuclear "mother" submarine. Only two DSRV's are currently funded. DSRV-1 was launched on January 24, 1970, and is undergoing sea trials. It is likely that after a submarine rescue phase has terminated, the DSRV would be available to support any salvage efforts.

The three-man crew (pilot, co-pilot, crewman) of the DSRV, operating in a shirtsleeve, 1-atmosphere environment, have many potential salvage capabilities at their command. A wide array of sensor systems, namely, high-intensity lights for optical viewing, television and camera systems, active sonar (obstacle avoidance and high resolution) and passive sonar, qualifies this vehicle as an effective means for surveying a wreck to determine, for instance, the work requirements of the salvage task. In fact, it is likely that the DSRV crew would have obtained information on the conditions of the wreck while making excursions to and from the downed sub during the rescue phase. The DSRV would also be able to communicate directly to her support ship by means of an underwater telephone (UQC). She also has a central processing computer to aid in the functions of sensor data processing and display, vehicular control, and navigation.

The midsphere area above the mating shirt is presently engineered to produce a hyperbaric environment of 5 atmospheres (165')--thus affording a modest diver lockout capability presently, with an increased capability possible down to 600'.

Also controlled from the midsphere is a mechanical manipulator arm that can grasp, cut cables, and direct a water jet. The manipulator arm could afford a capability for clearing debris from a wreck, and performing simple rigging tasks without committing a diver to the water.

In addition, in the mating shirt, a hook and winch assembly is provided to facilitate mating in a current or steep angle (maximum 45° in pitch and/or roll). This hauling capability, coupled with the magnetic anchors used to stabilize the DSRV during rendezvous and mating, could be useful in the clearing of metallic debris and the preparation and rigging of a submarine for salvage lift.

The analysis contained in Appendix A lays out the basic operations and work tasks performed by the crew of the DSRV and by the supporting ASR as these may be specified at the present time. The analysis typifies a modern submersible operation and characterizes the procedural detail and complexity which are becoming common in underwater systems. The training requirements which develop from this analysis are defined in the following section of this report.

TRIESTE II. The Trieste II is the Navy's only operational bathyscaph, and its deepest diving DSV (20,000 feet). A bathyscaph uses aviation gasoline for position buoyancy, an iron shot for negative buoyancy (which can be dropped as the Trieste II descends and the gasoline cools and compresses with increasing depth). The Trieste II has a 5-ton payload and endurance of 5 hours at 2 knots. The 7.2 foot diameter control sphere is the pressure-resistant and watertight space for the two-man crew, the pilot and co-pilot. A third person may be carried. The control sphere protrudes from the main hull or float which contains 47,000 gallons of gasoline. It is the float which mainly contributes to the overall dimensions--75 feet in length, 15 feet in beam, and 14 feet in height. The Trieste II must be towed to and from the operating area and supported on site by a vessel, such as an ARD (BS) or an LSD.

The operational capabilities of Trieste II are provided by a mechanical manipulator arm, TV cameras and external lighting for search and viewing the operation of the manipulator arm, a Mk 15 navigational computer, a CTFM sonar display, and an optical viewing system.

This DSV has already successfully performed as a deep diving platform in search of a lost submarine when it found the main portion of the USS THRESHER hull in 1965, and documented its finding with a series of photographs taken at 8,400 feet.

A simulator for the Trieste II is located at the Submarine Development Group I in San Diego. The simulation is of the control sphere, including operational sensor, navigation, vehicular and manipulator arm control equipments, and all controls and displays. The device provides training dives for Trieste II pilot trainees. In addition to simulating normal operations, such malfunctions as "dribbling" shot, ruptured gasoline tanks, Mk 15 navigational computer failure, overloaded motor, and the loss of 400-cycle current can be imposed. The simulation lacks any rotational or translational motion; this absence is probably of very little significance because pitch and roll angles are small and acceleration rates are low in the real vehicle.

SWIMMER DELIVERY VEHICLE (SDV) AND CONSTRUCTION ASSISTANCE VEHICLE (CAV). The SDV and CAV are examples of "wet" type submersibles that are currently being developed by the Navy. The crew members, in both cases two men, are divers and are immersed along with the vehicle. They use SCUBA gear and are dressed in wet suits. The purpose of the SDV is to transport the divers underwater. Presently the SDV is thought of only as a Naval tactical system. A limited number of SDV's have been made, and sea trials and crew performance tests have been conducted. Vaughan (1968, 1970) has reported on the ability of divers to control, keep depth, and navigate an SDV. His studies indicate that experienced divers can operate an SDV very adequately. While cold is the chief stress experienced, the degree of cold is not sufficient to impair performance noticeably.

The CAV is an experimental wet-type submersible to be operated by two divers using wet suits and SCUBA gear. It is being developed by the Naval Civil Engineering Laboratory. Its purpose is to provide a man/machine equipment transport platform to assist divers in performing construction and repair tasks, and would therefore have likely application for salvage. The CAV is 27' long and 10' in width. It is electro-hydraulically propelled and has a maximum operational depth of 120 feet. The cockpit contains a mechanical/hydraulic control system, without any electrical connections near the diver. The vehicle has a dead weight of 18,000 pounds and will carry an equipment payload of 2,000 pounds and several additional divers if required.

DIVER PROPULSION UNIT (DPU). A Diver Propulsion Unit (DPU) is a small, propeller-driven unit which the diver hangs onto. There are a variety of models, some of which are in standard Naval use.

The advantages of the DPU are low cost and simplicity due to the absence of the need to fabricate spaces for crew members, relative independence from surface support and sea conditions, and the fail-safe features of easy diver "bail-out" in the event of a maneuverability problem. Its relatively small size makes it quite maneuverable in close quarters. A DPU may be adapted to provide a source of additional breathing gas, and pneumatic or electrical power to drive power tools.

DIVING EQUIPMENTS

The apparatus and equipments available to enable the salvage diver to perform useful work in the sea are many. They are varied in their complexity and capability. The diving packages to be described first are those to be found aboard ATS, ARS, and ASR ships. Then the systems under development will be described.

TETHERED DIVING APPARATUSES. There are two basic types of tethered diving rigs currently in use: the Deep Sea Diving Outfit and Lightweight Diving Outfit.

Deep Sea Diving Outfit. This familiar rig is composed of a heavy, solid, watertight helmet and canvas suit, weight belt and weighted shoes. The diver's breathing mixture (compressed air or mixed gas) is supplied to him from the surface through an air hose. The diver's ascent and descent is controlled by a liftline from the surface; hardwire communications also exist between the diver and surface.

The primary advantage of this outfit is the maximum physical protection afforded the diver while doing such heavy salvage work as the washing of a tunnel under an imbedded wreck, rigging of slings and pontoons, clearing of debris from the wreck, operation of heavy tools in effecting repairs to the hull of a wreck, work in heavy currents, mud and bottom ooze, and inside ships.

Lightweight Diving Outfit. This outfit consists of a full face mask, a heavy canvas suit, weight belts, and weighted shoes. Air is supplied only to the face mask, rather than the entire suit as in the deep sea outfit. There is considerably more mobility provided the diver with this apparatus; however, communications via a bone conducting device are not as effective as the speaker/microphone in the helmet of the deep sea rig.

In both of the above-surface-supplied tethered outfits, the diver must constantly be on guard against fouling his air line, and is dependent upon a lifeline for ascent and descent. His mobility is considerably less than that possible with SCUBA. However, the diver's endurance is generally greater than with SCUBA, due to unlimited breathing gas and the exterior and thermal protection supplied by these diving rigs.

SELF-CONTAINED BREATHING APPARATUS (SCUBA). There are three different diving packages in this category: open circuit/demand; semi-closed circuit, and the closed circuit. The swimmer is free from surface attachment, and in control of his submerged movements. At present, however, SCUBA is not approved for use within ships during salvage operations.

Open Circuit-Demand. The Open Circuit-Demand Rig is the simplest and most frequently used SCUBA gear in USN salvage operations. The diver carries cylinders of compressed air on his back, with the amount of air delivered to his breathing mouthpiece controlled by a pressure-reducing and depth-sensitive regulator built into a mouthpiece. The diver draws air as he needs it (demand) and exhales into the water through his mouthpiece (open circuit). Other components of this outfit consist of a face mask (covering nose and eyes), fins for the feet to enhance propulsion, weight belt, and very often a tight-fitting neoprene wet suit for thermal insulation.

Semi-Closed Circuit. This system was developed to conserve the diver gas supply for diving at deeper depths. It is a mixed gas system, either nitrogen/oxygen or helium/oxygen, where the proportion of O_2 selected (60, 40, and 32.5% O_2 is common) is proportional to the depth of the dive. The diver employs a full face mask or mouthpiece to obtain a regulated gas supply. A major proportion of his gas supply is rebreathed after it passes through a baralyme canister to absorb CO_2, with a certain amount of the mixture continuously discharged into the water (thus, semi-closed circuit). In other respects, the equipment used by a diver with this breathing apparatus is the same as with open circuit. The Mk VI has been the standard model of this system, with the Mk VIII and IX being used in the exercises associated with Sealab III.

Closed Circuit. In this system, the diver breathes in and out of a breathing bag, with a CO_2 absorbing canister between the diver and the breathing bag. Pure oxygen is used as the breathing mixture and little, if any, of the gas is exhausted (closed circuit). A pure oxygen mixture poses a severe limitation on the use of this system, as pure oxygen becomes toxic at a depth greater than 1 atmosphere (33 feet) and at lesser depths after a stipulated "safe" period is exceeded. Its use is therefore restricted to experienced and qualified personnel. The advantages of this sytem are its light weight and portability, and the absence of exhaust bubbles. It is suited, therefore, to clandestine operations. It is seldom, if ever, used in salvage work.

Self-contained diving equipments, in summary, present the advantages of diver mobility necessary for light to medium work, and ease of employment. On the negative side, communications to and from topside are not nearly as effective as with the hard wire connected tethered diving systems, and the diver has limited immersion time.

DEEP DIVING SYSTEMS. The diving equipments described above represent the current inventory of means of providing life support under the water. The Mk I and Mk II Deep Diving Systems represent the current Naval development of complex diving systems enabling, if desired, saturation diving and diving depths to 850 feet or more. The two systems are similar, with the Mk I being a lightweight and transportable version and the Mk II being a larger, "heavy-duty" version.

The Mk I DDS will provide the capability to transport two divers at a time to a depth of 850 feet (with a decompression capability to 1000 feet). Up to four men can be supported working in two-man teams alternately diving to the working depth, with a total mission time up to 29 days. The system is scheduled for installation aboard the new class of salvage tug, the ATS. Seventeen other crew members on board are required to support system operations. This system is also air transportable in two C-141's. The Mk I DDS is currently undergoing test and checkout at the Naval Civil Engineering Labs in Port Hueneme, California.

The MK I DDS contains a Main Control Console (MCC), a Life Support System (LSS), a Deck Decompression Complex consisting of two Deck Decompression Chambers (DDC) with an Entrance Lock (EL), a Personnel Transfer Capsule (PTC) and a handling system. The MCC, the heart of the system, contains the controls and displays for regulating and controlling the DDC's, EL, PTC, power, breathing gas, pressurization lighting, communications and TV surveillance. The LSS provides breathing gas for the DDC's and EL, carbon dioxide removal, humidity and temperature control, hot and cold water, and treats waste from the chambers.

Each of the two joined DDC's accessible through the EL (the pressurized entranceway to the DDC's) can support a two-man team of divers in the required barometric environment either for a rest period between dives, or to undergo decompression after terminating a mission. The DDC provides essential living accommodations and life support, and a pressurization capability down to 1000 feet.

The PTC is the pressurized chamber which serves to transport two divers from their surface environment (1 atmosphere or pressurized DDC, as the case may be) to the submerged work environment. Bottles are attached to the outside of the PTC and supply breathing gas to the diver through an umbilical. The umbilical also carries a communication line. Access and egress are accomplished through a double hatch (lock-out). All monitoring, control, and communications functions are self-contained, with electrical power supplied via a strength/power communication (SPC) cable from the surface ship.

The PTC is designed to mate with the DDC complex, one side of which is pressurized to the working depth of the PTC. This enables the divers to transfer to the DDC and to rest between dives, while keeping them at the pressure of their wet working environment. When the divers have completed their work, the DDC is used to decompress divers as required.

Mk II DDS. The Mk II DDS functions very much like the Mk I DDS, except that it is larger and heavier. It is not portable, and is scheduled for permanent installation aboard the ASR-21 class ship.

The major components of this system are two DDC's (one each installed in each hull of the catamaran ASR), two main control consoles (MCC), two PTC's, two deck winches, two SPC's, two submersible winches, and life support systems for the DDC's and PTC's. Each PTC and DDC is capable of supporting four-man diving teams.

The PTC is guided to its work site by means of a detachable submersible winch containing a down haul cable. The anchor is carried to and implanted at the work site. The positively buoyant PTC, attached by a cable to this anchor, would thus float above the anchorage during diving operations. Descent is controlled primarily by the submersible winch and may be operated by the divers in the PTC while ascent is primarily controlled by a deck winch.

The DDC is 23-1/2' long and 7-1/2' in diameter, it is divided into a 5-foot-long outer entrance lock and an 18-1/2'-long inner lock; it has a top-mounted mating/transfer lock and an end-mounted service lock for supplies. The DDC and the PTC can be pressurized to accommodate the hyperbaric working environment experienced at 850-foot working depths. The DDC habitat can continuously support divers for a work period up to 14 days.

The two MCC's are the two-man operating stations for the monitoring and control of gas flow, electrical power supply, and communications for the DDS. Each MCC is located next to the DDC it controls. In more detail, each MCC provides the appropriate controls and displays for mating and unmating of the PTC and DDC, changing of internal pressures, control of lock valves, CCTV presentations, pressure indications, and communications.

The PTC is a 7-foot (ID) diameter sphere that transports up to four divers from the surface ship to working depth. Electrical power is delivered to the PTC from the surface ship via the SPC cable. Gas for breathing (HeO_2) and pressurization is stored in self-contained tanks. Because of planned short confinements for personnel in the PTC, no attempt was made initially to control the temperature or humidity of the PTC.

During testing of the prototype version of this system in conjunction with Sealab III trials it became apparent, in using the PTC to depths of 600', that divers were considerably chilled before entering the water. It is thought that the chilling may have contributed to the fatal accident incurred during the early, and subsequently abortive, stages of Sealab III deployment. The system is presently undergoing major redesign due to a number of equipment and operational problems. In the redesigned system there will be a temperature-controlled environment for the PTC and the means for warming the suits of deployed divers.

Saturation Diver Breathing Systems: Mk VIII and Mk IX. To compensate for the increased volumes of breathing gases used at greater diving depths, means other than self-contained or surface-supplied mixed gas (HeO_2) breathing systems have had to be developed. Such breathing systems are necessary for use in conjunction with Sealab-type habitats and the Mk I and II DDS's. Semi-closed circuit design systems are appropriate for this purpose. The significant feature of the new systems is that the primary gas supply is via an umbilical from storage tanks aboard the habitat or PTC. It is termed the "Hookah" system. In the case of failure of the main umbilical supply, the diver may switch to makeup gas from two 11.5-liter tanks on his backpack, providing enough breathing gas (180 cu. ft.) to more than "get home" as a free swimming diver after disconnecting his umbilical. Exhaled gases pass through a baralyme canister for the removal of

CO_2. The Mk VIII breathing system weighs 150 lbs. in air and is neutral in the water. An oral/nasal mask within a "Clamshell Helmet" (a conventional mask and mouthpiece may be used) contains a microphone that, through hardwire connection through the umbilical back to the PTC/habitat, establishes a communication link to the surface. In addition, the umbilical can carry a hot-water line to supply an open circuit hot-water suit that the diver may wear. By using a valve, the diver may regulate the flow of hot water through the hot-water wet suit to achieve the desired heating effect. The source of the hot water was planned to be from a surface ship for Sealab III. Various other "hot-suits" have been developed depending either on electrical batteries or a radio-isotope cell as power sources to be carried by the diver. In this regard, it can be expected that considerable research and development work will be undertaken before any standardized method of heating the diver is established.

The 30-pound Mk IX semi-closed circuit system is a lightweight prototype that was to have been evaluated during Sealab III. It has a considerably smaller emergency gas reserve (just enough to get home), making it strictly a tethered rig.

With both the Mk VIII and Mk IX breathing apparatus, the diver must be thoroughly acquainted with the hardware, for he must dissassemble, clean, inspect, and reassemble the unit after each use. The heavy umbilical, it should be noted, poses considerable restrictions on his mobility and work effectiveness.

Tool Systems. There is an extensive array of tools which the Navy salvage diver may employ on salvage tasks. Some of these tools are specifically designed "underwater tools," while others are more or less conventional tools utilized in underwater work. A brief survey of the more frequently used tools will be provided. For the purposes of exposition, the various kinds of tools may be considered to fall within the following classes:

- Manual tools
- Self-contained power tools
- Surface supplied power tools
- Sensing devices
- Miscellaneous

Manual Tools. In many instances, conventional hand tools are used for accomplishing light work. Hammers, wrenches, hack saws, bolt cutters, chisels, etc., are in everyday use. Generally, such tools are those in common use. The diver's problem is to learn to use them effectively in the underwater condition.

Self-Contained Power Tools. The majority of these tools employ an explosive charge (usually a modified firearm cartridge of .38 or .45 caliber) to apply the necessary working force. There are three tools of this type currently in use:

- STUD 38 Driver--This "single shot," hand-held device can fire a threaded, solid stud into 0.5" steel plate or concrete for the purposes of installing light patches or padeyes. This lightweight stud driver can be used to a depth of 300 feet and a stud, properly installed, can have a pull-out strength up to 4,000 pounds.
- Model D Driver--This is a heavier duty version of the above stud driver, employing the same explosive operational principle. It can be used in depths up to 1,000 feet, and uses a larger, solid or hollow stud (for attaching air fittings); it also can fire a 5/8" hole punch. The solid stud can penetrate up to 1-1/8" of structural steel plate, yielding an average pull-out strength of 29,000 pounds.
- Power Velocity Padeye--Prefabricated, explosive-powered padeyes are available to facilitate the job of providing attachment points on the wreck for lift forces.

Remotely Supplied Power Tools. In this category would fall all the implements that a diver would use that are powered electrically, hydraulically, pneumatically, mechanically or by means of gaseous fuel from the surface.

- Oxygen Arc Electrode Torch--This is the most widely used underwater torch in naval salvage operations and is supplied in such tasks as cutting through steel plates or cables, burning holes and welding.
- Oxygen-Hydrogen Torch--Though still in tool inventory of diving ships, this torch is used infrequently due to greater effectiveness of the oxygen arc electrode torch.
- U Slot Cable Cutter--This velocity power tool uses electrical power to fire a special ballistic cartridge which, in turn, actuates a cutting punch to sever the properly emplaced cable. It can cut steel cables from 1/16" to 1-1/2" in diameter.
- Knife-Edge Hook--In cases where light rigging, such as radio antennae, needs to be cleared away, a three-foot-long, v-shaped

hook with a knife-edged notch may be used. The hook is attached to a ship's winch. When the diver has placed the cable to be severed in the notch, he signals the ship to haul away until the cable is cut.

- Cable Lift Attachments--To provide lifting force to move objects, assorted hooks and other terminal gear attached by cables to the ship's winches or cranes may be employed and rigged by the salvor diver.

- Chipping Tools--A chipping tool is used to clean off a metal object of marine deposits. It is a hand-held tool usually pneumatically powered.

- Drills and Rotary Tools--There exist a variety of rotary tools similar in appearance to a large hand-held drill. They are electrically, hydraulically, or pneumatically operated. Most operate on an impact principle. Some, such as the Battelle prototype, have both a steady torque and an impact capability. This prototype is a 3/4 horsepower "safe" underwater electrical drill; it operates on AC or DC and is operable down to at least 300 feet. Such tools are used to bore holes or, more generally, to turn bolts or nuts.

- Tunneling Jetting Nozzles--In the cases where bottom sediment needs to be washed away from the wreck's hull, or a tunnel under the hull prepared for fitting a lifting sling, jetting nozzles provide the diver with a means to do so. These nozzles are fitted to fire hoses, through which is pumped sea water by the ship's pumps. The high-pressure water flow emitted from the nozzle thus affords the diver a means for displacing bottom sediment away from the hull. The nozzles are so designed to substantially reduce the back force applied to the diver.

- Tunneling Lance--Where the hull of a submarine is deeply imbedded, and there would be the danger of a tunnel collapsing on the diver using a jetting -nozzle rig, a tunneling lance may be used to feed a lifting sling around the hull. The lance consists of a jetting nozzle attached to a curved section of pipe which is supplied with a high-pressure water stream from the surface; as the lance bores into the bottom near the hull, curved, rigid sections of pipe are added (shaped to the contour of the hull) until the nozzle emerges from the bottom on the opposite side of the hull. A messenger cable for a lift sling is threaded through the connected pipe sections of the lance and the lance withdrawn once this is done.

Sensing Devices. Sensing devices include underwater TV and a system presently under development for sensing the interface between air and water on the other side of a steel plate. A current example of a diver-operated sensing device is the lightweight, 10-pound, hand-held sonar called the DHS-2. This unit closely resembles the AN/PQC-1D recently acquired by the Navy. The DHS-2 is 12 inches high including the pistol grip handle, 12-1/2 inches long and 4-1/2 inches wide. The control panel is located at the rear of the device, and an illuminated compass is mounted on top. It is designed for depths to 650'. The housing has been successfully pressure-tested to a depth of 1,000 feet. The applications seen for this device include military, salvage, and commercial operations, where underwater survey and localization functions are required. The DHS-2 primary information display is a head phone assembly worn by the diver, which provides an audio reproduction of passively received or echo-ranging signals. In either the active or passive mode, the unit has diver selectable range scale of 50, 100 and 200 yards. Nine D-cell batteries will power the device in the active mode for 10 hours, and 20 hours in the passive mode. Operator training is required in signal discrimination and identification much along the lines of that presently administered to shipboard sensor operators.

Miscellaneous.

Cement Gun. Occasionally, when preparing compartments for dewatering, it is not possible to patch openings due to inaccessibility on the contour of the hull. To secure these openings, a surface-supplied "cement gun" is used to inject cement into the properly prepared fittings (as was done in the S-51 salvage mission to seal the hull ventilation valve).

Salvage Hatch Cover. This is an ancillary hatch cover that is applied to a hatch of the sunken vessel with special fittings (valves, pipes) to allow an otherwise watertight compartment to be dewatered. A diver enters the compartment to position the spill pipe as low as possible before the salvage hatch cover is finally emplaced and bolted down.

Hydraulic Jacks. In cases where heavy objects need to be displaced a few inches, a hydraulic jack can be employed. A typical jack can move 60 tons up to 18 inches per stroke.

Pontoon Systems. In addition to the dewatering of the salvage object compartments, and surface winching, salvage pontoons constitute an effective means of developing lifting force for the salvage object. By and large, properly rigged salvage pontoons are more stable in higher sea states than a surface ship applying external lift through her winching systems. Rigid pontoons have been successfully employed in the salvage of the F-4, S-51, S-4 and the USS Squalus.

The rigid pontoon is a steel cylinder with three watertight compartments, and covered by three-inch wooden planking. Each of the end compartments has blow, vent, flood and relief valves. The center compartment has blow and vent valves. The two end compartments provide the main lifting force, and the center compartment is used primarily to provide depth control when rigging the pontoon for a lift. With the two end compartments flooded, the center compartment will support most of the 35-40 ton dead weight of the pontoon, save 3.5 tons negative buoyancy necessary for positioning stability. The various types of pontoons available (types I, II, III, IIIA) provide net lifting forces from 60 to 90 tons each.

Flexible pontoons (large air bags) are also in use and are being developed to provide a more conveniently transportable pontoon.

SECTION IV

TRAINING IMPLICATIONS

INTRODUCTION

The foregoing material has set out data concerning the Naval forces and systems that are available for salvage, with particular attention being paid the human diver.

The implications for training in salvage operations are now considered. The analysis of training requirements is approached by means of describing a model of a salvage system. This model is descriptive rather than analytic due to the fact that formal salvage systems do not exist in the sense of being prefigured systems with defined capabilities. Rather, the Navy mobilizes a salvage force to meet a salvage requirement, so that salvage systems are variable to meet the circumstances of a given case of salvage.

Following the description of the salvage model, the specific training implications for topside personnel, diver and diver/equipment operations, diving systems, and submersibles are considered.

SALVAGE SYSTEM MODEL

GENERAL CONSIDERATIONS. The present state of affairs in Naval salvage is that the Navy maintains a diversified capability for operating under the water. There exist certain equipments specifically designed for salvage (e. g., underwater pontoons), but the great majority of equipments are more general-purpose in nature and provide a generalized capability. This capability is mobilized selectively for any particular salvage event. Depending on the salvage circumstances, equipment may be more or less available and more or less specifically adapted to the salvage task. Probably the major salvage event for which the Navy is best prepared is the case of a stranded vessel. Hence, for this case there exists a substantial body of experience, and an appreciable number of personnel have some on-the-job experience of refloating a stranded vessel. Specialized equipment called "Beach Gear"--by which large traction forces can be applied to a stranded vessel--is standard equipment on ARS's and other vessels. The Navy is also well-prepared for small-scale operations in shallow waters. Harbor Clearance Units (HCUs) are operational units which undertake a great variety of underwater tasks usually but not necessarily associated with the clearing of docks, harbors, and navigable channels.

The Navy is probably least prepared for salvage of large objects from deeper depths. The original LOSS (Large Object Salvage System) program was engendered to remedy this deficiency, a deficiency which the loss of USS Thresher had made plain. Operations at the deeper continental shelf depths (down to approximately 1,000 ft.), and the handling of large objects at these depths, it was recognized, required special capabilities. Some of these capabilities are in the process of being realized, such as the diving capability which may be expected from the Deep Diving Systems and manned submersibles.

It should be noted that LOSS represented something more than an increase in depth and size of object in salvage operations. It was conceived of as a system in the same terms as other systems; that is, it was established as a plural entity with:

- A purpose;
- A mission profile (the maximum mission profile was the salvaging of an intact fleet-type submarine from 850 ft.);
- A specified complement of personnel and materiel;
- A set of specified subsystems;
- A continuity over time such that it would be available in a state of readiness to be utilized as needed.

It was to be a designed system with functions and tasks defined within the purpose of providing the capability desired. Within such a "system" context, the training implications and requirements may be readily developed out of an analysis of the tasks to be performed by the personnel.

However, the actuality is different. A credible salvage system at the present time is one which is a mobilization of resources. It will be ad hoc and composed of the vessels, equipment, and personnel that are available and appropriate for the salvage task. As has been the practice in the past, the "salvage system" will be created on the spot as a response, within the resources available, to the particular problem of salvage which is being tackled.

The training implications for this type of temporarily mobilized system are appreciably different from those for a structured system. In the latter, men carry out more or less prefigured procedures and perform tasks of a relatively specified nature. The effectiveness of a structured system is based in large part upon the assumption that tasks are definable, and men can be previously trained to perform these tasks.

In a mobilized system, on the other hand, the personnel contribute more or less isolated skills, including skills in operating subsystems which are developed elsewhere and which have to be coordinated into an effective working force on the site.

The training implications for a mobilized system are, therefore, of two general sorts. The first is training the "Command and Control" function so that the coordinated entity is created and becomes effective on the spot; the second is training for all the specialized functions and skills, particularly those used in underwater operations, which may be required in any given instance.

These training implications will be placed within the context of a "descriptive model" of salvage operations. This descriptive model sets out the categories of operations and equipments used in salvage work. It is from these categories that a particular salvage capability will be mobilized. The extent of mobilization, that is, the nature of the capability, would be adjusted to the salvage task. The salvage capability required depends on such considerations as the size and character of the object to be salvaged, the salvage depth and location, the urgency with which salvage is required, etc.

COMPONENTS OF "SALVAGE SYSTEM MODEL." Salvage operation control is represented by the Salvage Operations Control Center (SOCC). Salvage operations are controlled from the SOCC under the direction of the On-Scene Commander and his staff.

The Command and Control requirements of a salvage force include all the normal naval procedures as well as those concerned with the salvage operation. The specific problems to be encountered, and the decisions required, are variable with respect to the unique circumstances of each wreck. However, the following are the main phases of operation which would have to be accomplished in the salvage of any underwater wreck.

Phase I--Location of the Wreck. Generally, the salvage force is brought on the scene when the wreck's position has been located and marked. The initial task of the salvage force is to locate the wreck precisely and

and establish means of locating it again if the mission has to be aborted temporarily due to weather or other reasons.

Phase II--Survey of the Wreck. Survey of the wreck is carried out by divers and/or submersibles to ascertain:

- Its attitude and position on the bottom, and its relation to bottom features
- Its structural state
- Its degree of flooding
- Its embedment in the bottom
- The oceanic and geological environment of the wreck

Phase III--Determination of Salvage, and Deployment of Required Salvage Forces. On the basis of the information acquired in Phase II, a salvage plan is prepared and the required ships, materiel, and personnel are brought to a state of operational readiness and positioned on the site.

Phase IV--Preparing and Rigging the Wreck Preparatory To Lift. The wreck must be prepared and rigged in readiness for the lift operation. This phase may require any or all of the following:

- Cutting away of damaged parts or parts that may impede the lift operation.
- Securing parts; making compartments airtight; placing patches; filling parts with concrete or foam.
- Passing cables around the wreck by means of tunnelling devices, as may be required.
- Emplacing padeyes, etc., on the wreck to provide traction points for cables.
- Dewatering and flooding compartments to attain the required overall buoyancy and buoyancy distribution in the wreck.

Phase V--Breakout. Breakout consists of the application of sufficient lift to wrench the wreck from the bottom and bring it to a position somewhere above the bottom in a controlled and stable state.

Phase VI--Lifting. The lifting operation is normally conducted in a sequence of operations. Lift is regulated to control the rate of rise and is distributed to maintain the attitude of the wreck. The immediate objective of the lifting operation is to bring the object to the surface where it may be further worked on to provide the desired buoyancy and to assure its continued physical integrity.

Phase VII--Towing. The wreck will normally be towed to a harbor. The wreck is rigged for towing so that it may encounter the sea and weather states to be expected, and adequate precautions are taken against the foundering of the wreck.

Phase VIII--Docking. In many cases the wreck will be towed to shoal waters where further buoyancy may be afforded to the wreck. Then the wreck may be brought to dry dock (as was the case for the USS Squalus) and repaired or otherwise disposed of.

SALVAGE OPERATION CONTROL. Salvage operation control consists of multiple functions. Most significant to the salvage operations proper are:

Communications. Higher command: reporting on progress of operations; referral on matters of policy exceeding local circumstances; information concerning supplies, materiel, personnel, etc. Local forces: maintenance of updated information concerning the local force; communication of orders and directives to the local forces.

Status Keeping and Monitoring. Maintenance of updated information in relevant and useful forms concerning:

- Weather and sea conditions--current and forecast
- Oceanographic information concerning water state (temperature, turbidity, current, biological aspects) and bottom state (general geological features, specific local features, action when disturbed)

- Surface units--maintenance of information on capability status of all units and any special factors which constrain or facilitate operations.

- Critical salvage factors--critical salvage factors will vary according to the site and the nature of the work. Examples are:

  - Wreck attitude and status
  - Deployment times and work tasks assigned to divers and/or submersibles
  - Status of moors, cable tensions, possible fouling of lines, etc.
  - Pontoon status and security.

INFORMATION PROCESSING AND CALCULATION. Salvage, especially salvage of large objects from under the water, requires the application of many aspects of marine engineering. Adequate engineering solutions are dependent on the acquisition of accurate information and the appropriate calculations being made. Typical problem areas are:

Moor Design. The design of the moor for the surface vessels is a complex matter which has to take into account:

- The number and size of the vessels to be moored
- Expected winds and sea states
- The weather conditions which will be sustained before abort
- The water depth and water currents
- The nature of the bottom
- The mooring equipment available

Breakout Force. In lifting an object from the sea bottom, there is usually extra lift required to overcome the suction effect; the breakout force applied must be sufficient to lift the object and overcome the suction effect. Breakout force is a time dependent function. The required force is inversely proportional to the duration of application provided certain minima are met.

Buoyancy Package. In lifting an object, the two most critical factors are the amount of lift and the control of the lifting force. Clearly, sufficient lift must be applied to raise the object. The lifting force may be made up of any or all of the following:

Cables from cranes and derricks on surface ships

Cables attached to pontoons

- Dewatering of object (replacement of trapped water by air)
- Use of "foam" (replacement of trapped water by foam)
- Tidal lift (cables from surface ship tightened at low tide; tide lifts surface ship and wreck)

In many instances, the problem is not so much the provision of sufficient lifting force, but the control of the lifting force and the maintenance of stability in the wreck/lifting force combination. A correct prediction has to be made of the behavior of the ensemble at the time sufficient force is applied to achieve breakout and subsequently. In an actual case, accurate prediction may be difficult to achieve. There is an overall tendency for lifting forces to generate instability rather than to be self-correcting.

As soon as the wreck breaks out of the bottom suction, there exists an extra buoyancy force which must be controlled to avoid an uncontrolled rush of the hulk to the surface. This dramatic and most undesirable eventuality may be controlled by having a sufficient proportion of the initial lifting force applied by pontoons placed at shallow depth. When breakout is achieved, the upper or "control" pontoons rise to the surface and then lose their lift effect. Hence the lift ceases, and control is maintained.

The "air bubble" or "free surface" effect describes the fact that air will seek the higher level so that, once a tilt is established, there is a progressive tendency for the higher part to become lighter and the lower part heavier. This results in the wreck tending toward a vertical attitude.

Air expands as depth is lessened. In an actual circumstance, the expansion of air trapped in a wreck may cause either increased buoyancy or decreased buoyancy, depending on whether the expansion displaces water or causes the spillage of air.

Various other matters may affect the buoyant condition, the attitude of the wreck, and the control of the lift. For example, the wreck may be structurally weakened and, as lifting force is applied, the wreck may bend or fracture, bulkheads may give way, hatches may pop, etc. There are, in fact, a large variety of events which may occur to affect the lifting of the wreck.

It is the responsibility of the SOCC to carry out an adequate survey of the wreck, its condition, and the surround; to design a lifting plan; to calculate the most probable sequence of events with proper allowance of safety factors; to gain data at each stage of the lift; and in general to implement the plan with judgment based on adequate calculation and proper information.

That this is no easy task may be judged by the salvage of the USS Squalus. In the course of salvaging this submarine from 200 feet, the boat twice rose out of control to the surface, only to founder and sink to the bottom again.

TOPSIDE OPERATIONS ON-SITE.

Communications. Of particular importance are the communications between topside and divers and/or submersibles. In most instances, underwater communication tends toward being inadequate. Hardline communication between a hard-hat diver at shallow depth and topside represents the most favorable condition. Comprehensibility of speech communication is probably never over 70%, and is generally much less. Therefore, diver communications must rely on simple speech and/or rope signals. Inter-diver communication can be conducted by signals or by writing. A definite policy of communication with operating rules has to be established in light of the equipment available and the conditions of diving.

Diver Support Systems. Topside operations are responsible for providing the breathing gases for divers and for any other life support systems. In the case of the Deep Diving Systems, this represents a relatively elaborate complex, comprising the PTC (Personnel Transport Capsule), the means of lowering and raising it, deck decompression chambers, heat, light, communications, food, sanitary arrangements, etc. Equipments, such as the hot-water diver heating system, for instance, require considerable experience and expertise on the part of both topside and diver personnel.

Other Equipment. A large variety of equipments may be used in a salvage operation. Most of them are associated with diving operations. Topside personnel (including most usually the divers themselves) are required to rig, set up, and check out the items. Each item will have its own procedures. Some of these procedures are very well established after many years of use (e. g., preparing the hard-hat diver), while others may be novel and require on-the-spot development of appropriate procedures.

Among the systems and equipments which topside personnel may have to rig, set up, check out, maintain and operate as required are:

Hard-hat diving equipment and gas supply
SCUBA diving equipment
Deep Diving Systems
Decompression facilities
Tool systems (e.g., pneumatic tools supplied by air from deck compressors)
Lighting systems
Diver Propulsion Units (DPUs)
Deep Submergence Vehicles (DSVs)
Explosive devices (e.g., stud guns)
Underwater TV
Air, foam, cement, hydraulic, etc., lines
Underwater refuge stations
Tunnelling devices
Communication systems
Winching and hauling systems
Pontoons
Patches

UNDERWATER OPERATIONS. Diving operations are concerned with the provision and preparation of diving equipment and diving systems and the tasks involved in preparing them for the diving operations proper.

The diver in the water may have to use any of a large variety of tools and equipments as well as to maintain surveillance over his own safety and the integrity of his life support system. He must remain alert to the condition of his environment and pay particular attention to man-made objects, such as lines which, notoriously, may endanger him by entanglement.

The divers' tasks and the equipment he may utilize have been noted previously. In summary, the divers' tasks cover:

- Maintenance of his health and safety
- Survey and reconnaissance
- Sensor and communication procedures
- Use of tools
- Attachment and rigging of equipment

SPECIFIC TRAINING IMPLICATIONS

GENERAL-PURPOSE AND SPECIFIC SALVAGE SKILLS. The preceding has provided a "descriptive salvage model" which rests on the assumption that there will not be a prefigured salvage system to be brought to a wreck site but, rather, that the necessary equipments and personnel will be mobilized on a temporary basis as needed. The training implications of the state of affairs can now be stated.

Much of the Naval salvage capability rests on general-purpose equipment and general-purpose skills. Salvage, like any other marine activity, rests on adequate seamanship in the broad sense as well as the proper conduct of duties and special skills by all personnel.

In addition, however, there are special problems and skill requirements associated with salvage. It is these operations which are the logical candidates for training procedures and training facilities.

From the foregoing analyses of the operations, it is concluded that there are four areas of training needs, representing special skills required in salvage:

- Topside operations for salvage master and staff
- Diver and diver/equipment operations
- Diving systems
- Submersibles

TRAINING IMPLICATIONS FOR TOPSIDE PERSONNEL. In the category of "topside" personnel are included all persons on the salvage scene who have a decision role to play. These persons are, typically:

- The on-scene Commander
- The salvage officers, including, on large salvage operations, a ship's architect
- The diving officers

These persons and others are responsible for establishing the strategy and tactics of a salvage operation and to amend the operational plan in light of contingencies and developments.

At present there is virtually no training provided for these roles. Reliance is placed on knowledge and experience.

A training facility is required which would have the capability of simulating, in model form, a broad range of salvage situations. The situations would cover the requirements for:

- The surface force
- Salvage equipment
- The problems of mooring the surface force
- Diver capability
- Simulation of weather and sea states, bottom conditions, etc.

A scenario would be established, setting out the salvage problem. The team would be required to conduct the complete salvage operation.

The operation would be "carried" on a computer, and the most probable consequences of any action would be simulated. Various contingency conditions would be simulated.

The above describes the general nature of the training facility. The details of the training facility may be envisaged.

A model visible to the participants would represent the ocean, the wreck, and the surface force of ships. The salvage crew would gather in front of the model under the direction of the instructor. The instructor would provide the initial scenario which would contain the information which would be known in a real case. Such information would be the type of ship (or other object) which lies on the bottom and is to be salvaged; details as to the known or probable cause of sinking; the estimated damage to the boat; depth at which the wreck is assumed to be; local bottom topography, etc.

The initial task of the salvage crew is to determine what data is necessary to be obtained and how to obtain it. At this point, the simulation could enter a time line, and the exercise would be progressively recorded on a computer print-out.

The salvage crew calls for some surface force and some underwater capability from the inventory that is available and which is appropriate for wreck surveillance and initial salvage operations.

The work-force being assembled is represented in the model.

Typical wreck surveillance operations are undertaken. Divers are sent down and instructed to report on specific aspects of the wreck.

The scenario (previously stored in the computer) responds with the appropriate data as the salvage crew takes the necessary steps and requires specific information.

The appropriate lift force is called for, and the wreck is rigged and prepared for lifting. These operations are simulated on the computer so that changes in the buoyancy or attitude of the wreck are recorded and simulated.

The lift force is deployed and applied to the wreck. The model responds, appropriately guided by the calculations carried out on the computer. The breakout and initial rise occur. The attitude of the boat and its stability in the water are calculated on the computer and represented in the model as they would actually occur. All being well, the lift would continue through successive stages until the wreck is floated and in towable condition.

An important aspect of the simulation would be the introduction of contingencies and uncertainties, such that the initial plans for salvage would work out to be unsatisfactory and would have to be modified.

A series of scenarios should be developed, ranging from relatively simple salvage operations to complex ones requiring coping with numerous difficulties and unexpected eventualities.

It is thought that particular interest might be given to this training by having scenarios which would be reenactments of actual salvage operations. The actual historical salvage could be shown so that, for instance, the initial abortive attempt to raise the USS Squalus could be studied. Then, given the same circumstances, the adequate salvage solution could be worked out and tried out on the model.

TRAINING IMPLICATIONS FOR DIVER AND DIVER/EQUIPMENT OPERATIONS. Divers presently available for salvage purposes are graduates of the Naval School of Diving and Salvage, and have variable amounts of subsequent training and experience.

The diver will be competent in the use of the life-support systems, diving clothing and personal equipment, and some of the standard tools. The average, current Navy diver, as a minimum, has experience with hand tools, acetylene torch, pneumatic-powered hand-held tools and, possibly, an explosive tool. The amount and degree of experience with these tools and others is most variable and depends upon the particular experience of the individual.

In the second section of this report, it was found that many essential diver skills are developed and refined only by experience in the water. The use of underwater tools, the use of new life-support systems, etc., cannot be learned fully, it is believed, except by their use in the water. The water condition cannot be simulated; it can be replicated. That is, training, in order to be complete, requires the diver to exercise the required behaviors in water, preferably in a tank or in a protected body of water.

The recommended training facility is a water chamber facility combined with diving conducted in open water. The water chamber training facility would provide for the training of divers under the direction and surveillance of instructors and with the safety factors associated with tank diving. The functional aspects of the water tank should include:

- Shallow-water depth to provide for safe recovery of any divers experiencing equipment malfunction or other difficulties.
- Enclosure of tank and ancillary facilities to provide a comfortable, all-weather facility for the dressing of divers and the rigging and installation of underwater work tasks.
- Provision for the control of lighting conditions from relatively bright levels experienced in clear, shallow waters, to relatively dim or dark conditions in deep or turbid waters.
- The capability for introducing and purging varying degrees of turbidity.
- The capability for controlling water temperature within the ranges experienced under real-world operating conditions.
- The capability of introducing water currents to accustom the diver to resisting the effects of moving water.
- Provisions for complete monitoring of diver performance.

- Reliable communications between instructors and trainee divers.
- Provision of salvage tools and equipments for practice by the divers.
- Large enough space to accommodate sections of a ship's hull plating so that salvage tools and techniques may be practiced.

Typical training operations would be:

- Clearing of debris, using cable cutters, cable hoists, hydraulic jacks, cutting torches.
- Patching holes and repair of other damage, use of stud-guns, power drills, welding torches, patches, etc.
- Installation of explosive and conventional padeyes for cable attachment.
- Use of explosives for cutting, hole punching, trenching, etc.
- Conduct of safety and emergency procedures.

Other tasks could best be experienced in the open water and, preferably, operating on a hulk. Such tasks would be:

- Surveillance of a wreck to report degree of embedment, structural damage, attitude, oceanographic environment, etc.
- Tunnelling under a wreck, using jetting nozzles or a tunnelling lance to enable the rigging of chain slings and lifting cables.
- Rigging and emplacement of salvage pontoons and lifting lines.
- Attachment of airlines to salvage air fittings to accomplish dewatering of compartments.

It is judged that in order to provide worthwhile training of tasks such as those listed above, a tank facility would have to be unacceptably large. Therefore, on the assumption that such tasks may be excluded from the training in the tank facility, the specifications of the diver training tank may be set out provisionally as follows:

- Bottom area approximately 200 sq. ft., minimum
- Depth of water 25 to 30 ft.
- Observation portholes at eye height for convenient viewing by instructors
- Brightness controllable from 10 ft. lamberts to 0.01 ft. lamberts
- Turbidity controllable to provide visibility from clear visibility to a visibility range of 3 to 6 inches
- Temperature controllable to provide water temperatures from about 45° to 70°F.
- Hardwire communication facilities

TRAINING IMPLICATIONS FOR DIVING SYSTEMS. Diving systems include the MK I and Mk II Deep Diving Systems (DDS), any form of bottom habitat, such as Sea Lab, Tektite, etc., and submersible lock-out systems.

Operation of any of these diving systems is a complex and skilled operation. Experience at DSSP Project Office, San Diego, during 1969, demonstrated the absolute necessity of establishing standard operating procedures for the Mk II DDS and training the diving personnel in these procedures. The successful operation of this system is dependent on the accurate and complete conduct of a set of procedures which must be learned and practiced in detail.

Suitable training for the DDS could have been provided in a mock-up facility, which was not available. The actual DDS had to be used in the training facility. The mock-up facility or simulator required would be a procedures trainer, and would simulate the sequence of events as the Personnel Transfer Capsule (PTC) is activated, lowered into the water, descends to depth, etc. Simulation of changes in gas pressure and gas make-up would occur to copy the successive stages of compression and decompression. Mating and de-mating of the PTC to the decompression chambers would be simulated in terms of achieving pressure equality and opening and closing the communications hatchways.

Such a trainer would be a procedures trainer and would practice the trainees in the precise operational routines which are mandatory for the safe operation of any Deep Diving System.

The trainer would consist of a replica of the real system. As the real system has not yet been standardized, it is not possible to describe the precise hardware involved. However, the essence of effective training in such a procedures trainer is to provide an identical copy of the original and to provide for the strict conduct of the procedures which are required in actuality.

TRAINING IMPLICATIONS FOR SUBMERSIBLES. Operation of a submersible is also a complex undertaking. Specifically, the operation of the DSRV, through its mission profile of submarine rescue, requires high orders of skill and competence with every aspect of the system. The task analysis of DSRV operation provided in this report details the particulars of the operation.

Initial crews of the DSRV-1 were trained and made familiar with the vehicle's operations on a "trainer" containing many of the actual components of the operational vehicle; the same components were later installed in the DSRV-1. The pilots were taught the dynamics of the boat by means of a computerized simulation.

The training implications for submersible operation are very similar to those for aircraft operation and for which OFT's (Operational Flight Trainers) are the appropriate training instruments. The present Trieste II Operational Trainer is an example of an early version of such a training instrument. It is not questioned that the trainer is a positive help toward providing a student with operational competence. Also, such trainers are effective in maintaining control skills and procedural skills when operational time in the actual vehicle is circumscribed, as will probably be the case in submersibles of the DSRV class. Hence, the maintenance of operational readiness of the DSRV system (vehicle, supporting equipment, and crew) is likely to be dependent on the existence of an adequate operational trainer.

The characteristics of an operational trainer for a submersible should incorporate the following:

- Simulation of the motive power system
- Simulation of the control operations which determine the attitude of the vehicle in the water and its passage through the water
- Simulation of all normal and emergency systems, including communication systems, secondary control systems, emergency flotation systems, lighting systems, sensor systems (including optical, acoustical, sonar systems), etc.

- Simulation of mission phases which are described in detail in Appendix A and which are, in summary:

  Pre-launch preparation
  Departure and descent
  Surveillance and classification of observed objects and their localization
  Acquisition of target object
  Mating to target object
  Operations with target object (e.g., in DSRV case, rescue evacuation)
  Ascent
  Terminal activities
  Securing boat

- Environmental simulation should be representative of the oceanic environment in terms of color (progressively more yellow-green as depth increases), brightness (decreasing as a function of depth), and bottom objects as seen by the optic or sonar sensor.

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APPENDIX A

DSRV OPERATING ANALYSIS

The DSRV operating analysis which follows has been carried out at a level of detail to make plain the nature of the human tasks involved in the situation where the DSRV is supported by the surface ship (ASR). The operation of the vehicle presents a multiplicity of tasks requiring knowledge, intelligence, precision, and procedural thoroughness. As stated in the main text, should the DSRV be put on an operational basis and be required to be in a state of readiness as a system, training will have to be instituted on a systematic basis.

The system is an example of a modern submersible, and the major categories of tasks involved are representative of the tasks to be performed by crew members of such systems. The major categories of task are:

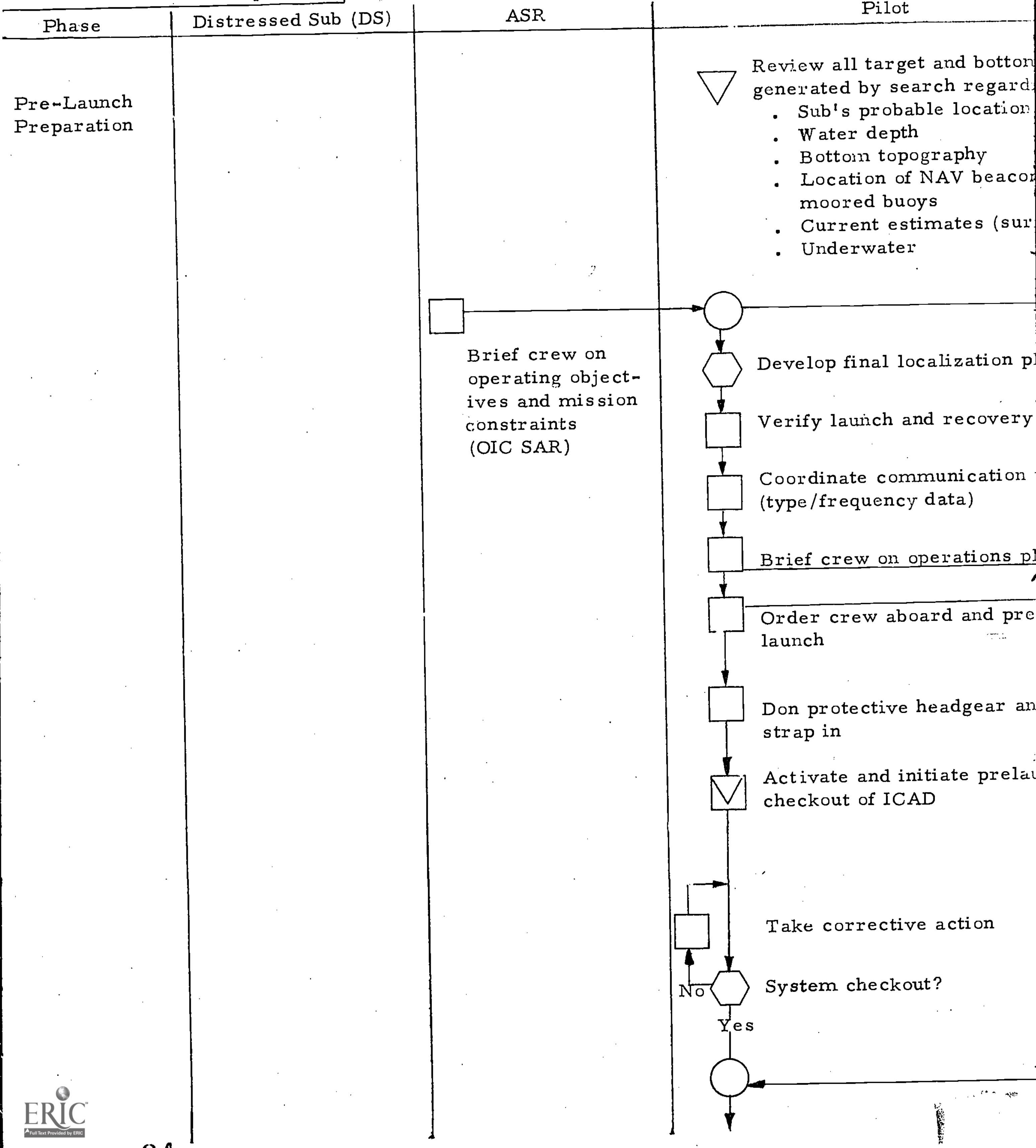
- Control skills required in maneuvering the vehicle. They include operation on the surface, descent, passage, navigation across bottom terrain, coming to terminal area, closing and/or mating to target, ascent, recovery.
- Procedural skills required in set-up, check-out, and operation of all subsystems.
- Use of sensors required in surveillance, recognition, and classification of targets, localization, and navigation.
- Special skills (dependent on specific system). In the DSRV case, mating to disabled submarine, effecting passageway between the boats, rescue and evacuation of personnel. Other special skills: use of remote manipulators, lock-out of divers, etc.

It should be noted that the operational descriptions which follow represent the best available estimate of DSRV human performance requirements at this time.

LEGEND:

⬡ Decision
○ Information
□ Action
▽ Perception

DSRV RESCUE MISSION, ASI



ISSION, ASR IN SUPPORT

Assumptions:
1) Single DSRV deployed
2) Operational tasks
3) Sub location known and is cooperative
4) 1st trip to sub which has > 1 atmosphere

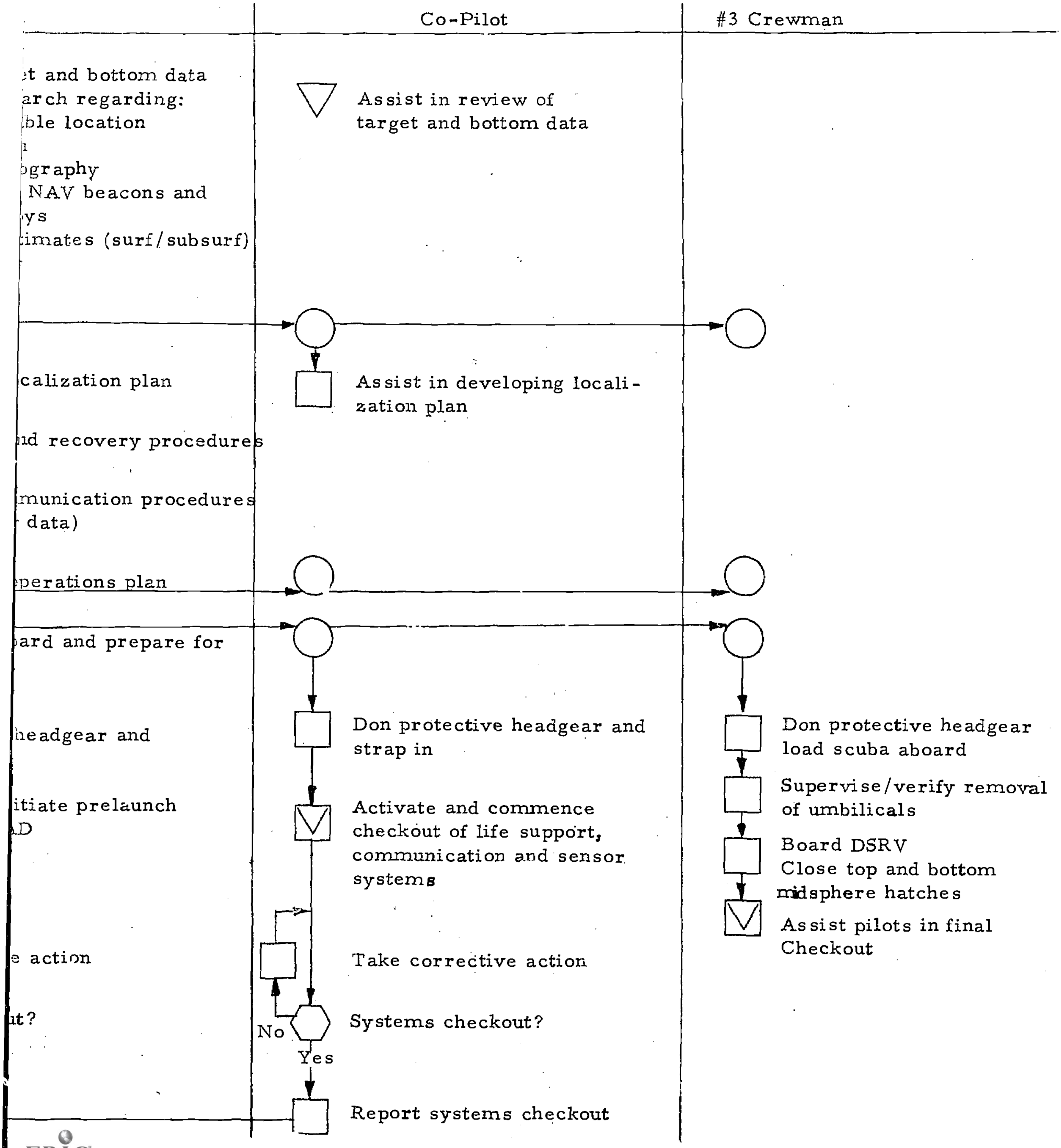
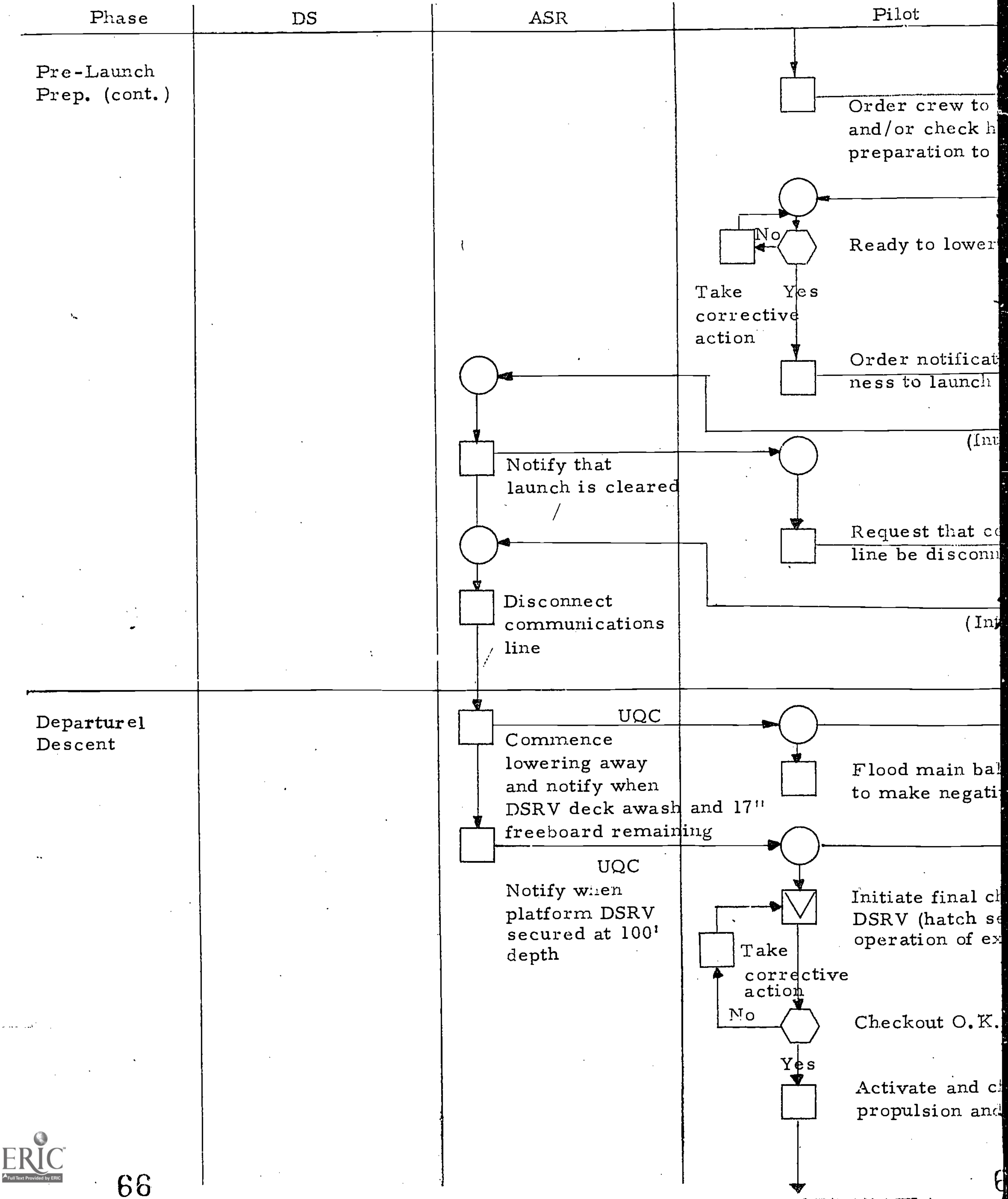


Figure 3. DSRV Rescue Mission, ASR In Support (Part 1 of 15 Parts)


Phase
DS
ASR
Pilot
Pre-Launch Prep. (cont.)
Order crew to
and/or check h
preparation to
Ready to lower
No
Yes
Take corrective action
Order notificat
ness to launch
(In
Notify that launch is cleared
Request that co
line be disconn
Disconnect communications line
(In
Departurel Descent
UQC
Commence lowering away and notify when DSRV deck awash and 17" freeboard remaining
Flood main bal
to make negati
UQC
Notify when platform DSRV secured at 100' depth
Initiate final ch
DSRV (hatch se
operation of ex
Take corrective action
No
Checkout O.K.
Yes
Activate and c
propulsion and

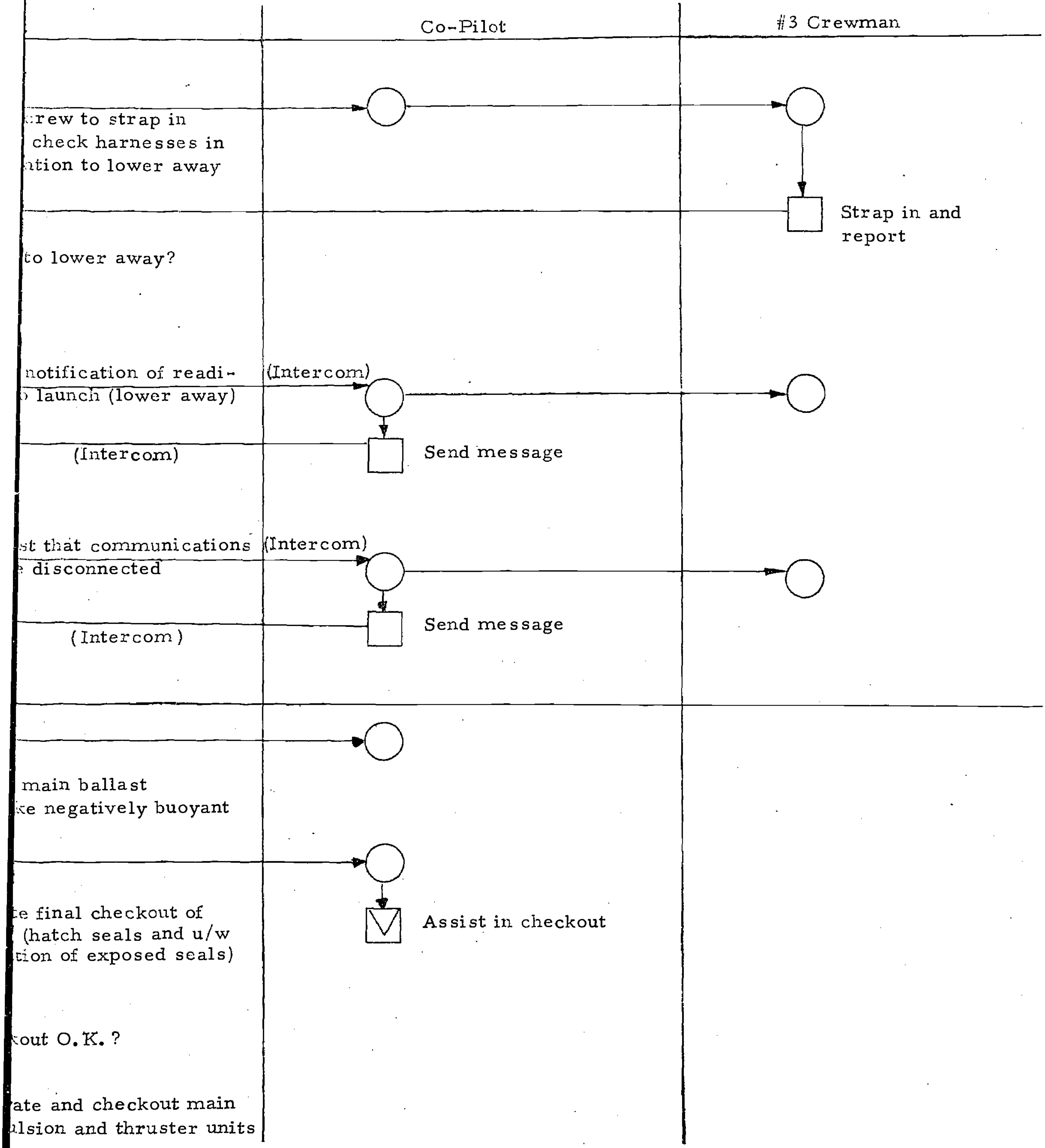
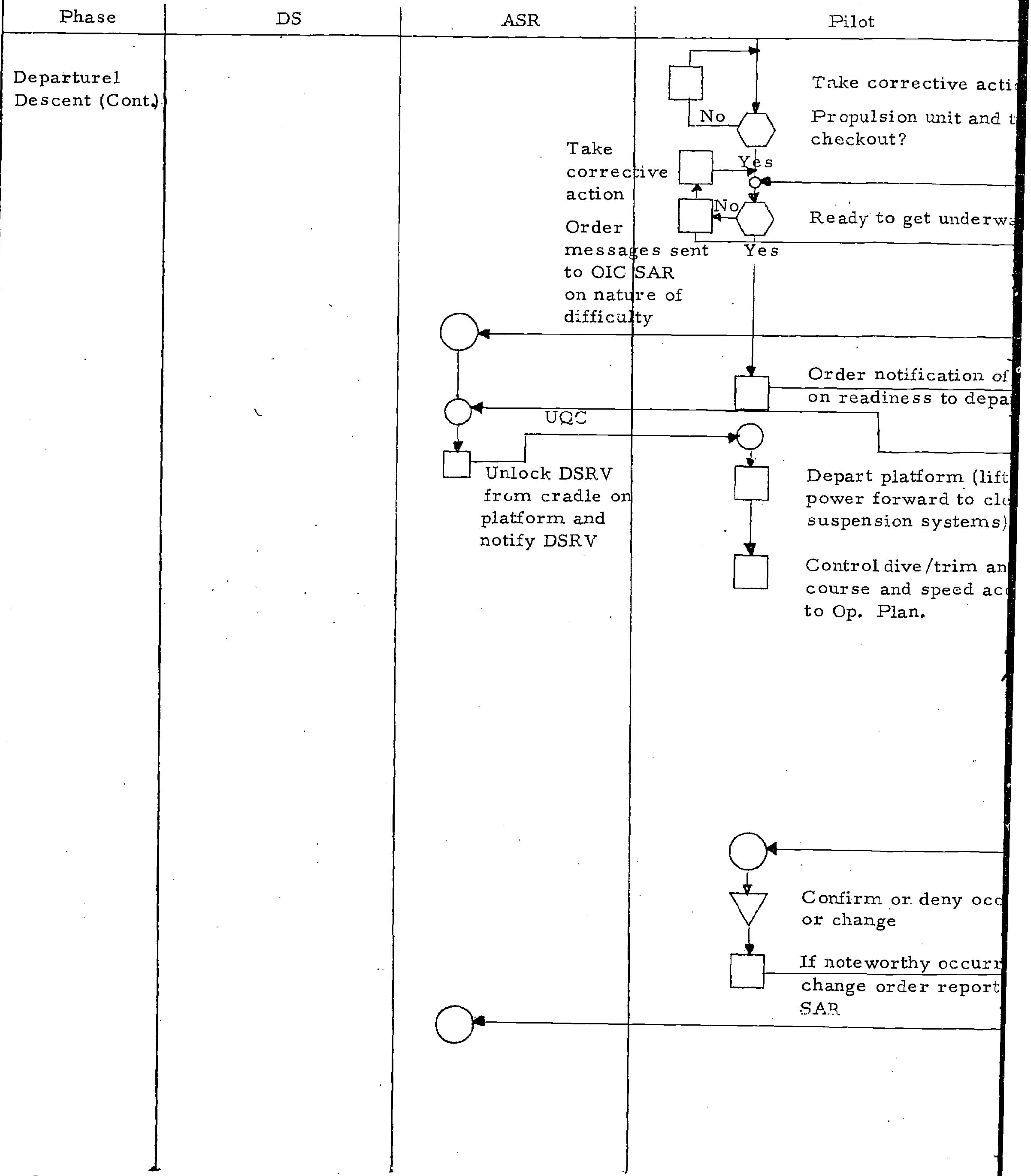


Figure 3. DSRV Rescue Mission, ASR In Support (Part 2 of 15 Parts)


Phase
DS
ASR
Pilot
Departurel Descent (Cont.)
Take corrective acti
No
Propulsion unit and t checkout?
Yes
Take corrective action
No
Ready to get underwa
Order messages sent to OIC SAR on nature of difficulty
Yes
Order notification of on readiness to depa
UQC
Unlock DSRV from cradle on platform and notify DSRV
Depart platform (lift power forward to cl suspension systems)
Control dive/trim an course and speed ac to Op. Plan.
Confirm or deny occ or change
If noteworthy occurr change order report SAR

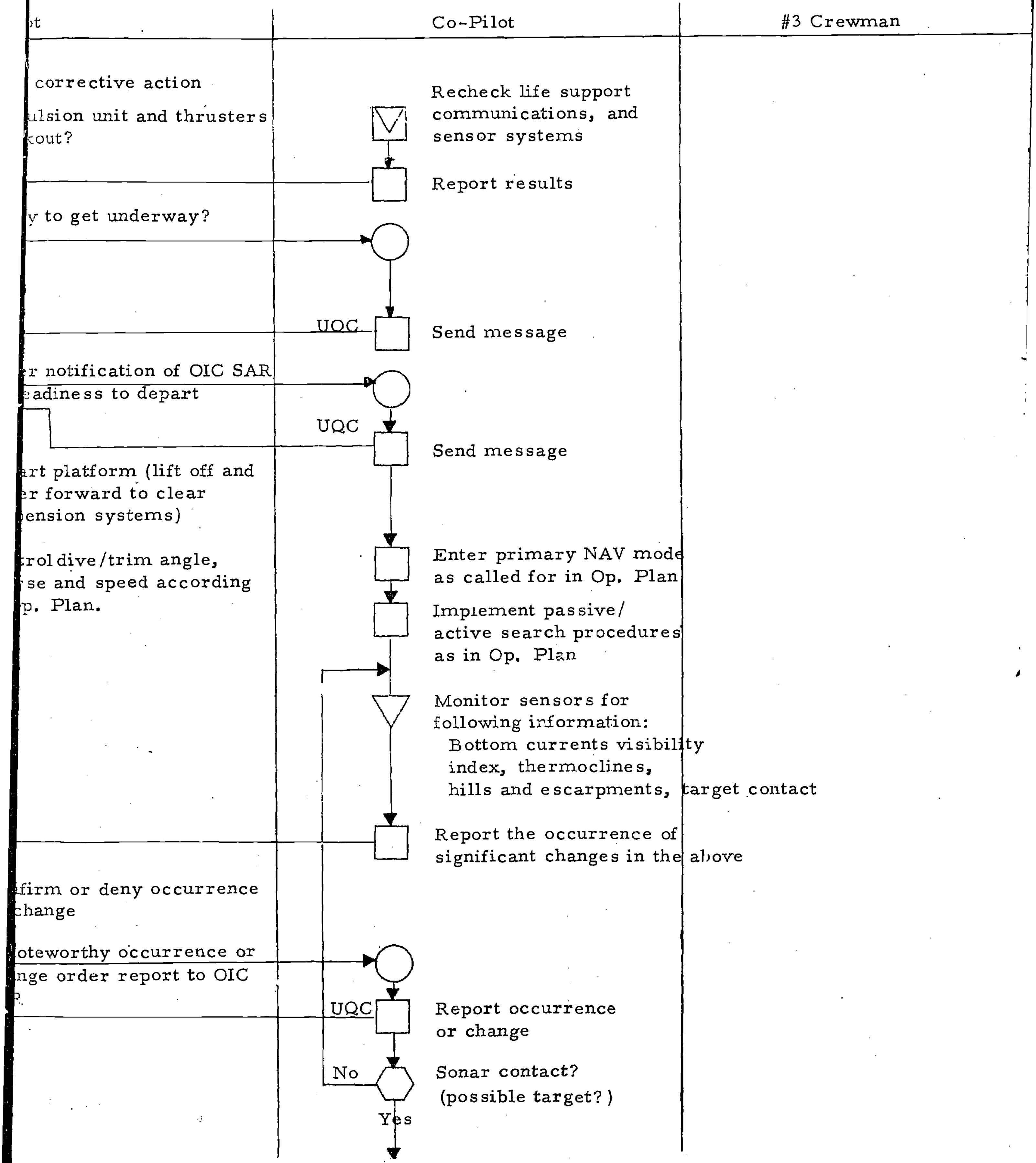
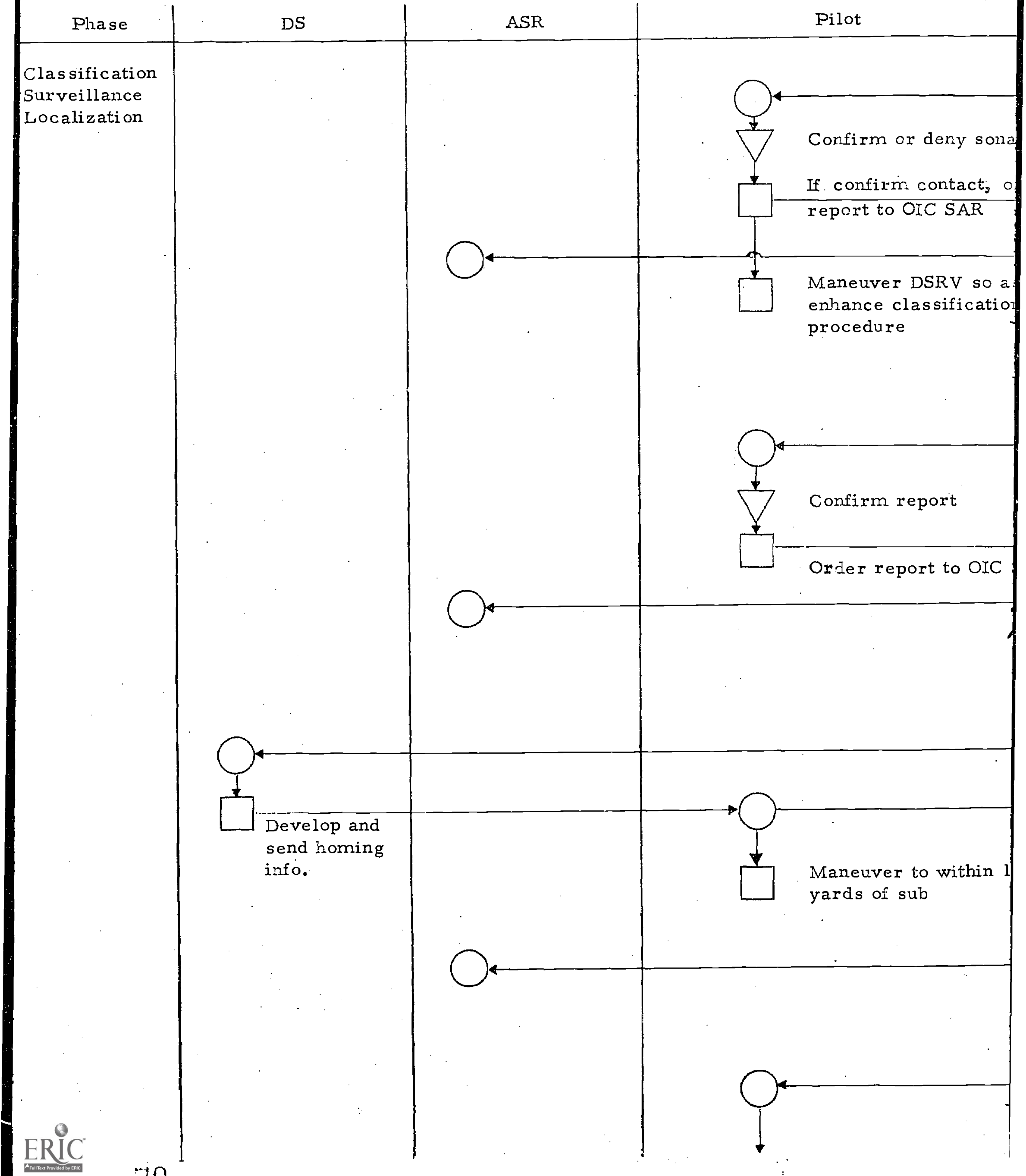


Figure 3. DSRV Rescue Mission, ASR In Support (Part 3 of 15 Parts)


Phase
DS
ASR
Pilot
Classification
Surveillance
Localization
Confirm or deny sona
If. confirm contact, o
report to OIC SAR
Maneuver DSRV so a
enhance classificatio
procedure
Confirm report
Order report to OIC
Develop and
send homing
info.
Maneuver to within l
yards of sub

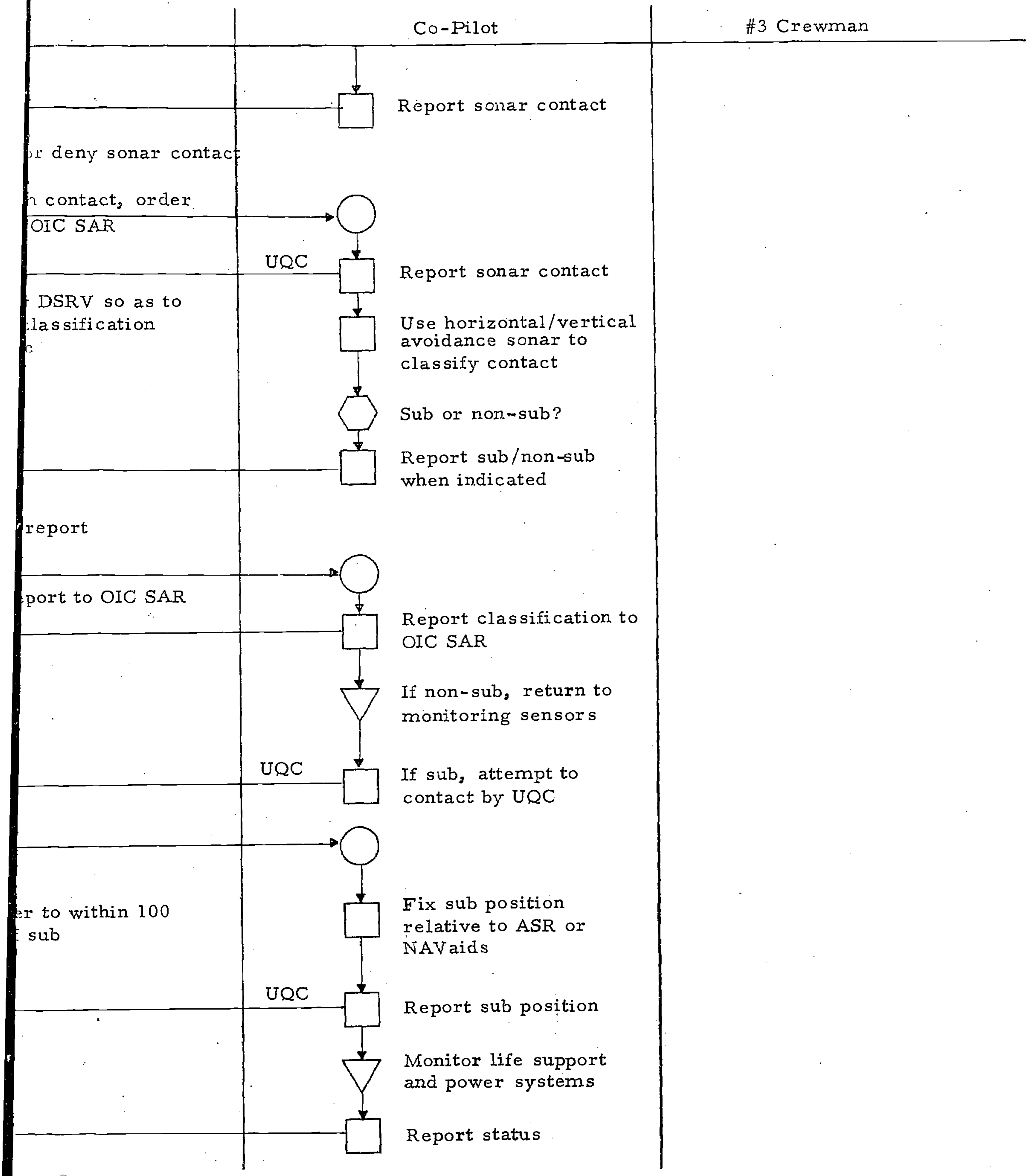
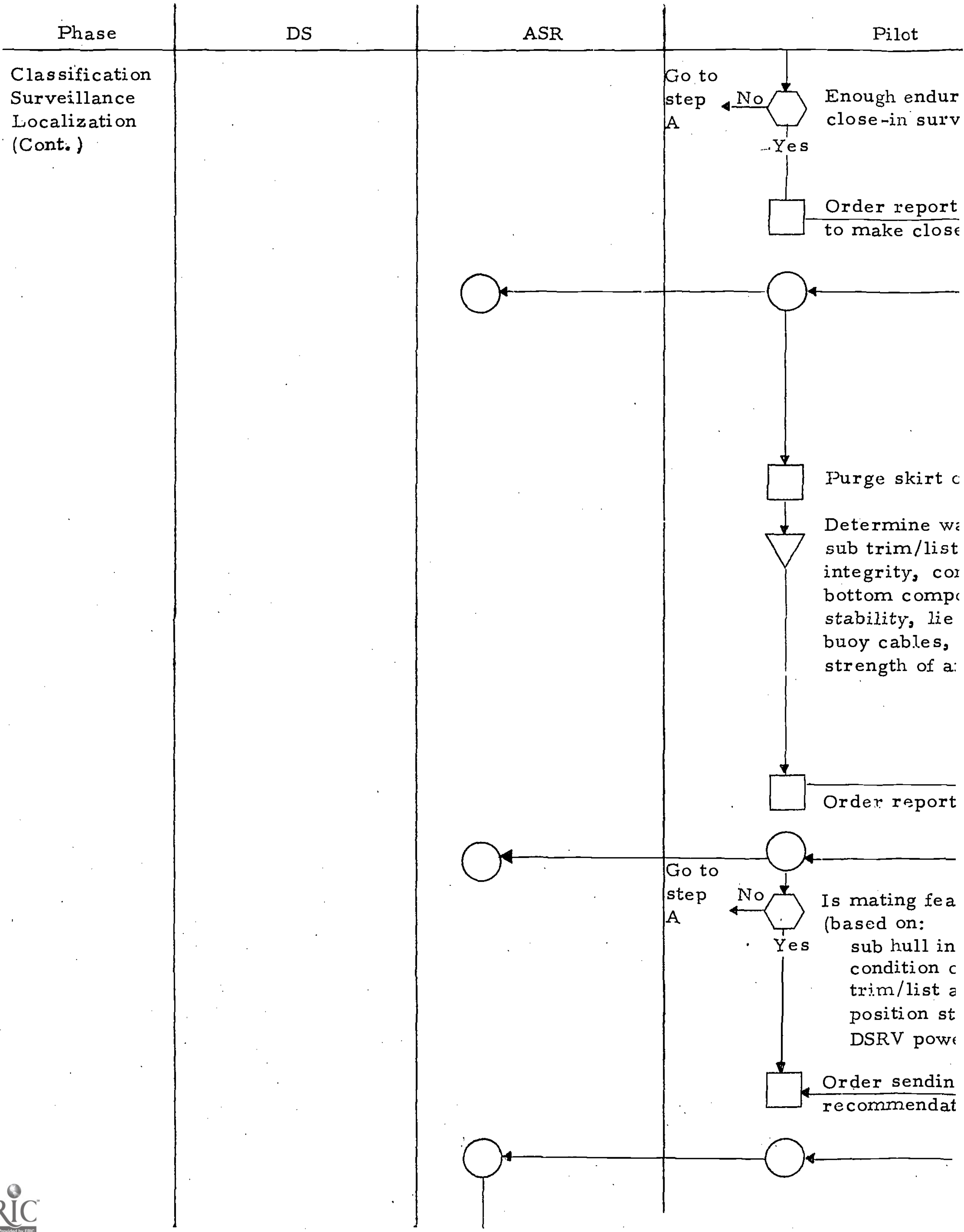


Figure 3. **DSRV Rescue Mission, ASR In Support (Part 4 of 15 Parts)**


Phase
DS
ASR
Pilot
Classification
Surveillance
Localization
(Cont.)
Go to step A
No
Yes
Enough endur
close-in surv
Order report
to make close
Purge skirt c
Determine wa
sub trim/list
integrity, co
bottom compo
stability, lie
buoy cables,
strength of a
Order report
Go to step A
No
Yes
Is mating fea
(based on:
sub hull in
condition c
trim/list a
position st
DSRV powe
Order sendin
recommendat

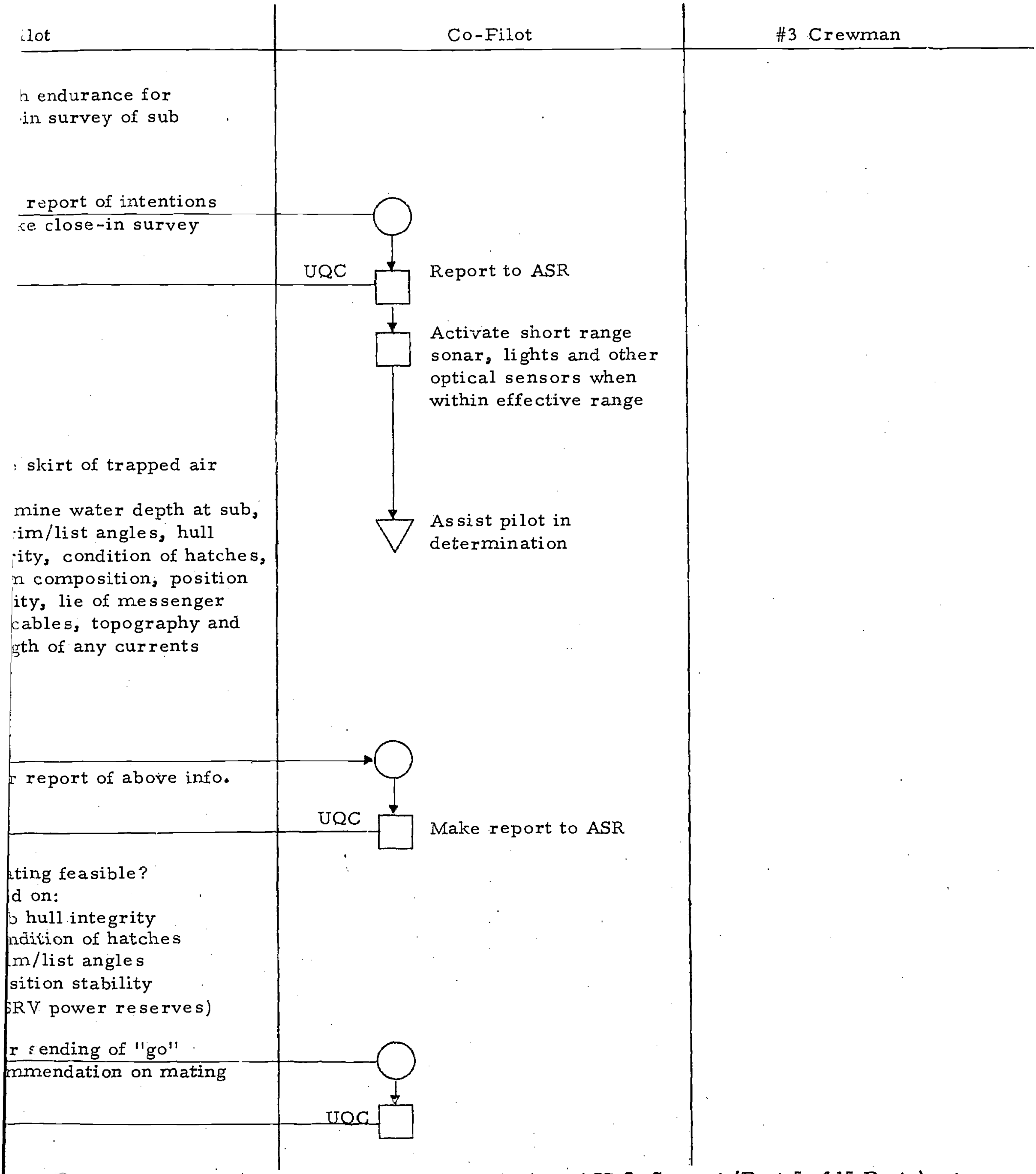
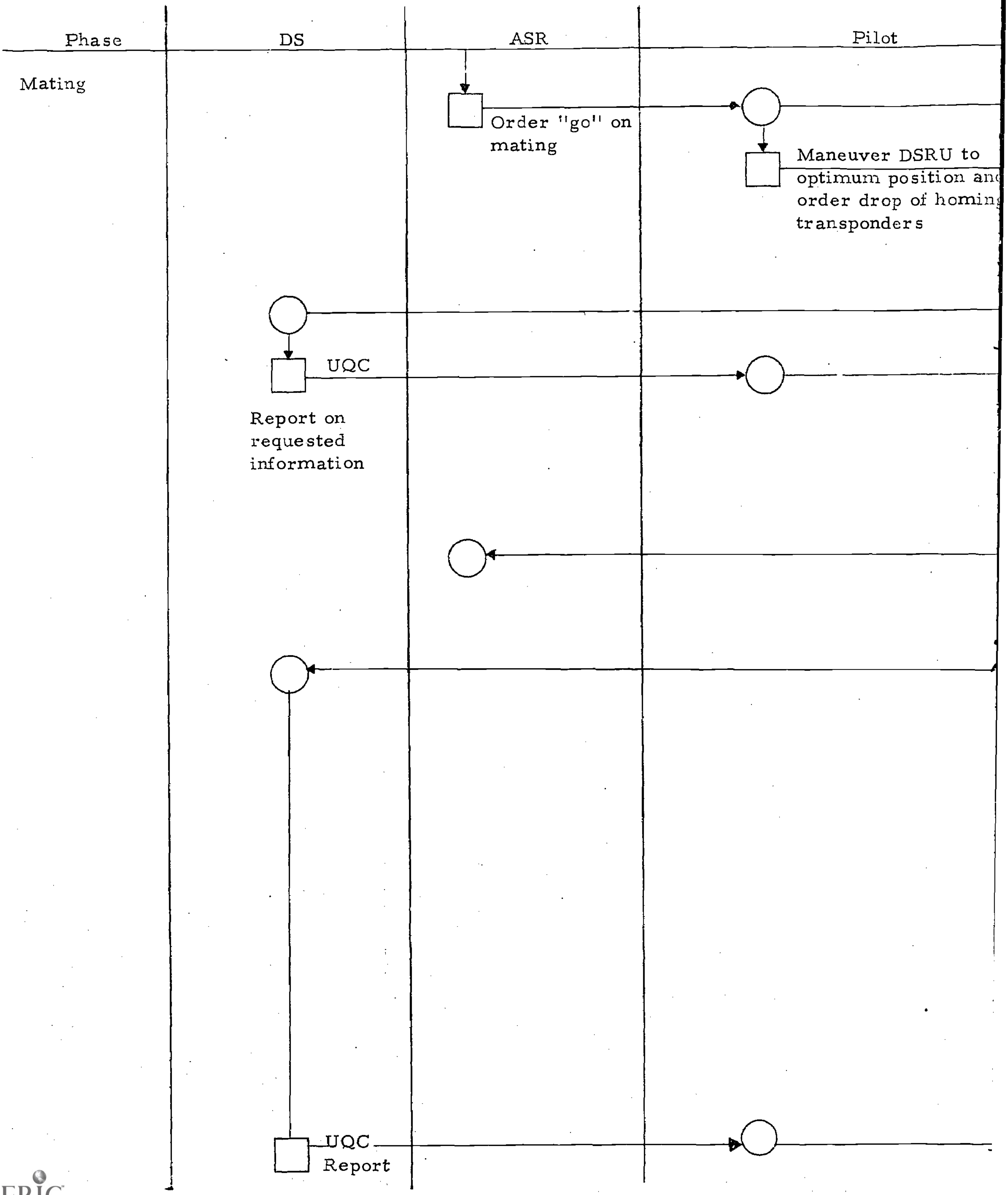


Figure 3. DSRV Rescue Mission, ASR In Support (Part 5 of 15 Parts)


Phase
DS
ASR
Pilot
Mating
Order "go" on mating
Maneuver DSRU to optimum position and order drop of homing transponders
UQC
Report on requested information
UQC
Report

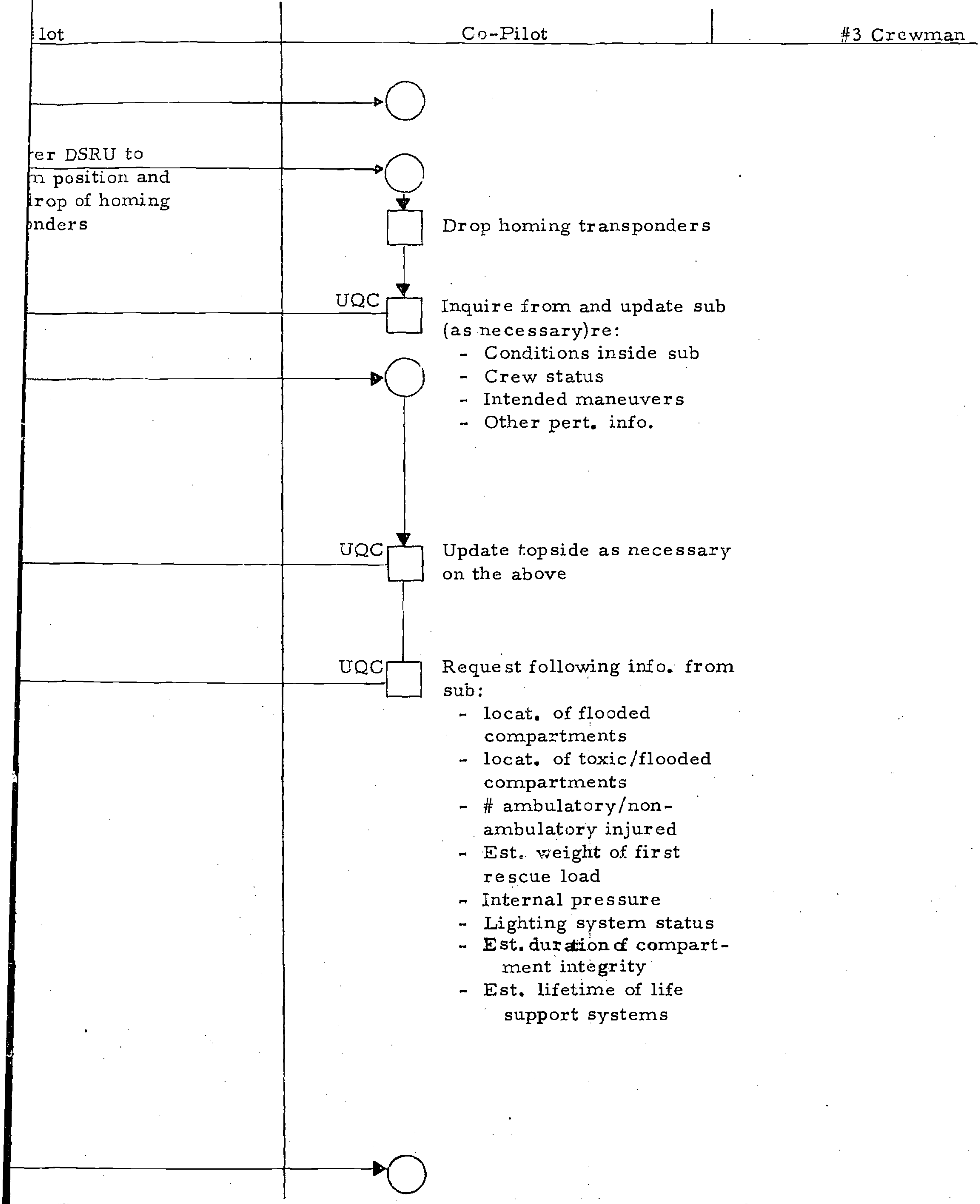
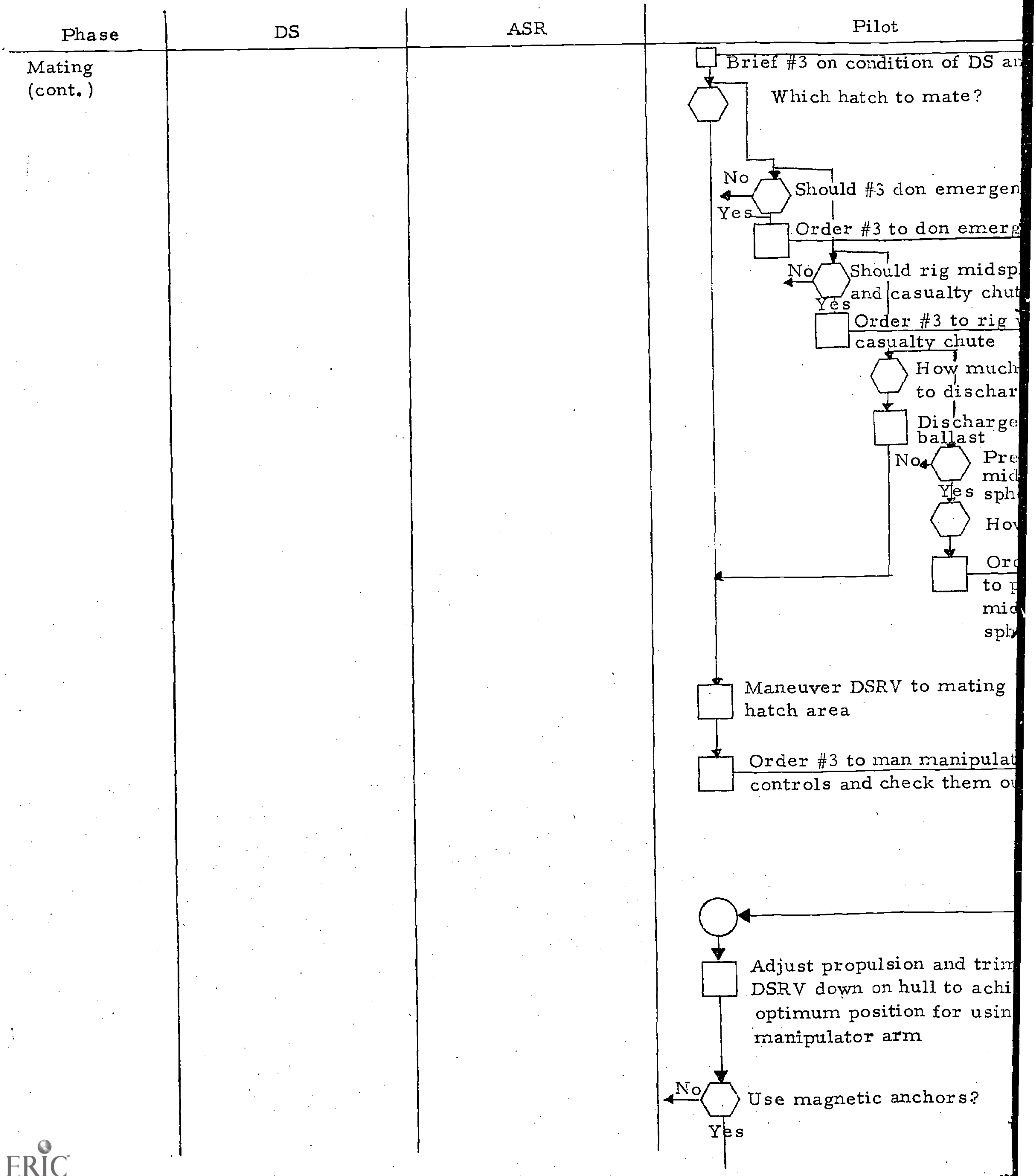


Figure 3. DSRV Rescue Mission, ASR In Support (Part 6 of 15 Parts)


Phase
DS
ASR
Pilot
Mating (cont.)
Brief #3 on condition of DS an
Which hatch to mate?
No
Should #3 don emergen
Yes
Order #3 to don emerg
No
Should rig midsp
and casualty chut
Yes
Order #3 to rig
casualty chute
How much
to dischar
Discharge
ballast
No
Pre
mid
sph
Yes
Hov
Orc
to p
mid
sph
Maneuver DSRV to mating
hatch area
Order #3 to man manipulat
controls and check them o
Adjust propulsion and trim
DSRV down on hull to achi
optimum position for usin
manipulator arm
No
Use magnetic anchors?
Yes

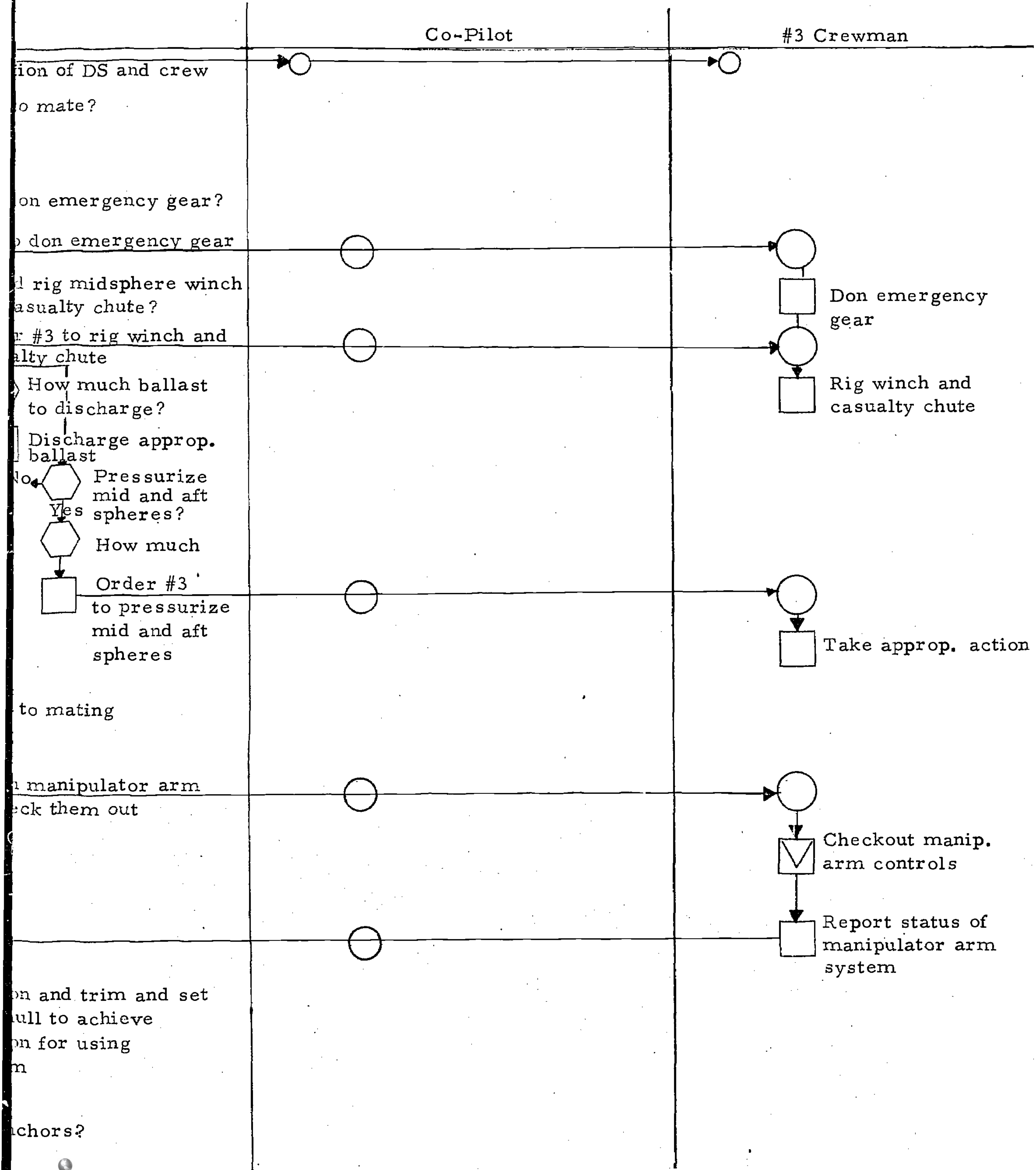
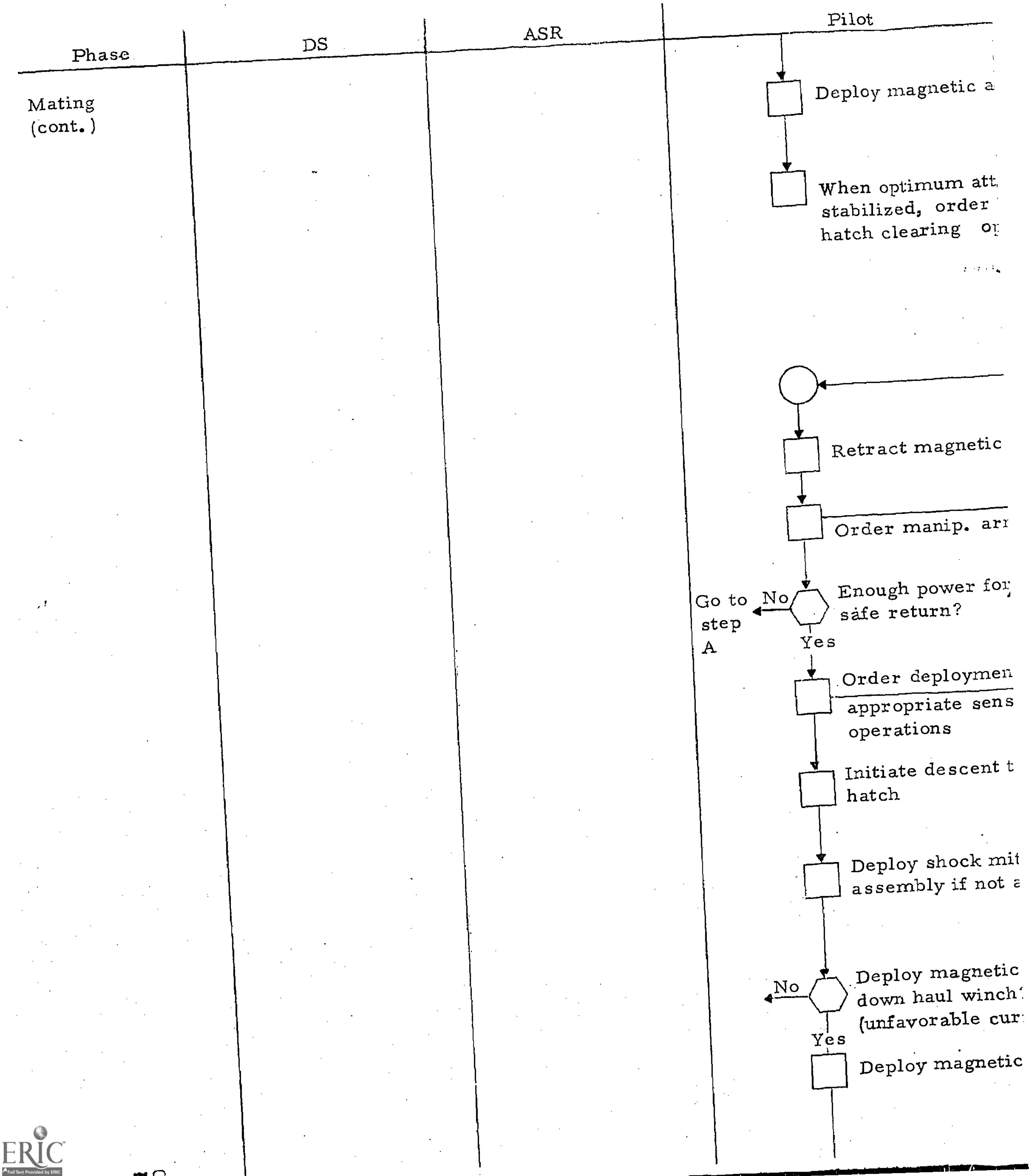


Figure 3. DSRV Rescue Mission, ASR In Support (Part 7 of 15 Parts)


Phase
DS
ASR
Pilot
Mating
(cont.)
Deploy magnetic a
When optimum att
stabilized, order
hatch clearing op
Retract magnetic
Order manip. arr
Go to step A
No
Enough power for
safe return?
Yes
Order deploymen
appropriate sens
operations
Initiate descent t
hatch
Deploy shock mit
assembly if not a
No
Deploy magnetic
down haul winch?
(unfavorable cur
Yes
Deploy magnetic

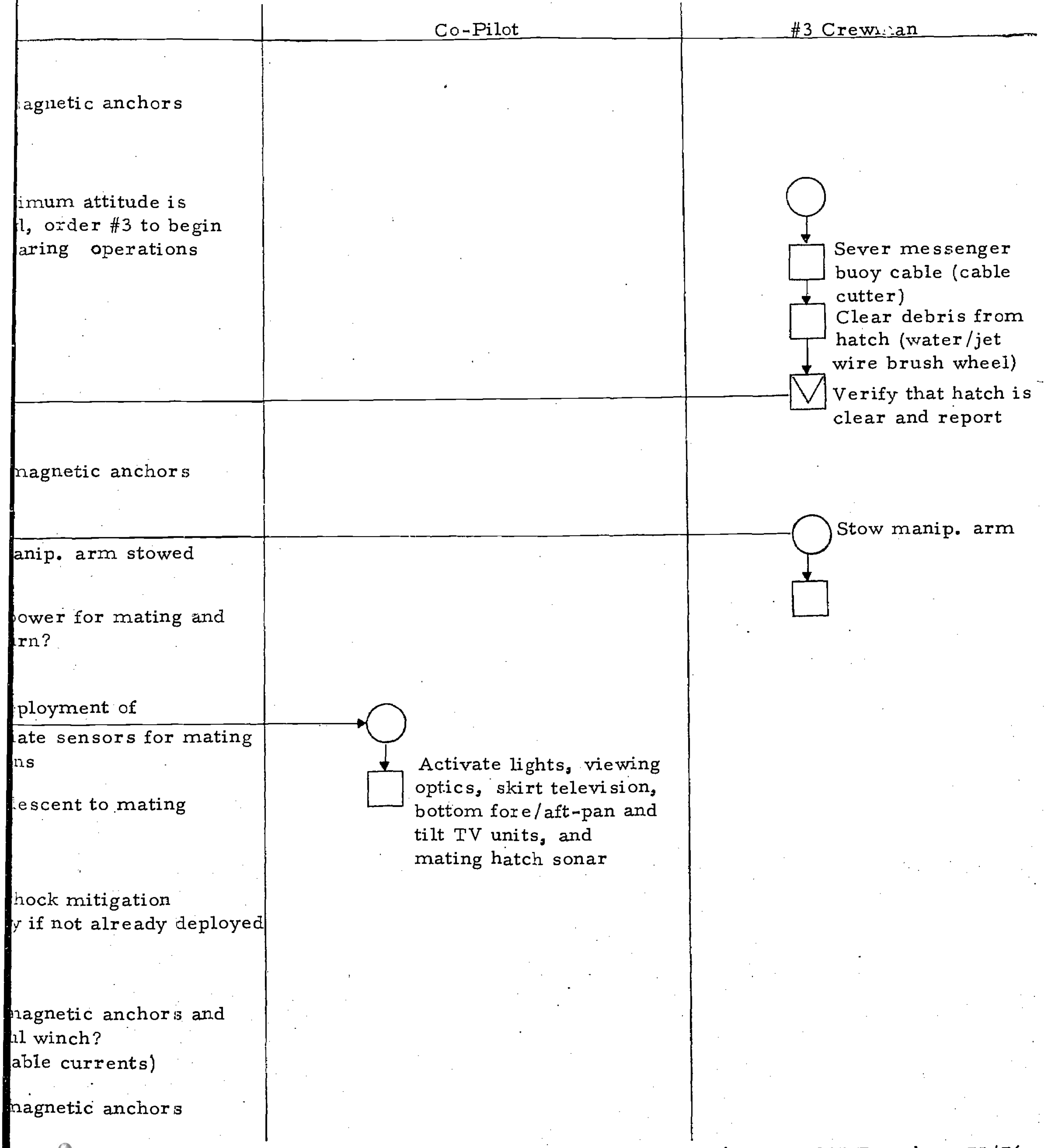
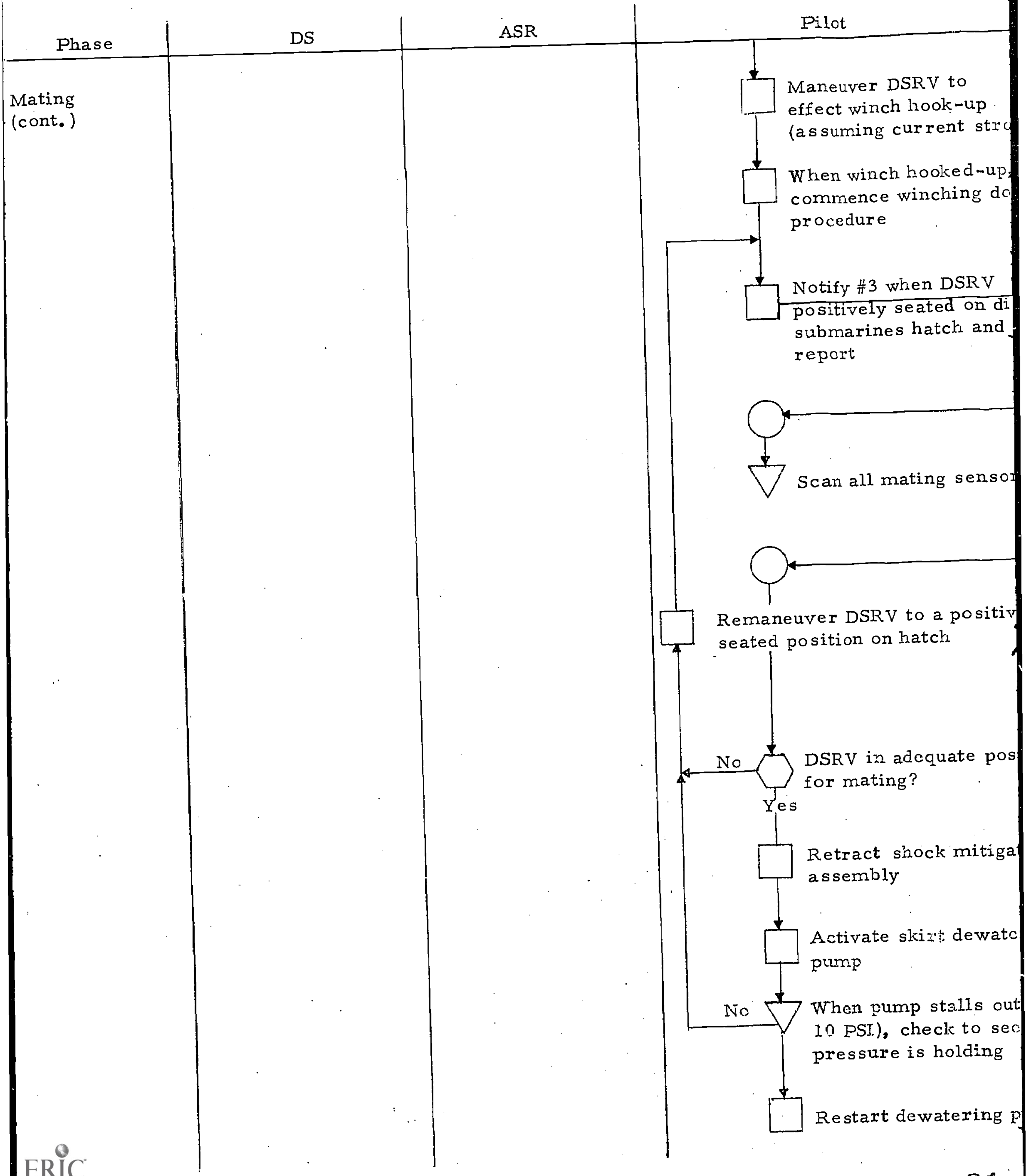


Figure 3. DSRV Rescue Mission, ASR In Support (Part 8 of 15 Parts)



Maneuver DSRV to effect winch hook-up (assuming current str

When winch hooked-up, commence winching do procedure

Notify #3 when DSRV positively seated on di submarines hatch and report

Scan all mating senso

Remaneuver DSRV to a positiv seated position on hatch

DSRV in adequate pos for mating?

Retract shock mitiga assembly

Activate skirt dewatc pump

When pump stalls out 10 PSI.), check to sec pressure is holding

Restart dewatering p

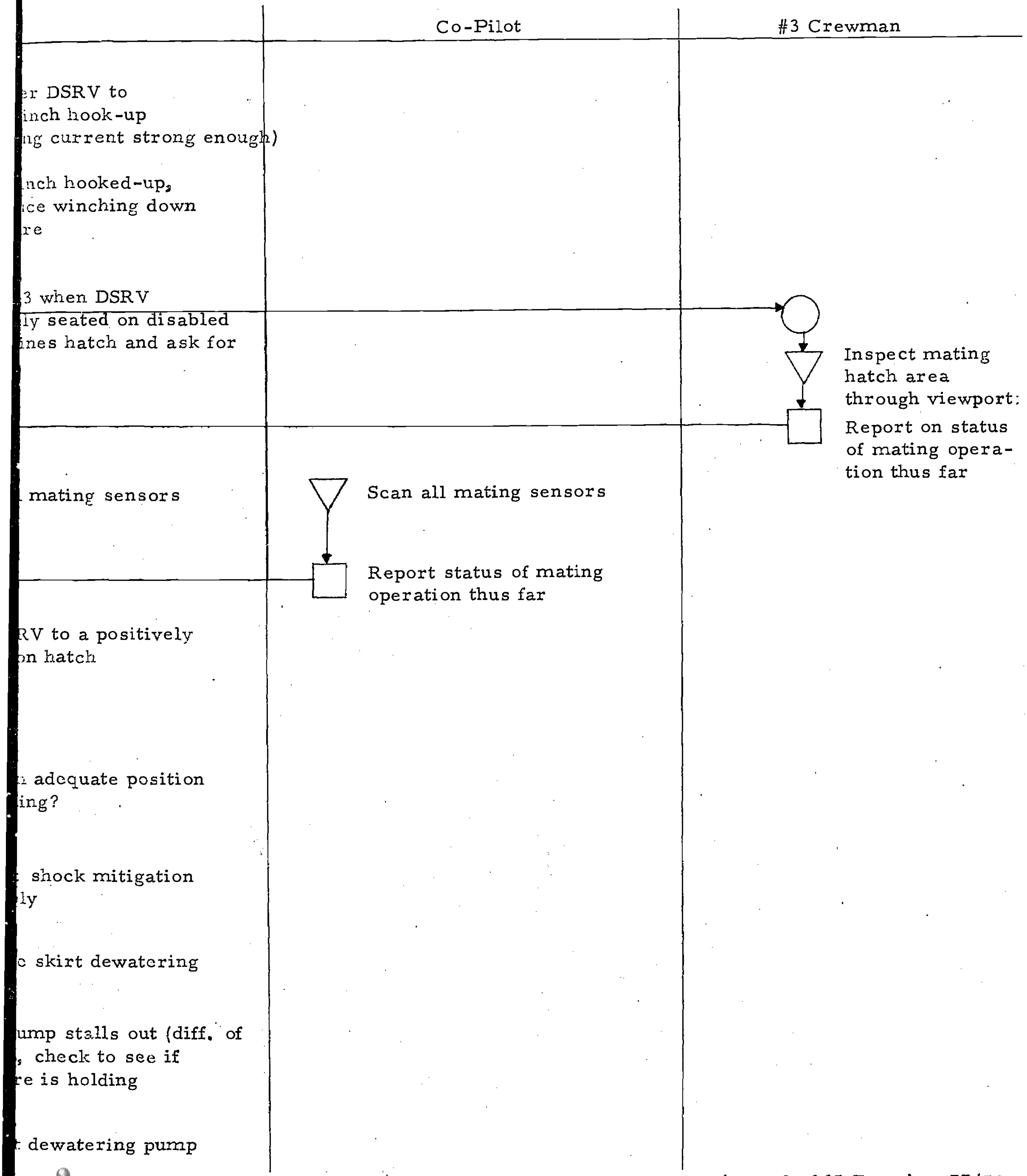
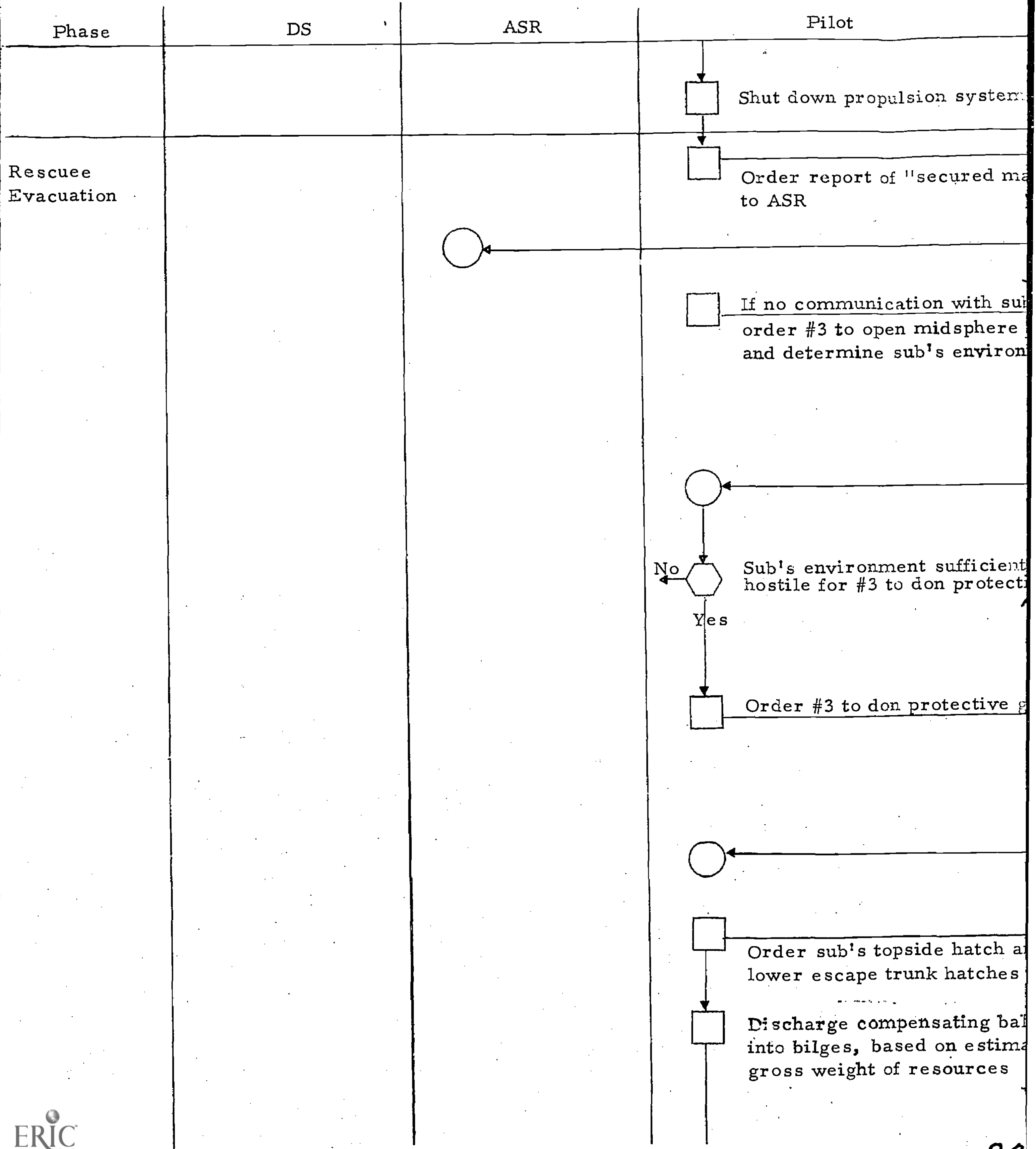


Figure 3. DSRV Rescue Mission, ASR In Support (Part 9 of 15 Parts)



Shut down propulsion system

Order report of "secured ma
to ASR

If no communication with sub
order #3 to open midsphere
and determine sub's environ

Sub's environment sufficient
hostile for #3 to don protecti

Order #3 to don protective g

Order sub's topside hatch a
lower escape trunk hatches

Discharge compensating bal
into bilges, based on estima
gross weight of resources

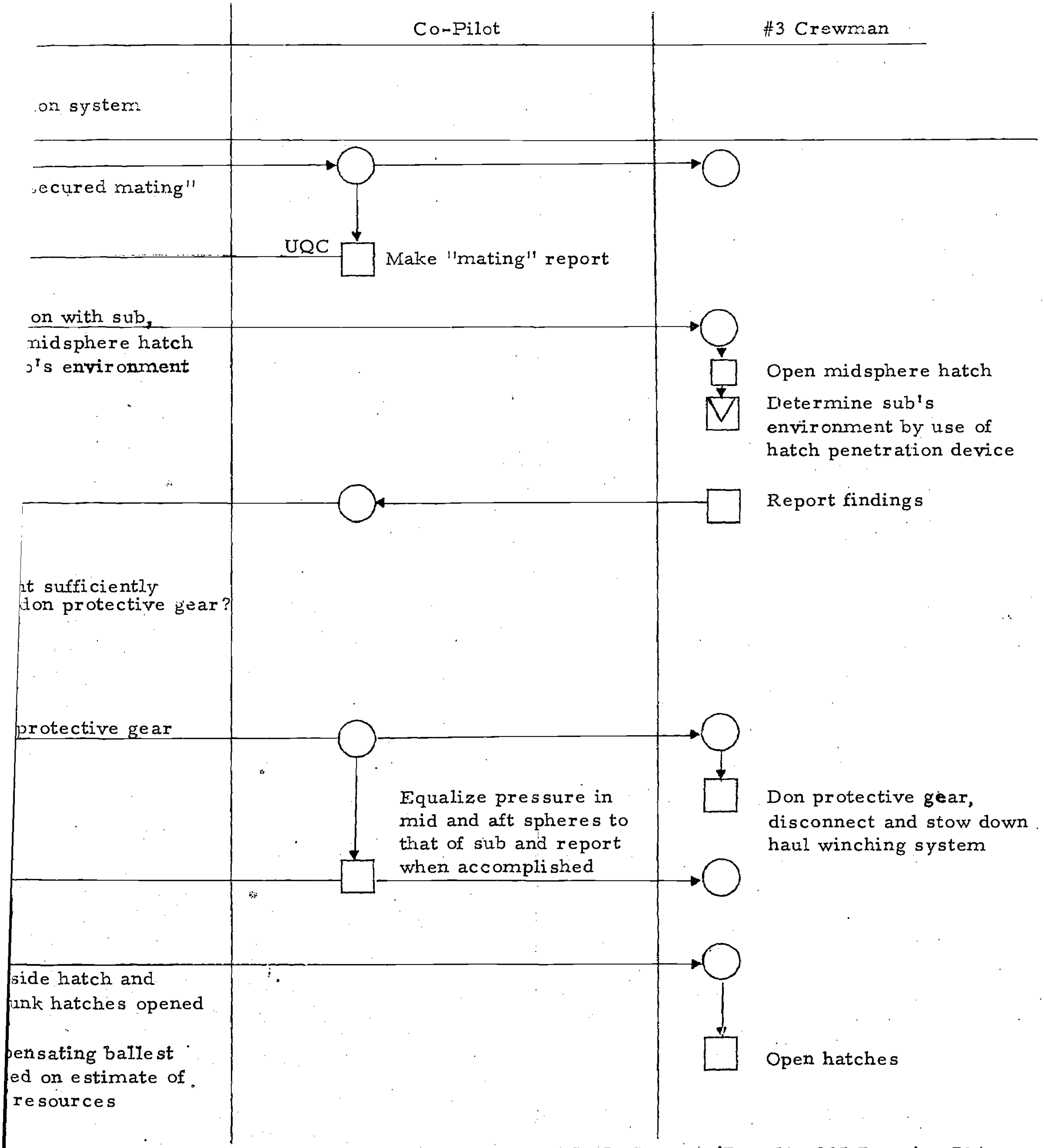
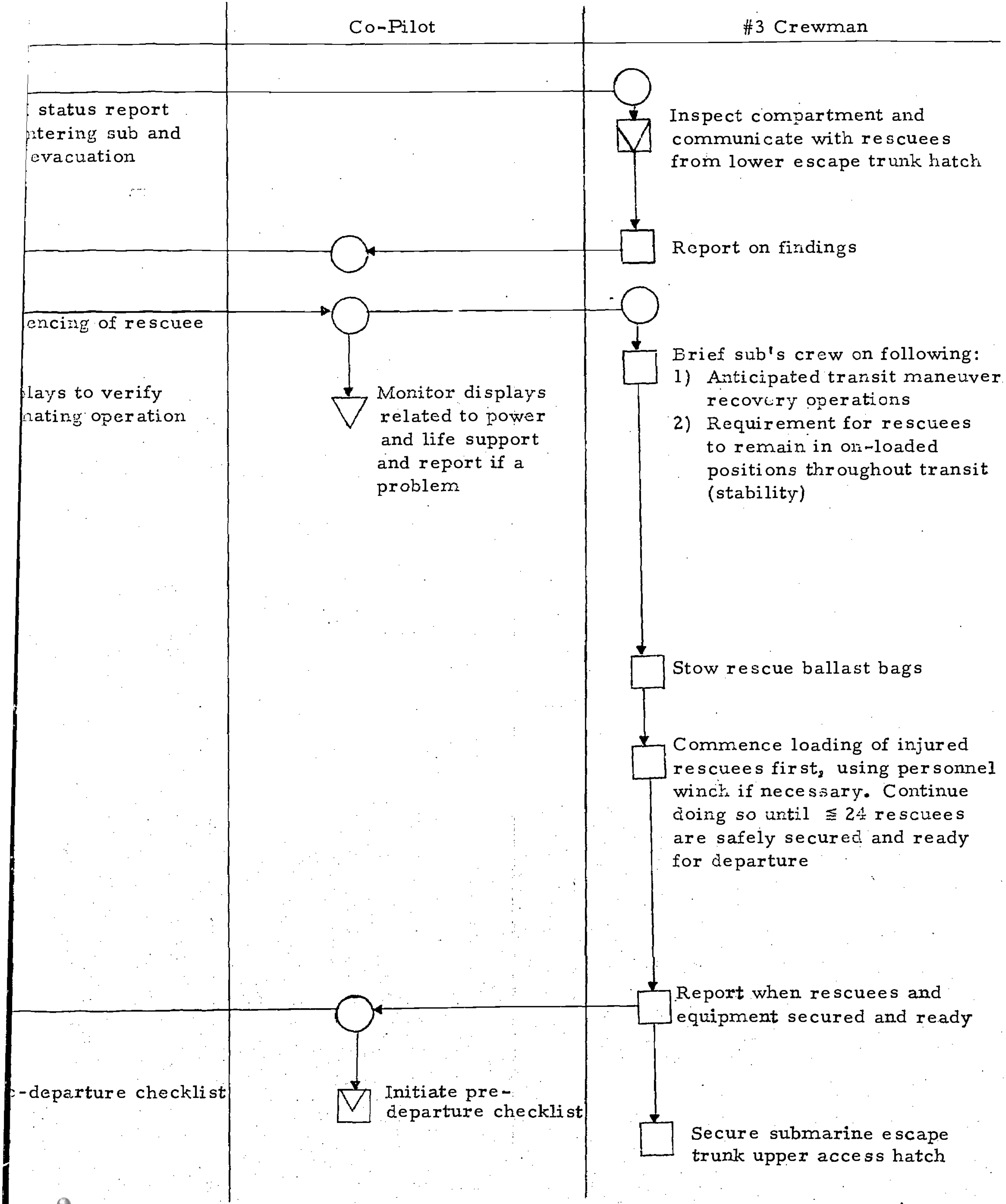


Figure 3. DSRV Rescue Mission, ASR In Support (Part 10 of 15 Parts) 79/80

Phase	DS	ASR	Pilot
Rescuee Evacuation (cont.)			☐ Request final status repo prior to #3 entering sub commencing evacuation
			○
			☐ Order commencing of re evacuation
			▽ Monitor displays to verif stability of mating opera
			○
			☒ Initiate pre-departure c



status report
ntering sub and
evacuation

Inspect compartment and communicate with rescuees from lower escape trunk hatch

Report on findings

encing of rescuee

Brief sub's crew on following:
1) Anticipated transit maneuver recovery operations
2) Requirement for rescuees to remain in on-loaded positions throughout transit (stability)

lays to verify
nating operation

Monitor displays related to power and life support and report if a problem

Stow rescue ballast bags

Commence loading of injured rescuees first, using personnel winch if necessary. Continue doing so until ≦ 24 rescuees are safely secured and ready for departure

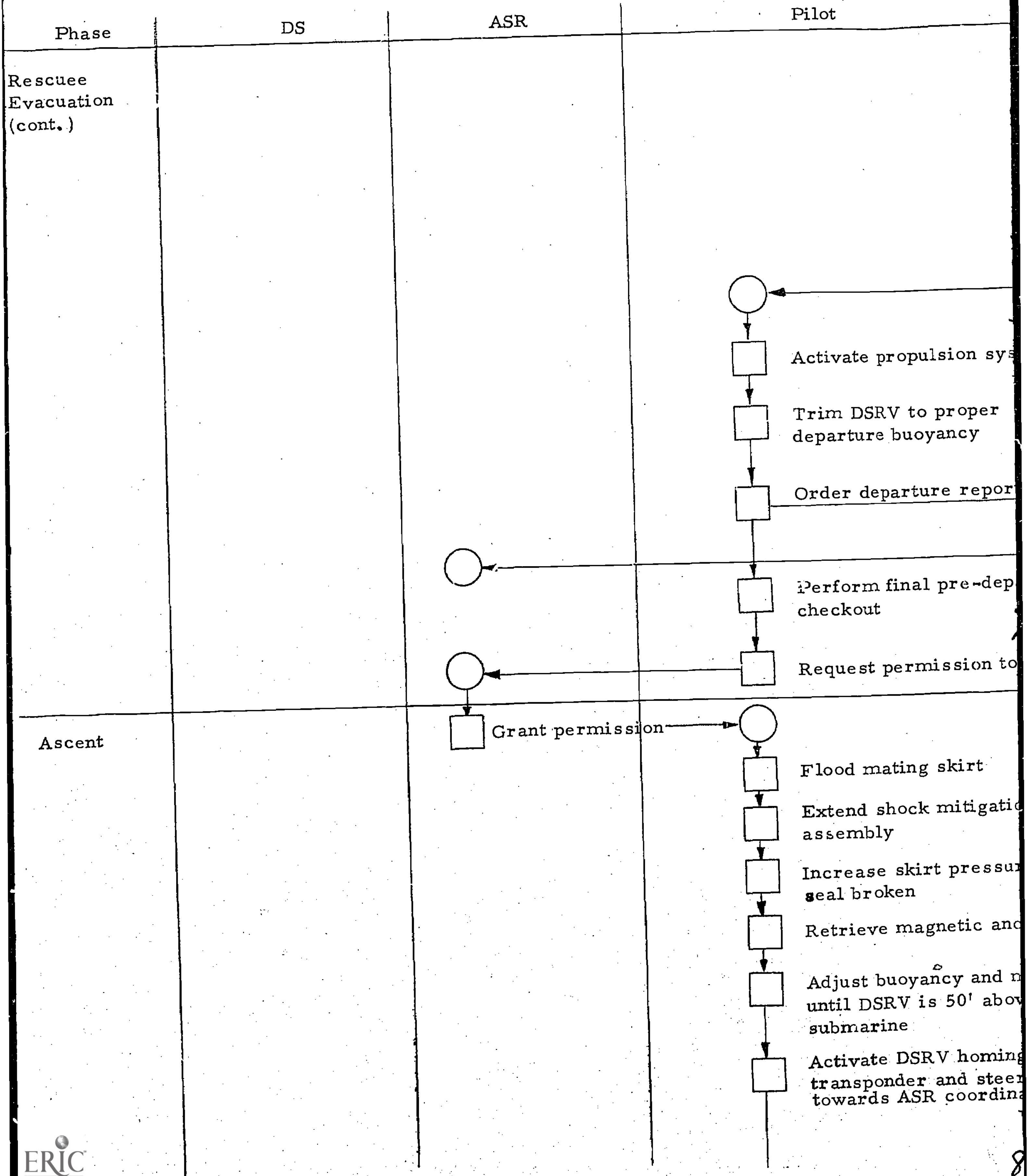
Report when rescuees and equipment secured and ready

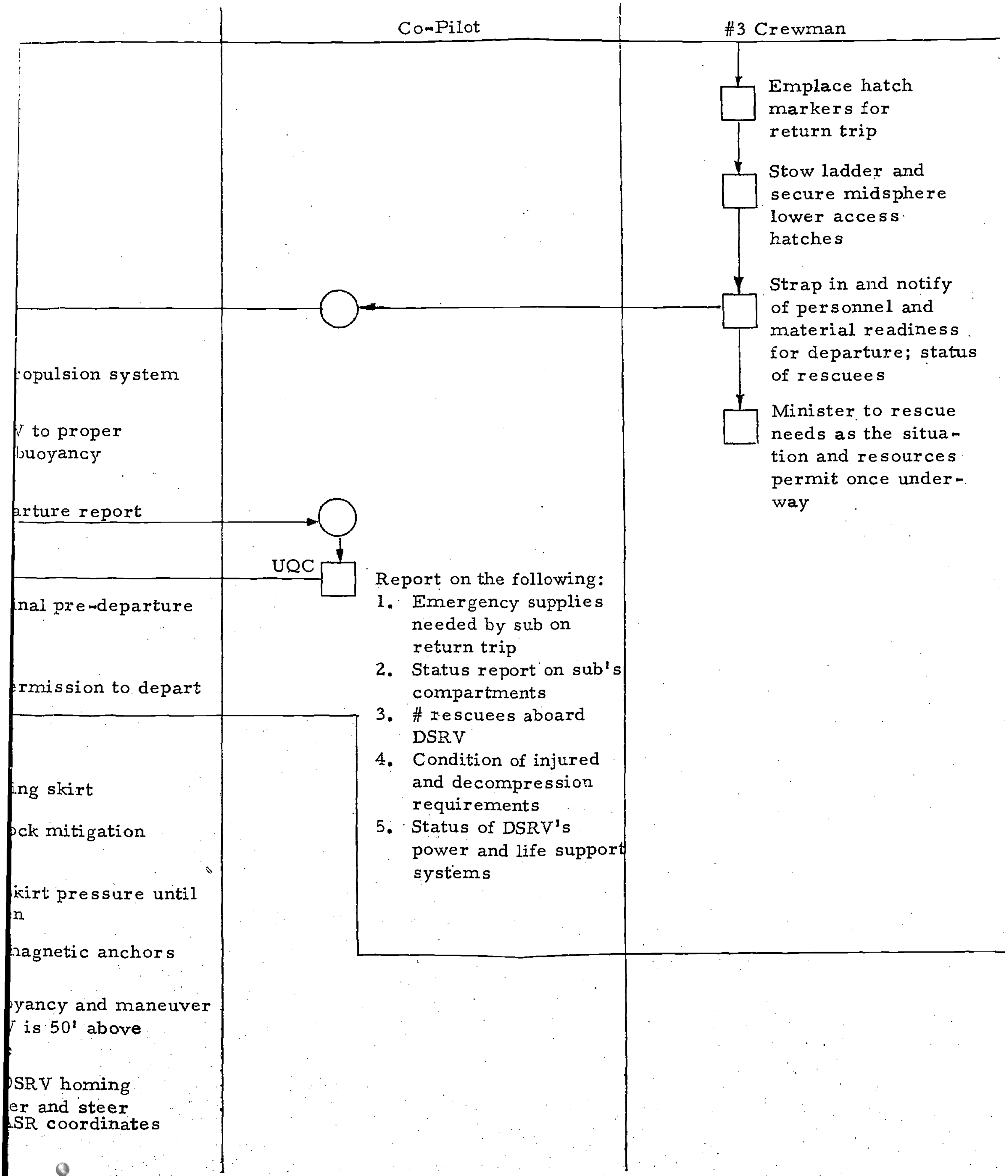
-departure checklist

Initiate pre-departure checklist

Secure submarine escape trunk upper access hatch

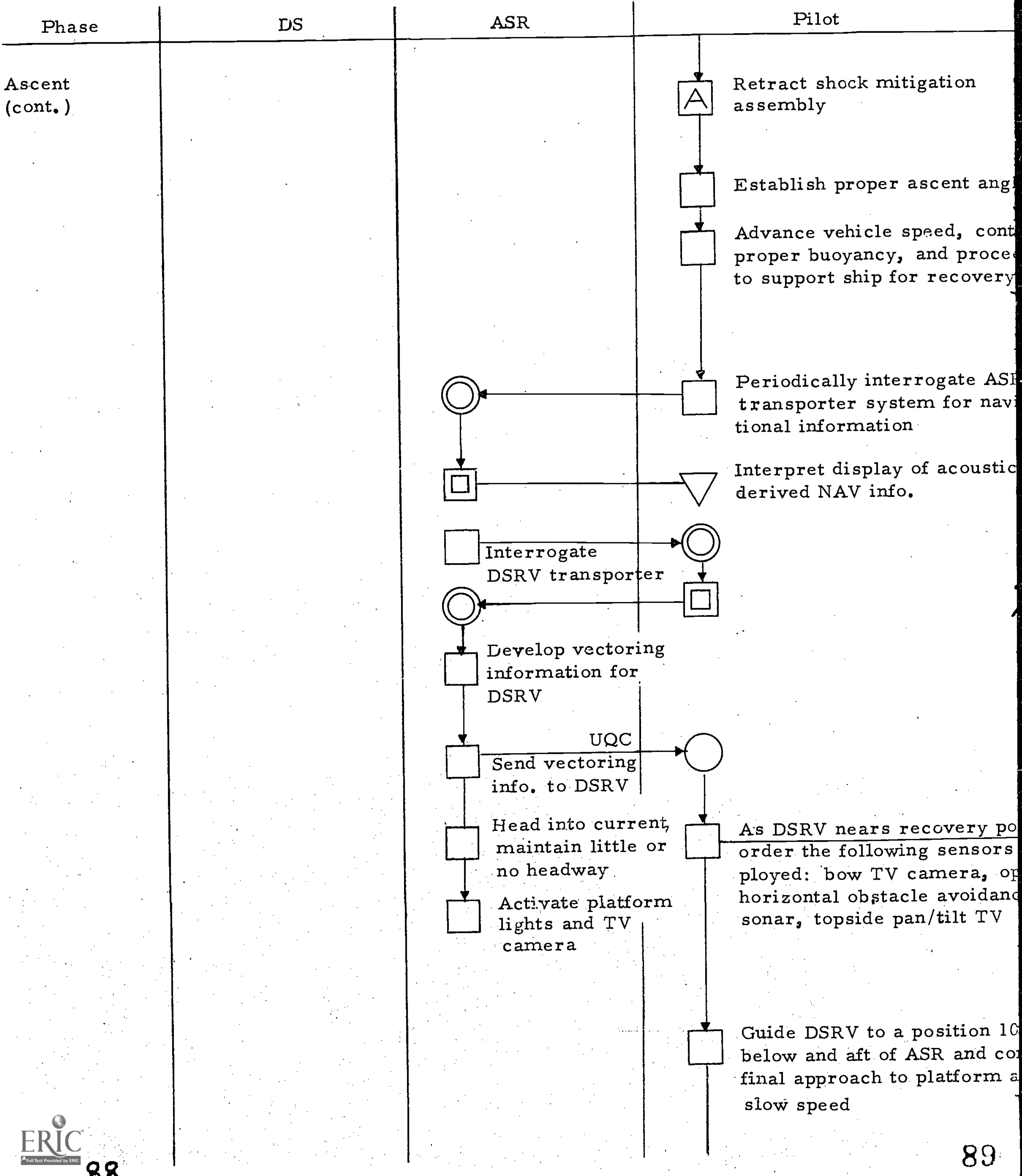
Figure 3. DSRV Rescue Mission, ASR In Support (Part 11 of 15 Parts)


Phase
DS
ASR
Pilot
Rescuee Evacuation (cont.)
Activate propulsion sys
Trim DSRV to proper departure buoyancy
Order departure repor
Perform final pre-dep checkout
Request permission to
Ascent
Grant permission
Flood mating skirt
Extend shock mitigati assembly
Increase skirt pressu seal broken
Retrieve magnetic anc
Adjust buoyancy and n until DSRV is 50' abov submarine
Activate DSRV homing transponder and steer towards ASR coordin



Report on the following:
1. Emergency supplies needed by sub on return trip
2. Status report on sub's compartments
3. # rescuees aboard DSRV
4. Condition of injured and decompression requirements
5. Status of DSRV's power and life support systems

Figure 3. DSRV Rescue Mission, ASR In Support (Part 12 of 15 Parts)



Retract shock mitigation assembly

Establish proper ascent ang

Advance vehicle speed, cont proper buoyancy, and proce to support ship for recovery

Periodically interrogate ASI transporter system for navi tional information

Interpret display of acoustic derived NAV info.

Interrogate DSRV transporter

Develop vectoring information for DSRV

Send vectoring info. to DSRV

Head into current, maintain little or no headway

Activate platform lights and TV camera

As DSRV nears recovery po order the following sensors ployed: bow TV camera, op horizontal obstacle avoidanc sonar, topside pan/tilt TV

Guide DSRV to a position 10 below and aft of ASR and co final approach to platform a slow speed

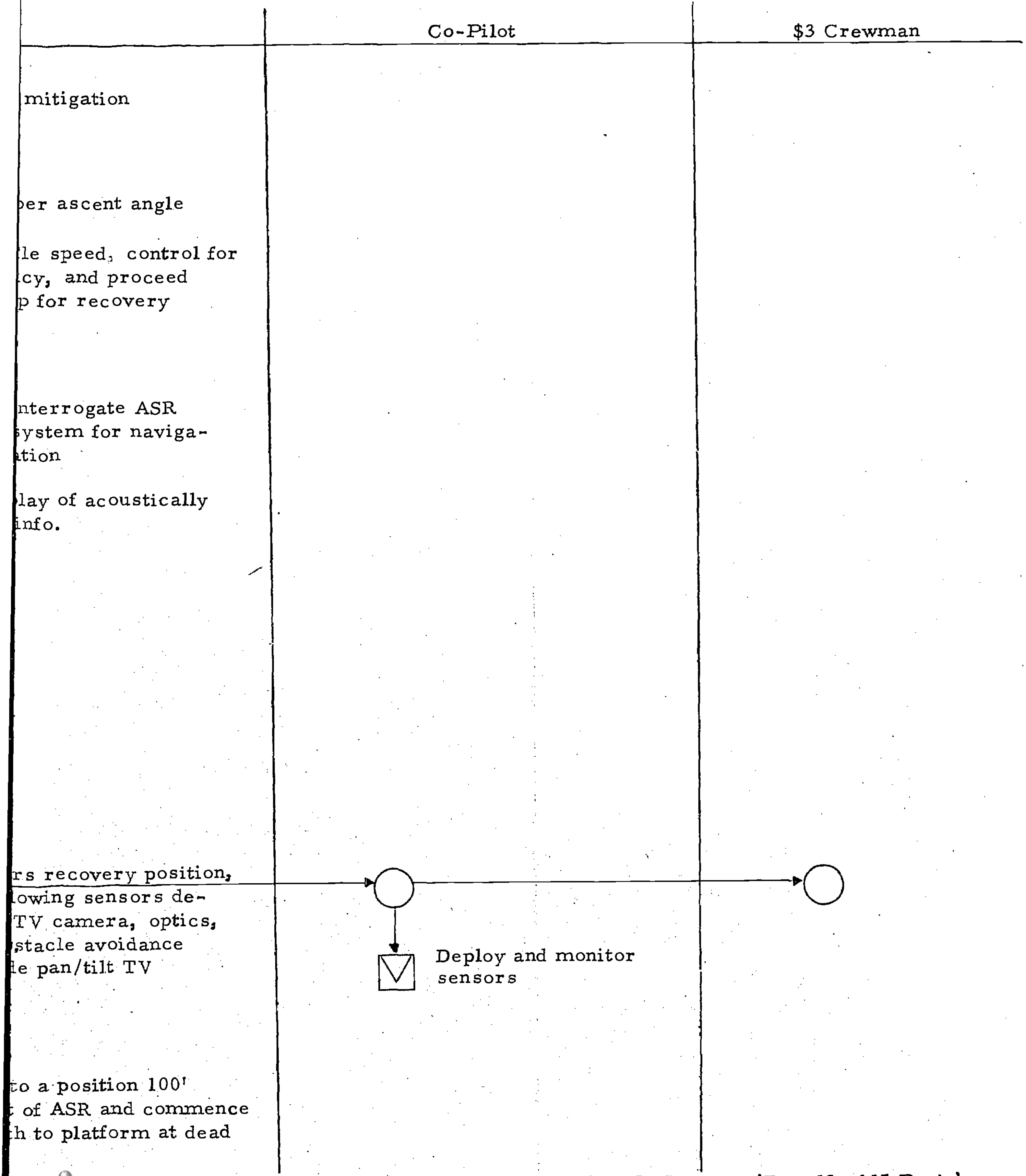
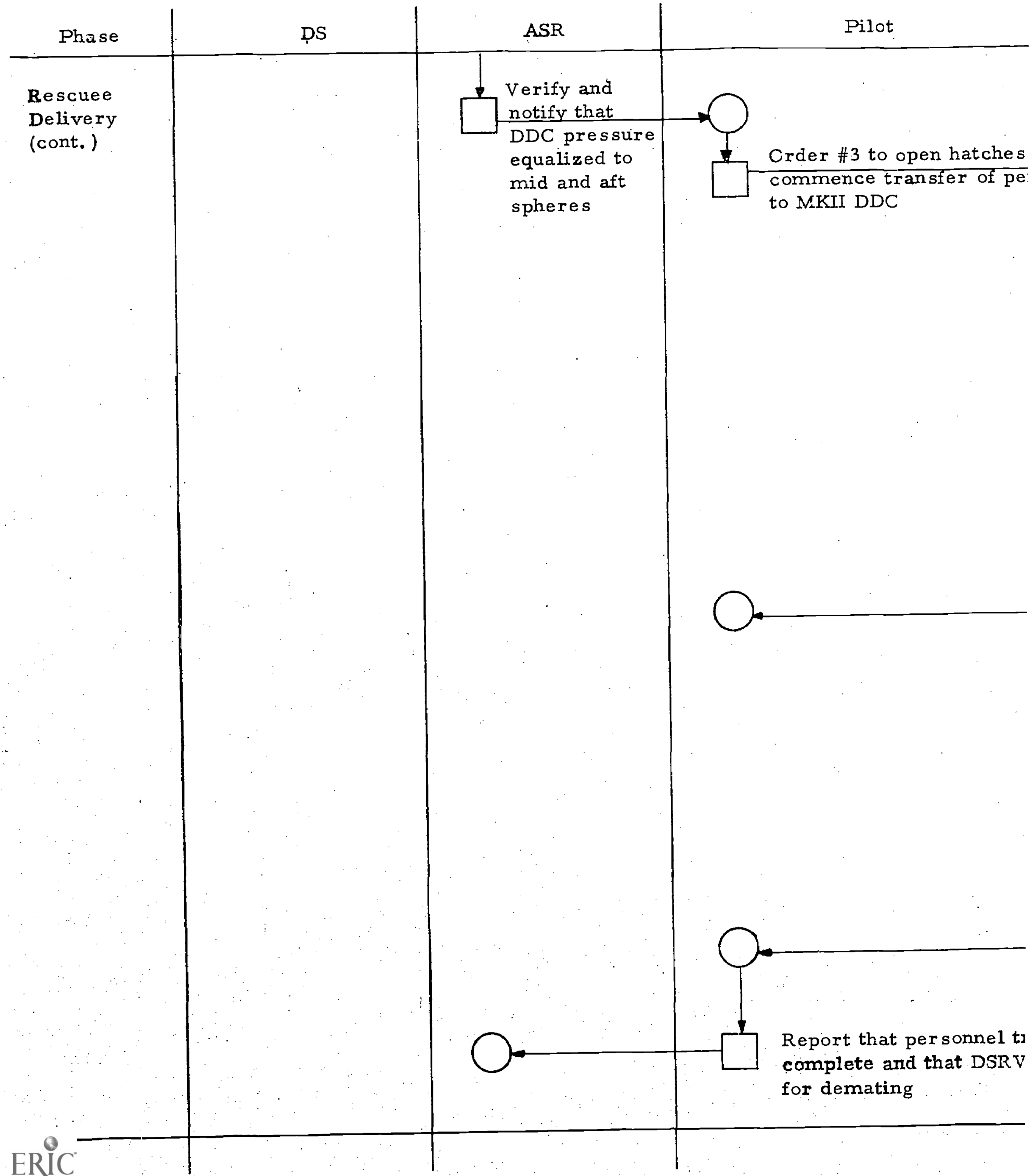


Figure 3. DSRV Rescue Mission, ASR In Support (Part 13 of 15 Parts)


Phase
DS
ASR
Pilot
Rescuee Delivery (cont.)
Verify and notify that DDC pressure equalized to mid and aft spheres
Crder #3 to open hatches
commence transfer of pe
to MKII DDC
Report that personnel t
complete and that DSRV
for demating

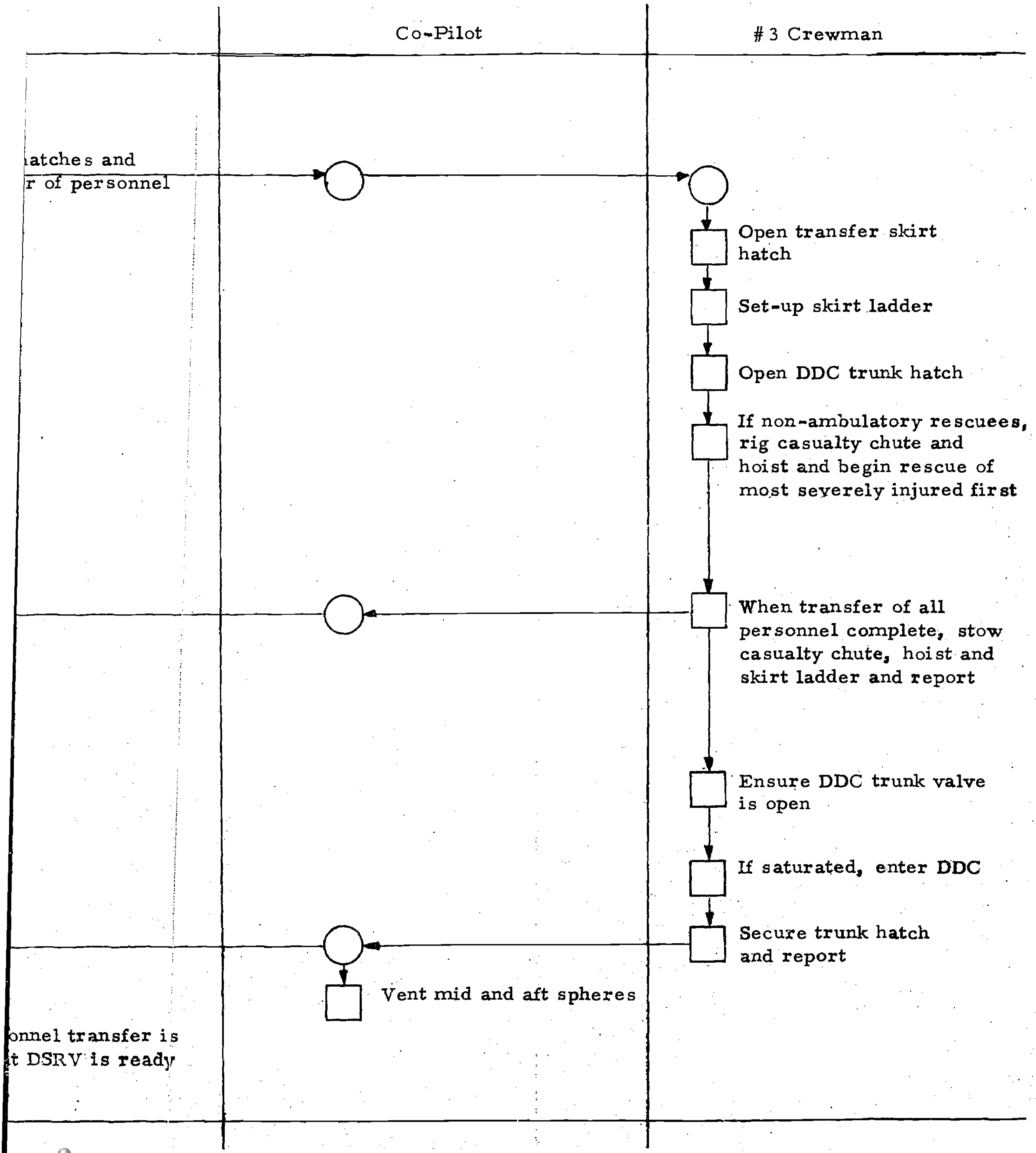
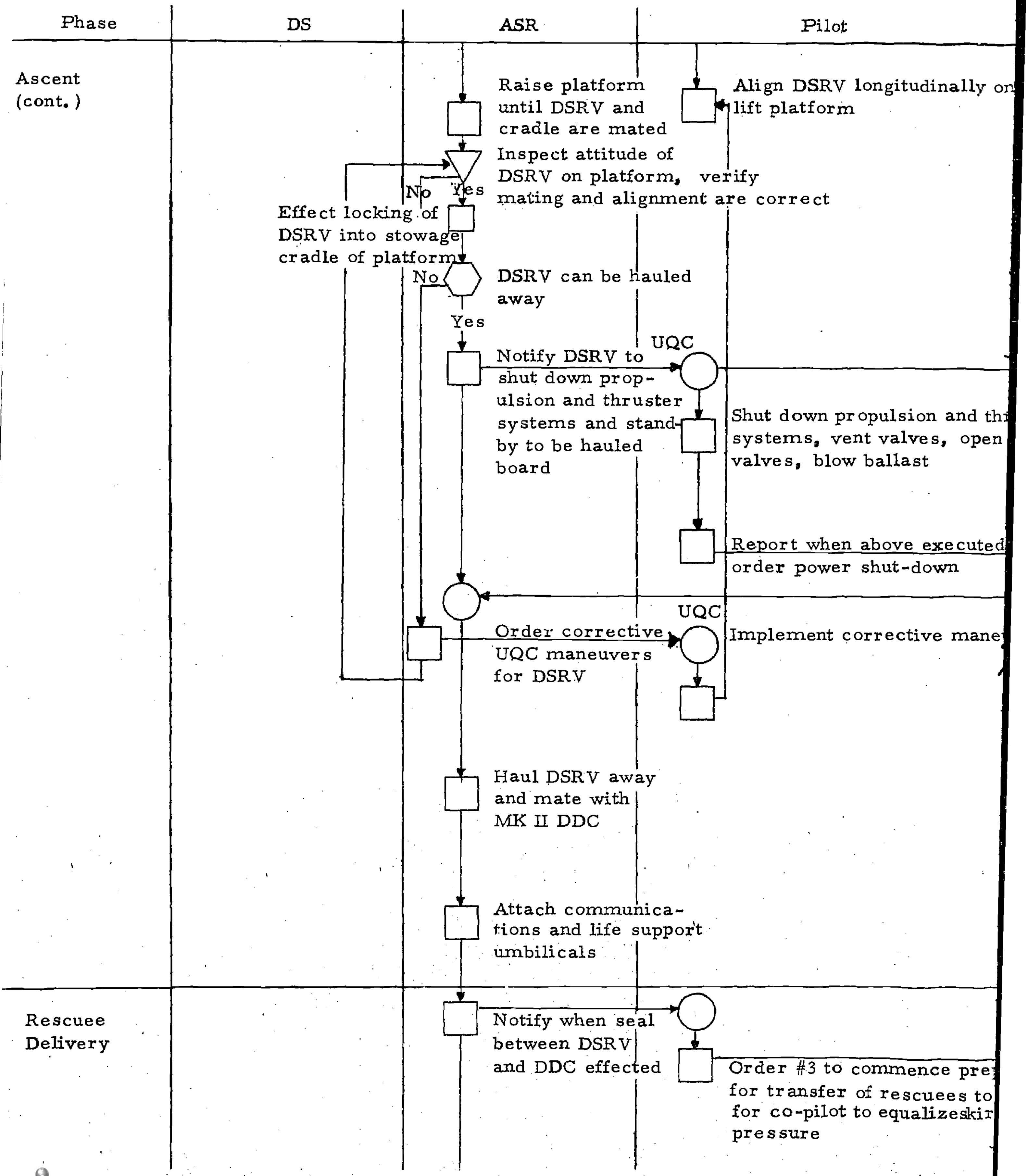


Figure 3. DSRV Rescue Mission, ASR In Support (Part 14 of 15 Parts)


Phase
DS
ASR
Pilot
Ascent (cont.)
Raise platform until DSRV and cradle are mated
Align DSRV longitudinally on lift platform
Inspect attitude of DSRV on platform, verify mating and alignment are correct
No
Yes
Effect locking of DSRV into stowage cradle of platform
No
DSRV can be hauled away
Yes
UQC
Notify DSRV to shut down propulsion and thruster systems and stand-by to be hauled board
Shut down propulsion and thr systems, vent valves, open valves, blow ballast
Report when above executed order power shut-down
UQC
Order corrective UQC maneuvers for DSRV
Implement corrective mane
Haul DSRV away and mate with MK II DDC
Attach communications and life support umbilicals
Rescuee Delivery
Notify when seal between DSRV and DDC effected
Order #3 to commence pre for transfer of rescuees to for co-pilot to equalizeskir pressure

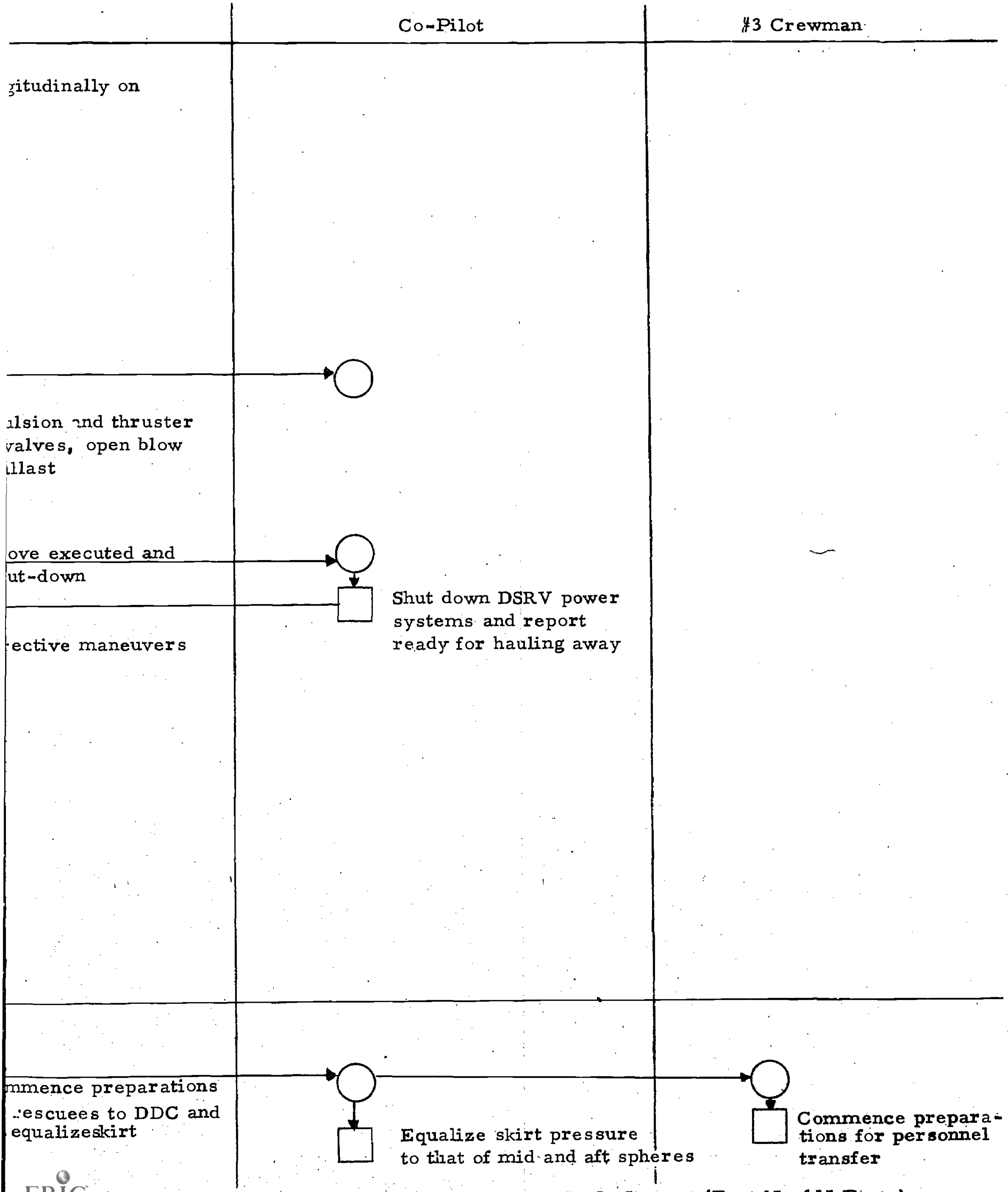


Figure 3. DSRV Rescue Mission, ASR In Support (Part 15 of 15 Parts)

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13. ABSTRACT

The study reviews man's involvement in undersea salvage operations as conducted by the Navy and defines the relevant training requirements. Naval Salvage Systems are mobilized from specialized and general purpose equipments. The configuration of any salvage system is determined by the salvage task. There are no "standing" salvage systems; rather, there exists a multiplicity of components and personnel of various abilities from which an ad hoc salvage system is mobilized. Divers represent an important capability. However, the work usefulness of divers is attenuated at deeper depths and by the complexity of the required life support systems and other equipment. One-atmosphere submersibles offer an alternative capability. A considerable variety of surface ships, submersibles, diving systems and underwater tools is available. A descriptive model of the mobilization of these resources at a salvage site is offered. The following recommendations are derived from this descriptive model:

Divers must be trained in water; hence, training tanks are required. Suitable facilities are described.

Underwater systems require the carrying out of complex procedures and skilled tasks; appropriate simulators to train the required skills are necessary.

Salvage, from the point of view of the on-scene commander and his staff, is a problem-solving operation. Training is necessary and may be conducted by means of a model, an on-line computer, and scenarios depicting salvage situations.

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