DEVELOPMENT OF A TRANSFER-UNDER-PRESSURE FACILITY FOR SUBMARINE RESCUE

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ABSTRACT

The use of therapeutic decompression is well developed and practised through out the commercial saturation diving industry. This treatment is extensively recognized and supported by the medical profession and provides recovery from the adverse effects of disbarisum; the exposure to long periods of pressure change and its effect on human body tissue. Considering this and the effects on a submarine crew involved in an incident requiring them to be rescued from a submarine, disabled on the seabed, having suffered a prolonged increase in ambient pressure is a complex situation. Such an operation could well provide a rescue mission with a two fold problem of recovering the crew while still maintaining their ambient rescue pressure prior to therapeutic treatment. It is the aim of this article to identify, design and develop a portable world-wide deployable transfer-under-pressure system to deal with such an incident on board a submarine, or indeed from any form of hyperbaric environment. This will increase the safety at sea for both military and civilian submariners world-wide, providing better long term recovery chances for all survivors.

Introduction

Deep submarine rescue has for many years caused much debate within the submarine and ocean engineering worlds. Even as early as 1954 when the Bathyscaphe *Trieste* plunged to the depths of the Mariana trench on its pioneering voyage to explore some 10,000 metres below the ocean surface.[1] This adventure, in a steel sphere with only gasoline as ballast, bench marked submersible engineering and forced technological exploration to move ahead in dramatic fashion. Since then the quest for mineral wealth and military enhancement has pushed out the frontiers of this science, drawing a fine line between man and the natural hostile elements of the sea. Manned diving is now regularly carried out to 1,000 meters with divers living and working at depth in saturation.[2] This can have its cost in human terms, if an incident were to occur involving any unplanned rapid change in the carefully controlled ambient pressures. In the event of a submarine emergency taking place, with the vessel being disabled on the seabed, unable to return to the surface with its crew of approximately one hundred souls, any rescue mission could be both lengthy and complex.

Although there is only a very remote possibility of this 'worst case scenario' ever occurring,[3] it is possible that during the grounding phase of such an incident damage to the submarines pressure hull could well result. In consequence, failure of high pressure systems and/or leaking sea water into the vessel could raise the ambient pressure on board. This would potentially lead to the crew having to survive within their escape compartments at an ambient pressure in excess of 2 bar and as such would become air saturated over the prolonged period before a rescue mission could be effected. The treatment for this, and indeed any over exposure to disbarisum, requires slow controlled therapeutic decompression[A] to ensure full recovery from any potential long term effects of decompression sickness.

Preamble

In the event of any such emergency happening in North European waters the Royal Navy has, since 1983,[B] provided a complex rescue management system headed by the submarine escape committee (SM514) of the MoD(N). Within this 'think tank' the ethics of submarine escape and rescue are formulated. This includes the mobilization time for any submarine rescue mission, which has been calculated at twelve hours notice for response.

Such a rescue would consist of a number of specialist RN and/or merchant ships, referred to as 'ships-of-opportunity'. These vessels can be deployed to the scene of the incident having been loaded with a manned submersible (LR5) and a Remotely-Operated-Vehicle (ROV) namely *Scorpio 45*. This, together with portable eighteen man decompression chambers, each with individual support facilities and a team of specialist operators, engineers, divers and submariners would make up the rescue team. Once over the located disabled submarine (DISSUB) the ROV would inspect the submarine for damage. Then passing vital stores into the submarine in order that a safe breathable atmosphere may be maintained, i.e. oxygen candles, along with medical stores transferred in special containers. From this initial survey LR5 would then be deployed on a rolling cycle of rescue transfers to recover the crew from the DISSUB to the safety of the surface mothership. As yet only three survivors per journey is possible due to he limited size of the rescue compartment within LR5. The dry transfer of personnel from the DISSUB to LR5 is made possible by the use of a 'dry-mate' skirt that fits to the underside of the submersible allowing for escape hatches to be opened.

Having returned to the mothership LR5 will be secured into it's holding cradle from where the survivors can be transferred for medical care and decompression treatment. It is at this point that holding of the survivors at their transfer pressure is vital to avoid any further step decompression (one small step having already taken place due to the dead space between the DISSUB escape hatch and LR5).[4,5] This has also been highlighted by the public enquiry into the Piper Alpha disaster.[C] Thus any rescue mission that would follow this type of incident must take into account the effects of exposure to pressure change, ensuring that any decompression that is undertaken with probably traumatized survivors, is stringently controlled within a decompression chamber and managed accordingly.[A] Such treatment will provide prolonging and full recovery from unnecessary injury and can best be achieved by ensuring that once on board the mothership the transfer from the rescue submersible to the decompression chamber is carried out through a pressure transfer system.

Aim

In an effort to maximize the effectiveness of a rescue mission of this type the provision for a Transfer-Under-Pressure (TUP) facility, between the rescue submersible (LR5) and the decompression chamber (RCC) should therefore be identified. This need has also been recognized by the National Hyperbaric Centre.[6] Having established the need for such a system within the hardware available to a rescue organization, a system with a more flexible orientation should be considered. Also an option that the system can be mobilized for transportation either national and internationally will provide an invaluable and improved tool for this complex mission. It would also seem that containerization of such a unit would assist with its response time and adaptability for sea or air portability. The need also to assemble such a system on board the chosen vessel of recovery must be high on the agenda of design features.

Objectives

To design a TUP system using the extremities of the dry-mate skirt of LR5 at one end to the interface with the man-lock door of the Royal Navy type 'B' decompression chamber at the other. Due consideration for this system must be made for both air and road transportability with a high degree of flexibility to ensure deployment on a variety of 'ships-of-opportunity'. This will consolidate in a system that will increase the safety at sea for submariners and give long term full recovery for survivors from a hyperbaric rescue situation on a global basis, and eventually encompass all NATO and commercial fleets.

Literature survey

In order to gain the feelings and philosophies of submarine rescue and pressure transfer systems a literate survey has been carried out. It is easy to gain a romantic image of the oceans that surround our shores, but it is their depth and power that provide probably one of the last great frontiers that this planet has to offer. Indeed it was President Kennedy who, in 1962, referred to the hidden ocean floors that cover the earth as our 'inner space'.[7] There have been many passionate reports that have charted the pioneers on their journeys into this deep inner space. This includes Cook,[7] who notes:

> "We have seen more of the surface of the moon than we have of the seabed covering three-quarters of our earth's surface".

The more technical aspects to this dream have been covered in greater detail by, Wood and Lythgoe,[1] who identify just how many sciences have benefited from deep sea exploration.

More recent reports,[8] emphasises the commercial and scientific benefits of continued deep sea exploration. The new materials and techniques of manufacture for submersibles have increased the depths of such exploration up to 10,000 meters, the deepest point on the ocean floor with a pressure equivalent to eight tons per square inch. Operating to such depths comes with the promise of pushing out the forefront of science for the few who would face this challenge.

To deal with an emergency on board a submarine, the Royal Navy has spent much time evolving escape plans and providing on board escape equipment. Research that has been carried out,[3] which investigates and defines the policies of both rescue, escape and some of the issues of a pressure rise within the hull of a disabled submarine. Interestingly, in their conclusions, many questions are posed regarding the increase in escape capability from a pressurized submarine. This together with the need to increase the surface survival capability to escapees is also commented on. As such, submarine rescue has for many years been an important issue for the Royal Navy and the nation's submariners. Such research is now well established in the world of deep sea exploration and any such rescue mission should cater for the need to provide a TUP system for evacuees of a submarine, or any other hyperbaric system. This has now become an issue of great importance but one which is not yet provided for.

Dean[4] of the Institute of Naval Medicine (INM) has provided valuable insight into the effects of pressurization on the crew on board a disabled submarine. It is firmly believed that the maximum pressure that could be expected in such an event is 5 ATM (atmospheres) which provides a bench mark within any design consideration for a TUP system. The need to flush/refresh the atmosphere inside any reception facility is highlighted due to the contamination that could arise, such as pyrolysis and chlorine which may be present and of course the effect of any reactor leakage. The papers from INM suggest a possible portable decompression facility to cope with such a problem. However, this does not take into account some of the fundamental engineering practicalities of manoeuvring such a facility on a moving platform in a high sea state, along with many other points.

Although recognizing the need for a TUP system, LIDDLE[6] did not deal with the evacuation from a submarines. A point raised on page 208 of his paper discussed the future need for portability of such a systems. This was again echoed by the public inquiry into the Piper Alpha disaster[C] and is amplified by The Diving Operations at work regulations.[D] These publication have given more weight to the arguments that such a system should be capable of being both air and road transportable and deployable on a variety of ships.

Commercial information has already been gathered from Holden Offshore Limited who have considered the practicality of transferring personnel from a submersible into *Challenger*'s saturation diving system (*Challenger* being the ex-RN seabed operation vessel decommissioned in 1988). This information together with drawings from Slingsby Limited[E] has provided more valuable information on the state of current available technology. Also a study by Slingsby Ltd has been made available that covers modification proposals for the submersible LR5 which looks at the feasibility of increasing the payload from three to eight evacuees, plus one bellman or attendant, in the diver lockout compartment. An intended TUP system design must therefore be able to cope with this extra number of personnel. Such a modification would also increase maximum working depth of LR5 to 457 meters. Consideration must also take this fact into account for the increased pressures at that depth, such as the strengthening of the spool piece which would mate with the transfer system. At present this component is only capable of withstanding an internal pressure of 0.6 bar. The increasing overall weight and length of LR5 has also design implication. The cost of such a modification would be in the region of £790K.

The literature survey has provided additional scope and depth of knowledge both on and around the focal subject leading to a better understanding of technology currently applied to the deep sea environment. This investigation has also made good use of engineering papers made available via Compendex data base of Portsmouth University. Meeting with the teams who would have to deploy with and operate alongside such a system and those who would benefit from it's construction, has provided a valuable insight into the challenge ahead. A visit to Rumic Ltd, who manage LR5 for the Royal Navy, has helped recognize the operations involvement of this submersible together with the thoughts of the pilots whose skills would be called upon to dock LR5 with the disabled submarine. Visits and meetings with the management staff of the Superintendent-of-diving, Portsmouth, who would coordinate the therapeutic decompression, has also provided much useful background knowledge.

Design and build phase

The task of designing such a system can thus be undertaken and clear bench marks formulated. The number of decompression chambers that are available on board the mothership may also vary in number. This therefore highlights the need to ensure that the system is not degraded if only one chamber is on site, yet the system may be required to handle up to or as many as six.

To persuade the MoD that such a system is required for safety at sea is one thing, to persuade them to invest in such a venture may be an interesting and entirely different problem in itself. However, for the ease of deployment and assembly the use of commercial ISO containers that will fit onto twist lock trailers seems a sensible method for transportation. Companies that deal with the manufacture of hyperbaric technology should be targeted and investigated for refinements to construct the necessary hardware between the interfaces stated. This will ensure the wheel is not re-invented.

Limitations

The guidelines as set out in the statuary regulation and written codes of practice listed in the references should be adhered to. The limitation of the additional payload on board the mothership used for as the rescue should be calculated carefully together with the reserve of buoyancy of these vessels. The vessels free deck area for additional equipment layout and weight distribution which will need to be formulated for the ship's Master prior to loading. A list of suitable vessels has been identified by Rumic and are given at Table 1.

TABLE 1—*Suitable 'Motherships'*

Name	Owner	Deckspace m^2
Abeille Supporter	Abeille International	155
Alert	Cable & Wireless (Marine)	60
Aquamarine	Ocean Technical Services Ltd	511
Bar Protector	European Marine Contractors	800
British Magnus	Vector Offshore Ltd	520
British Viking	Vector Offshore Ltd	520
Buccaneer	Sondenfjelds-Norske	485
CSO Alliance	Coflexip Stena Offshore Ltd	550
Discovery	SubSea Offshore Ltd	1200
Fennica	Ugland Offshore A/S	1045
Flex Installer	Coflexip Stena Offshore Ltd	750
Flexservice 3	Cable & Wireless	880
Highland Fortress	Gulf Offshore	600
HMS *Belos*	Swedish Navy	400
Iolair	BP Exploration Ltd	2500
Kommander Amalia	Hays Ships Ltd	225
Kommander Michael	Hays Ships Ltd	110/120
Kommander Subsea	Hays Ships Ltd	130/150
Kommander Therese	Hays Ships Ltd	110/120
Lorelay	Allsea Engineering bv	1000
Lowland Cavalier	Lowline Shipping	528
Nexus	Cable & Wireless (Marine)	2300
Nordica	Ugland Offshore A/S	1045
Norlift	McDermott Subsea Contractors	1200
North Sea Surveyor	North Sea Surveyor A/S	300
Northern Surveyor	Saevik Surveys, Fosnavig	50
Northern Prince	UDI-Wimpol Ltd	337
Northern Explorer	McDermott Subsea Contractors	400
Ocean Stephaniturm	Oceaneering Int Services Ltd	284
Oceantech Yeoman	Ocean Technical Services Ltd	50
Rockwater 1	Rockwater Ltd	550
Rockwater 2	Rockwater Ltd	550

Saipem Ragno Due	Saipem SpA	872
Salmaid	MoD(N)	46
Salmaster	MoD(N)	46
Salmoor	MoD(N)	46
Seaspread	Cable & Wireless	800
Seaway Commander	Stolt Comex Seaway Ltd	250
Seaway Condor	Stolt Comex Seaway Ltd	850
Seaway Harrier	Stolt Comex Seaway Ltd	1000
Seaway Osprey	Stolt Comex Seaway Ltd	850
Seaway Pelican	Stolt Comex Seaway Ltd	600
Skandi Surveyor	Okland	250
Sovereign	B.T. Marine Ltd	500
Stadive	Barclay Mercantile (Shell)	700

Design limitation/performance requirements

In order to establish more fundamental detail for the design of this TUP system, it is essential to outline the performance requirements and limitations that the system will be required to undertake and perform during its effective working life. This will include being fully operational, from a dormant or 'stand-by' position, within a reaction time of 12 hours after being despatched onto the mothership. Once mobilized the system is to be capable of continual use for 24 hours per day, for up to a 14 day period operating in arduous sea conditions with a heavy salt water atmosphere. The system should also be capable of transferring a maximum total number of 190 personnel from the DISSUB.

The environmental conditions that the TUP system will be required to endure and operate within are as follows:

- Sea state of up to force 6, with a wind speed of 35 knots.
- An ambient air temperature of $-30°C$ to $+40°C$.
- The desired average turn around time for LR5 is to be taken as 90 minutes from launching on board the mothership, docking with and recovering survivors from the DISSUB, then surfacing and docking with the transfer system.
- The working pressure of the system is to be designed at 5 bar with a safety factor (or test pressure) of 1.5 times the working pressure. The maximum working pressure has been calculated in conjunction with information from the INM.[4] This has taken into account the maximum hydrostatic rescue pressure that could be expected which has been calculated as follows:

  The relationship between hydrostatic pressure and the depth of submergence in sea water is given by the formula:

  $$P= 0.1025H+2.9\times10^{-7}.H^2$$

  Where:

  P is the pressure in Kg/cm^2
  H is the depth of water in metres.

It is also important to identify that the TUP system is not for the use of decompressing survivors itself. The decompression stage will be undertaken in the decompression chambers provided on-site and under specialist supervision.

Depending on the nature of the rescue mission it is possible that the DISSUB may be lying on the seabed at an angle of more than 30 degrees. In this case an adapter, wedge shaped, distance piece will be fitted directly to the dry-mate skirt of LR5. This will provide an extra 15° to the hover angle for the submersible. Due consideration must be given to this and to its own mating face with the TUP system.

General design aspects that must be focused on and overcome are:—

(*a*) The interface between LR5 and the TUP system.

(*b*) The interface between the TUP system and the RCC(s).

(*c*) The transfer of survivors between the interfaces.

(*d*) The control of the 'environment' within the TUP system.

(*e*) The practicalities of deployment from on board the mothership.

Safety will be an essential requirement in order to gain approval from current Lloyds statutory regulations. These features will be fitted along the transfer system and will take the form of interlocks which will ensure that the opening/closing of all hatches can only be undertaken when the pressure to either side of the doors are equal; plus or minus 0.25 bar. Thus avoiding any inadvertent loss of pressure in the system that could lead to an uncontrolled decompression step. A situation that could prove fatal to any transiting survivors.

The downward thrust due to the weight of LR5 onto the support cradle will be 22.5 Tonne and more in the case of the modified variant. Added to this are the forces acting due to the changing thrusts resulting from the rolling/pitching effects of the sea conditions. There will also be forces acting during pressurization over the area of the escape hatch and the dry-mate skirt locking interfaces.

Basic construction

To deal with the design concepts that are posed by this project the construction of this system will be considered as a whole layout between the interface with the dry-mate skirt of LR5 and its termination at the coupling with the decompression chambers.

An overview of the TUP system components as laid out and assembled is as shown in (FIG. 1) and consists of the following:

An inverted 'T' shaped section or Transfer-Docking-Section (TDS)

A proposal for this unit is shown in (FIGS. 2&3). The TDS will provide the mating face with the LR5 skirt and will allow for access into the main pressurized trunking sections. Exit doors are to be provided either side of the Alert- Docking-Support-Cradle (ADSC) (so named due to its design with the cable ship *Alert*), which will generally face the port and starboard sides of the mothership. This will allow for the submersible to be recovered over the stern of the vessel and give space at the forward end for the submersible alignment and handling equipment. Sufficient internal room must be given for a 'skid' type stretcher to be handled between the submersible and the trunking in order to deal with survivors that are unable to make their own way into the main system. The top gas tight hatch should be designed to allow for the re-launch of LR5. This will ensure the least possible delay in the cycle time for each rescue journey, while still allowing for survivor transfer through the system. A pressurization method, to supply compressed air into the skirt

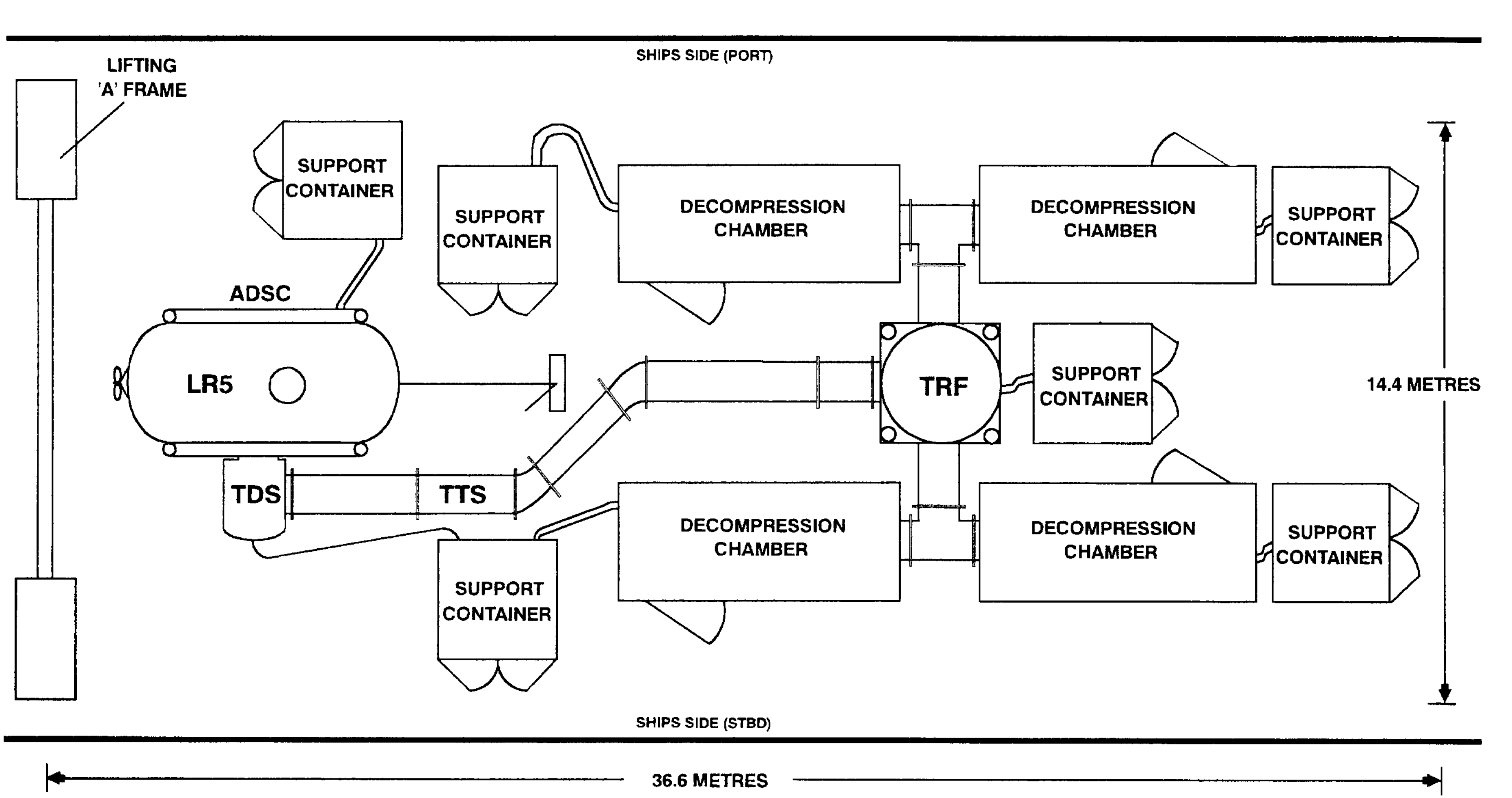

FIG. 1—GENERAL TUP SYSTEM LAYOUT

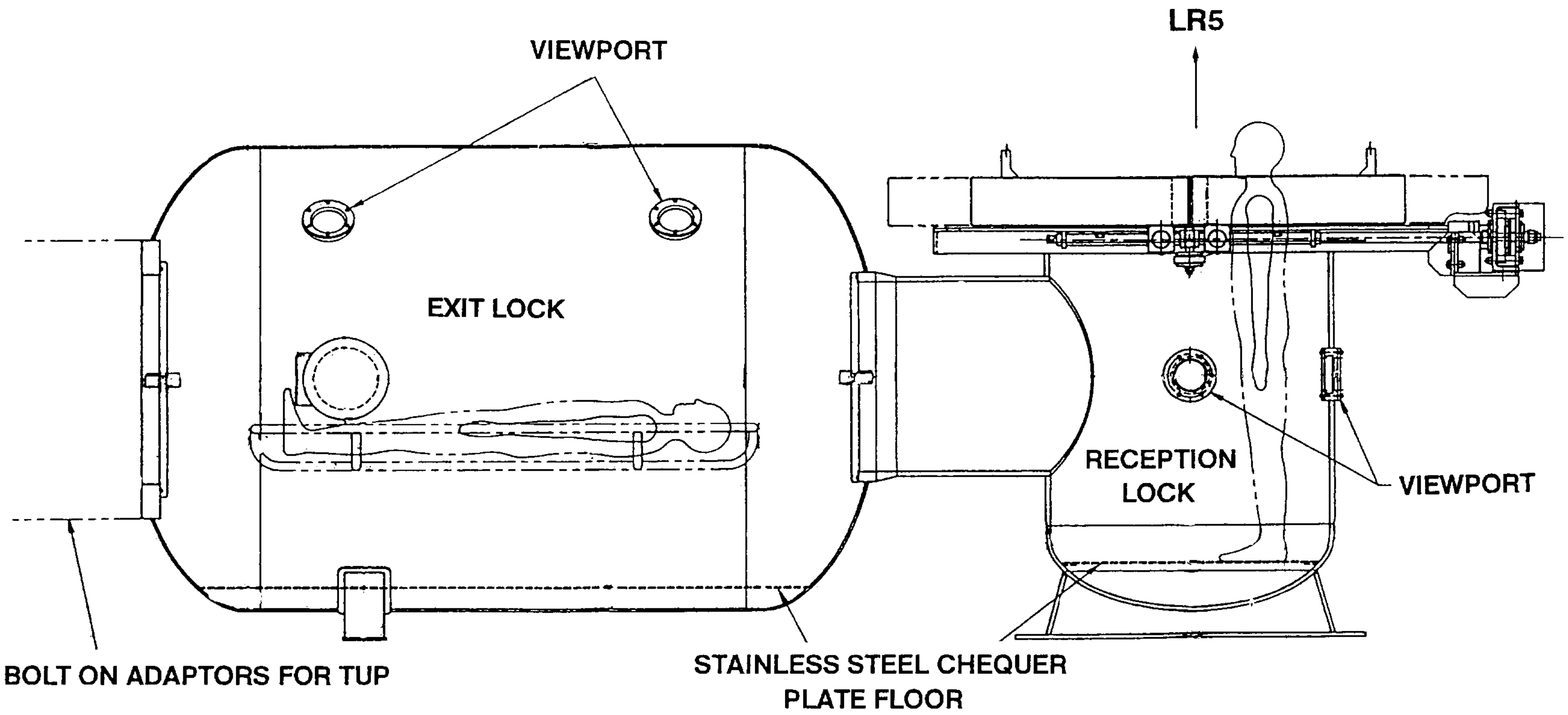

FIG. 2—PROPOSAL FOR TDS (ELEVATION)

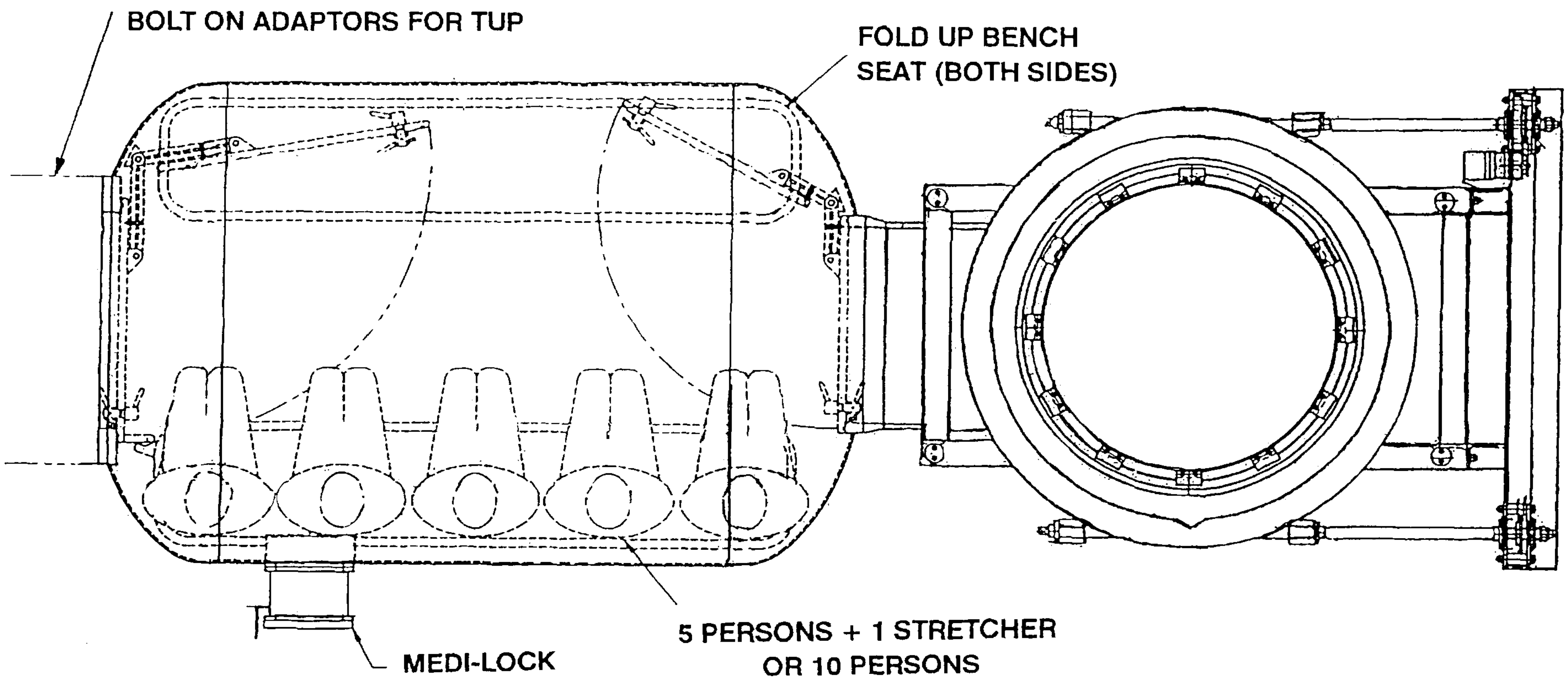

Fig. 3—Proposal for TDS (Plan)

spool space between LR5 and the TDS top hatch, will be required to enable system equalization.

The Transfer Trunking Sections (TTS)

The TTS sections will consist of trunking that will have to have a flexible configuration so as to cope with the differences in design and deck lay-out, depending on the mothership that is made available for the rescue. The trunking will need to be supplied in a variety of section lengths with a selective number of bends that can cope with system orientation. These sections will in turn lead to the interface with the Transfer-Reception-Facility (TRF). Trunking will also be assembled from the TRF to the Royal Naval type 'B' 18 man RCC. However, an adapter will be required to fit to the clamping ring of the outer door of the RCC and will need to be designed and identified separately.

The TRF

The TRF will essentially be the nucleus of the system. An area where the survivors can be warmed, medically examined and even given a change of dry clothing before entering the decompression chamber for therapeutic treatment. It is crucial to get the design orientation of this area right as it is this component that will provide an access link compartment into a number of decompression chambers that will have been set-up on board.

The ADSC (Fig. 4)

The ASDC, is vital for the stable location and docking of the submersible when it is on the deck of the mothership and therefore supports the weight of LR5. Vital to the mechanical properties of this cradle is the cross members that give strength to this cradle and as such supports the weight, 22 Tonnes, of LR5. It is considered that removal of any of these cross members, in order to make way for the fitting inside of the TDS, would weaken the structure to an unacceptable level. Thus it may be considered that a new design will be required for the whole structure or to build a new cradle or frame around the shell of the new TDS.

The support containers

These will supply electrical power and compressed gas (air and oxygen) to the TUP system as it cannot be assumed that the mothership will have any ability to supply these vital services. It should also be noted that this system could be asked to deploy operationally to a shore side base in some remote corner of the globe. Support container services will consist of:

(*a*) Normal and emergency lighting.
(*b*) Communications systems.
(*c*) Camera surveillance.
(*d*) Heating system for a hot water shower unit in the TRF.
(*e*) Gas supplies for pressurizing of the TUP systems.
(*f*) Mixture gases for breathing via the Built-In-Breathing-System (BIBS).

Reference A requires that a life support decompression system, of which this system can be classified, should have its own dedicated gas supply. This gas supply will be compressed air which will have to be provided from the support container via a compressor, probably diesel driven, via storage cylinders of 9.1 cu ft. and a gas supply system which must be capable of delivering breathing air to standards given in MoD Defence Standards 68/75 Issue 3, June 1993. A fixed AC electrical generator will also be required.

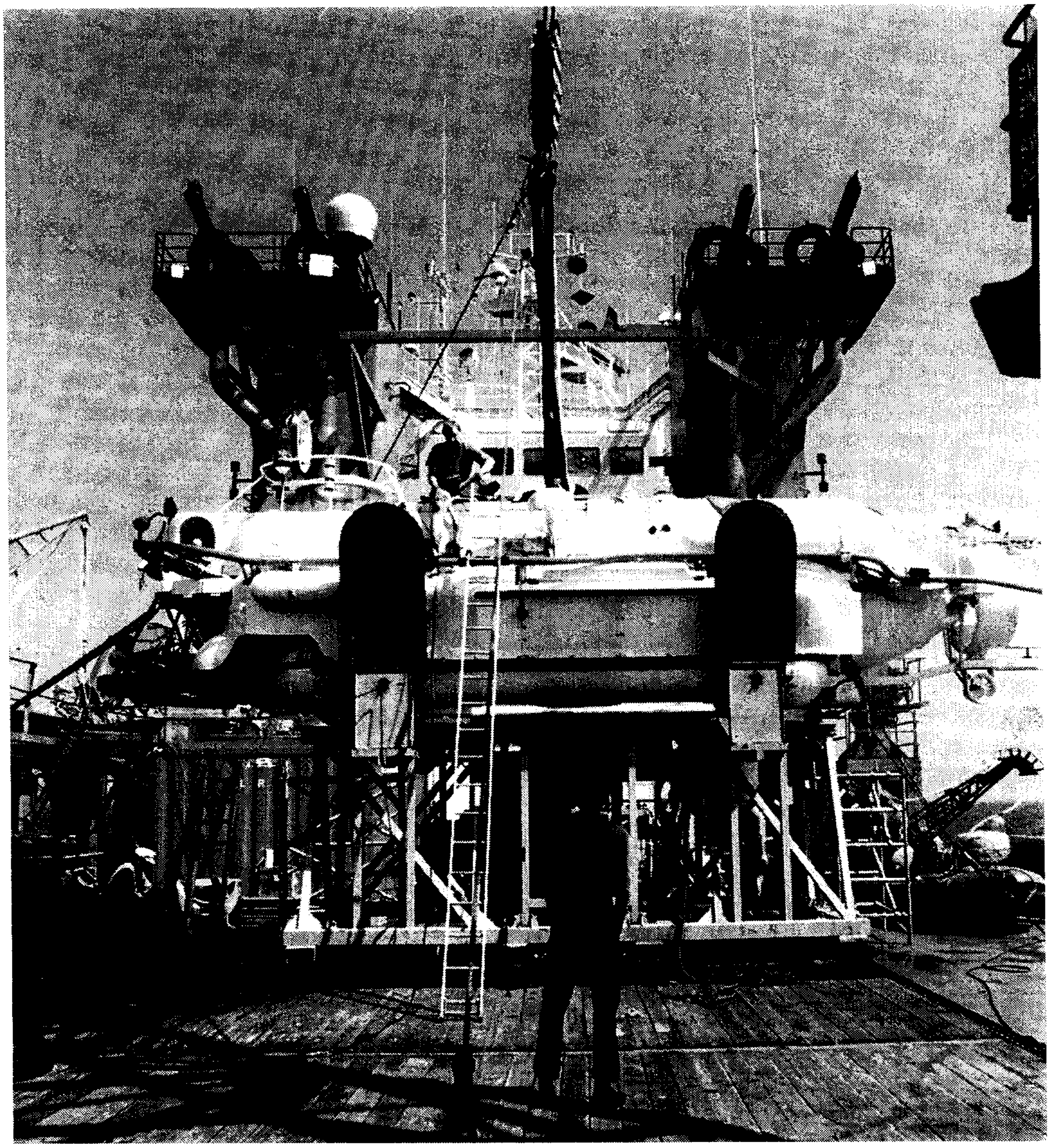

FIG. 4—LR5 SUBMERSIBLE ON ASDC

Transportation containers

These containers will be used for the dual role of acting as storage for all the system components and provide a means of standardized packaging for road and air mobility. Therefore allowing for system transportation from the despatch base to the area of deployment. Consideration for the current Road Transport Acts and Civil Aviation Authority regulations must therefore be given, together with the Royal Air Force Joint Air Transport regulations. It is also considered that the containers that will provide transport for the transfer trunking section can also provide a method of stabilizing the system on deck of the mothership. This will also alleviate the problem of stowing the containers in an already cluttered area. These containers will have to be bought-in and fitted out to carry the component parts of the system ready for on-site assembly.

In order to exit LR5 into the main pressurized system on board the mothership, a docking interface procedure will need to be established. This will involve the TDS being introduced as the docking position for the LR5. The TDS may eventually be an integral part of the docking cradle at a latter stage of development. However, the floating interface that must provide the gas tight seal as well as allowing for docking location will have a specified dimensional 'float':

10mm on the X axis and 4mm on the Y axis.

This float will help cut any docking delay time and therefore the dispatch period for survivors. This will also ensure that LR5 is not left suspended for any longer than is necessary while being docked in adverse weather conditions. The docking operation will then be dependent on the skills of the docking team and crane operators.

At the top of the TDS a manual clamping arrangement, that can be assembled and removed with a good degree of speed and that is capable of dealing with the maximum pressurisation of 5 bar (working pressure), will thus be required (FIG. 5). Three pressurization doors will also be fitted to this section. External control panels for monitoring gas pressurization, together with a video monitor, lighting and communication systems between the LR5 and the inside of the TDS will be required. A method of incorporating a clamping arrangement to deal with the 15 degree wedge shape adapter will also require to be designed.

The TRF should be capable of dealing with the throughput of up to nine survivors together with a bellman and a paramedic/medic for each trip that the submersible completes. This section will have the necessary breathing gases for use on the internal BIBS and a central control pressurization panel together with the communication and video surveillance.

Construction theory

To establish the design bench marks for the TUP system the following publications have been used as guidelines so as to ease problems that will be formed when it comes to obtaining a licence to build the system and gain Lloyd's approval. Thus ensuring that the optimum tools are available to allow for maximum system effectiveness .

Material selection

In order to select the material suitable for the manufacture of the main system component shells i.e. the TDS, TTS and TRF, guidance from the manufacturing sector, references F,G and H have be fully investigated. Having considered the options for these components the optimum strength for the task will be needed. This includes consideration that, due to the nature of the transportability and on-site assembly of the system, a light/strong material is therefore important without giving rise to unwelcome increased costs for a more exotic composite. Therefore these main components will be manufactured from Aluminium plate of a suitable size as calculated at reference I, (Part.2,Ch.1,Sec.4,Page.4) to the standards set out in British Standard in references F(part1) and G(parts1,2,3). The main structures will be formed and welded to the finished shape before non-destructive test inspections.

System mothership deck lay-out

The deployment of this system will greatly enhance the facilities available for a submarine rescue mission. Operational success, is in part, attributed to the ease of construction helped by minimum assembly time once embarked on board the chosen rescue vessel. Designing around this construction concept is therefore essential and deemed to be defined as the points from arrival on the quayside to the loading and full component assembly. Considerations have to be taken on the reserves of buoyancy available within the mothership

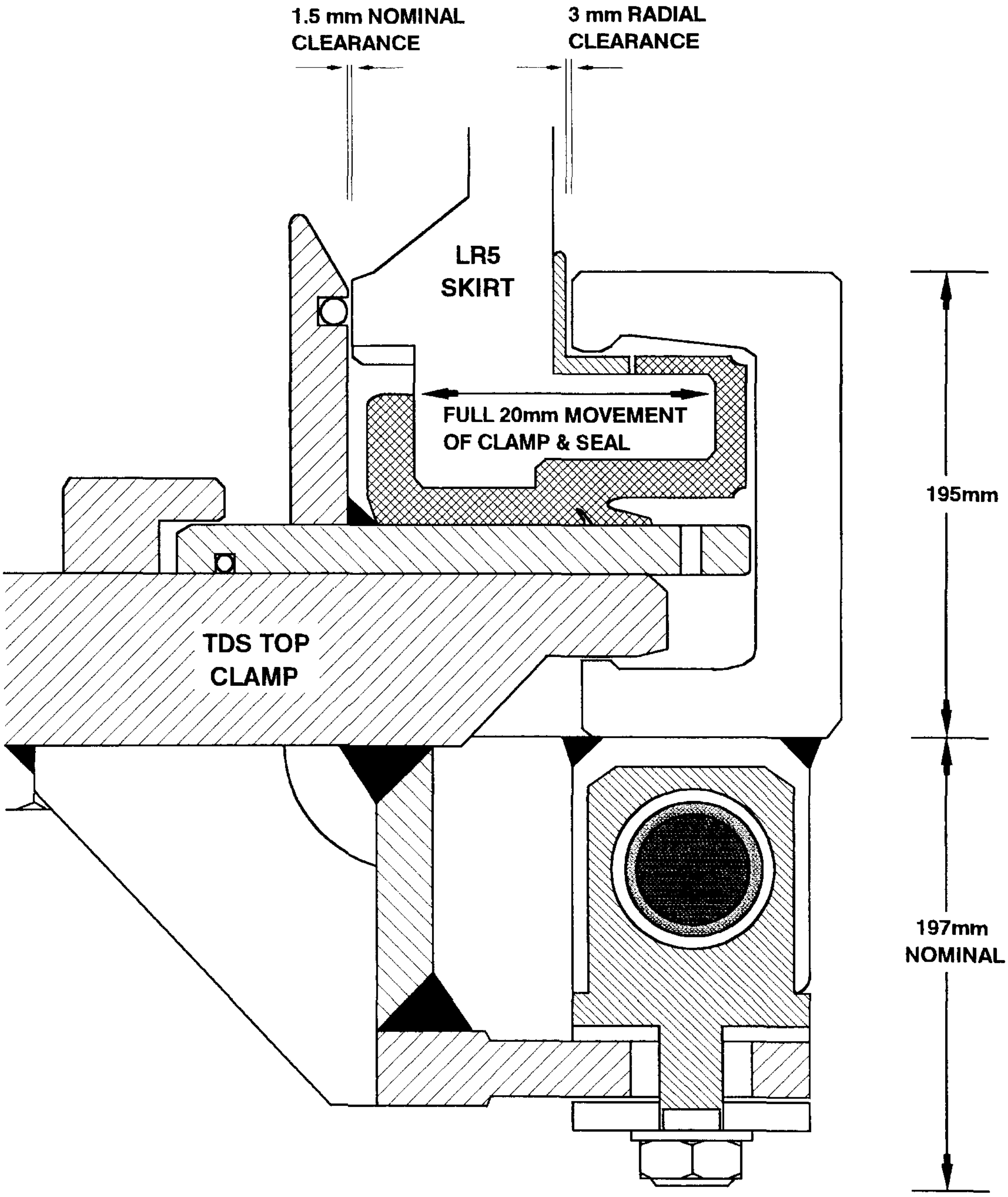

FIG. 5—TDS DRY-MATE COUPLING

for the carriage of this extra load of approximately 100 Tonnes. This extra top weight would also alter the ship's stability by reducing the metacentric height. Added to this, each ship will have its own deck layout. As such the free deck area may have additional clutter such as deck handling equipment that cannot be moved, but must be worked around.

All things considered the layout that seems to be more economical with the precious deck space available, whichever rescue mothership were to be deployed, is the 'H' shape configuration, as shown in FIG. 1. This will also allow for the central balancing of this large extra payload. Also it will give the opportunity for expansion or contraction to this fully integrated and flexible system. The central 'H' type theory would allow for a TRF to be used for establishing a triage area for survivors by a paramedic/medic or doctor.

Construction

Each unit shell will have its own environmental control ability. This will consist of flushing valves that are able to refresh the air within the individual areas, without causing any variation in pressure within that section. A radiation monitor should also be fitted to the TDS should this be a feature of the rescue scenario.

The TRF will give direct access to the 18 man RCCs via a short length of TTS. The structure of this will be of a spherical shape with three main access doors. One leading from the TDS transfer trunking and two doors leading to and connecting with the RCC. This configuration of doors should allow scope for the differing number of RCC's that could be available. A support structure will enclose this component in an aluminium tubing frame which will help stabilize the TRF in position on deck. This unit will also allow for storage of breathing gases around the base of the frame for use with the BIBS system. A service hatch, to pass food and medical items will also be fitted. Three fold-down seating benches should be fitted between the door areas to give a rest area for survivors and allow for a better chance of medical examination. The fitting of a shower will help rinse off possible contaminants from survivors prior to entering the RCC's.

The gas system carrying the driving air for the TUP system pressurization should have a maximum working pressure of 276 bar down to 20 bar at the pressurization valves. Pipes will be run in Tungum Alloy to BS.1306 or stainless steel to ASTMA312-GR316L. The pipe fittings to be of 'Tiple-Lok' type with JIC threads, as approved by Lloyd's Register of Shipping.[K]

The TTS connecting the main sections i.e. the TDS, TRF and the RCC's will require stability once assembled on the deck of a ship, this is critical for system safety and pressure integrity. The system must therefore be restrained from the rolling action in a high sea state. The trunking must also be manufactured in section lengths no more than three metres to aid handling during assembly. The inside diameter will be 860mm to align with the requirements of the man-lock entrance door with the RCC's. Due to this height limitation set by the centre line of the door into the RCC and the TDS, strengthening stands will be required to support the lengths of TTS and these must have some degree of adjustment to take up small deck misalignments from ship to ship.

A spider collar type flange will be welded on each end of the TTSs with a mating clamp ring that can be turned through 30 degrees to lock the sections together. The flanges will have two external groves to carry torodial sealing rings to form a gas seal. As the trunking will essentially be a crawl-way the bottom 20% of the curve will have a flat grid floor to help ease the personnel transfer and provide the base for a stretcher slide to cope with the more traumatized survivor. Under the grid flooring will run the pressurization pipe work for each length.

Service penetrators will provide a gas tight seal and carry services through the wall of the TDS, TTS and the TRF. This will allow for the provision of:

- Fire proof electrical lighting
- Gas/air pressurization inlets and exhaust systems
- Flushing vent system
- BIBS, which must have an overboard dump 'vent to atmosphere' system in order to meet the requirements of reference A.

A fibre-optic camera/communications system will be fitted to increase system safety and allow for open-line communication between inside and outside of the system.

Conclusions

This article has gone some way down the road towards developing and implementing a fully integrated and flexible TUP system to help with submarine and/or hyperbaric environmental rescue situations. It takes into account the effects of pressure (air saturation) on survivors and identifies the advantages for having such a system nationally and internationally deployable. This system will enhance the safety at sea and help to continue the close liaison between the submarine rescue service, RN diving and engineering while providing benefits for each organization. It is, however, true that due to the restraints, limitations and share size of the project the aims and objectives cannot be described as being fully achieved. Nevertheless, the challenges have been fully faced and much of the ground work has now been covered clearing the way for progression into the next stages of development. Identification of in-use technology, that with careful design manipulation, can be modified to achieve these aims and objective in full. Thus a primary tool for integration within the sub-sea rescue organization can be provided.

Implementation of such a system will need a high degree of investment for a system that is essentially an insurance policy covering a relatively small number of personnel. This could perhaps lead to a moral dilemma and it is anticipated that some strong argument will be needed to persuade the MoD to fund such a venture.

Some disadvantages that can be foreseen are that the merchant ships capable of deploying with this system may be relatively limited in number. It is also evident, due to the dimensions involved that the ADSC will need remanufacturing around the TDS.

The wedge shaped spool piece that can be introduced to the skirt of LR5, in the event of the DISSUB listing at too high a angle for the hover control of the submersible, is going to cause a good deal of design difficulty. Thus all effort should be made not to fit this if at all possible for a scenario involving the TUP system.

It should be noted that the requirements of the rescue performance limitation a crew size of 190 survivors has been quoted. This will of course require a total number of ten RCC's. The capacity of transferring this figure would be difficult to deploy on board only one system and mothership, therefore consideration for two units must be investigated.

Recommendations

Having thoroughly investigated the parameters and options for the development of this system it is considered well within the bounds of current technology for manufacture. It also seems very feasible that this system can succeed even though there is still some way to go before a fully working prototype will be seen on the hardware list of the submarine escape committee. The next stage towards seeing a system brought into operational use should therefore be promoted.

The following recommendations should now be considered for implementation to continue the momentum of this project:

- A considerable number of minute details will now need to be filled in. Ideally a small dedicated full-time team of engineers should embark on the completion of this quest. Such detail should include three dimensional computer modelling showing walk-through graphics of the system when embarked on a variety of motherships.
- Detailed drawings formulated on CAD, for each component will allow for accurate tenders to be placed in the commercial sector.
- Adequate funds also need to be made available, in the order of £790K to enable interest from industry.

- A scale module should be commissioned and promoted. This could also help gain wider interest from other navy's and help ship masters understand the system. It would also help design considerations and give a fresh angle to future rescue organisation briefs.

The need for such a system is well recognized by both the commercial and military underwater establishments. It is therefore hoped that this will in some way increase the safety at sea of many of the worlds submariners either from national, NATO or international fleets. It may also be possible to enhance the facilities that can be made available to a civilian organisation involved in the management of a situation that may have much to gain from the contraction of this type of TUP system.

It is interesting to note that the Korean Navy has launched itself into its own development programme for a system that can cope with a similar style scenario as this.

The paragraph headers shown below will have to be formulated and amplified as requirement for full investigation prior to the initial prototype system becoming operational:

- Transport considerations.
- Consideration is to be given to identifying the vehicles that will be required for mobilizing this large unit from its base to its despatch point.
- Assembly procedures.
- Containerization specifications.
- The support container design for TUP system supplies.
- Air quality of gas system.
- Quality assurance statement.
- Lloyd's certification of conformity for system use.
- Statement for pressure testing.
- Permit to work.
- Statement of system operation management.
- Risk assessment of system.
- Planned maintenance requirements.
- Slinging/tie down statement.

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