4.3 TECHNOLOGICAL REVIEW

SMERAS

(SUBMARINE ESCAPE, RESCUE, ABANDONMENT & SURVIVABILITY)

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The crew on board a downed submarine (a DISSUB or distressed submarine in accordance with standard SMERAS terminology) face far more hazards than the crew of a distressed surface vessel. To take to a lifeboat, life-raft or to enter the water is a measure of last resort for any mariner. For a submariner, other dangers have to be faced and overcome even to reach this stage. The complexity of underwater search and rescue is clearly spelled out in the *International Aeronautical and Maritime Search And Rescue (IAMSAR) Manual*, the standard, approved quick-reference guide for any seafarer who may be required to assist in such a situation: '… medical care requirements for survivors of an underwater or submarine accident is specialized and competent medical advice is required …'[1] In fact, all aspects of underwater search and rescue are more complex than an equivalent situation on the surface. These include vessel tracking, communications and alerting, search, casualty management and recovery, and – ultimately – the salvage of the casualty hull from the seabed.

Submarine forces around the world place strong emphasis on crew skills and training, the integrity of the vessel and its systems, and multiple layers of equipment redundancy. Prevention of a distressed submarine situation is infinitely better than cure. However, accidents and incidents still occur. The high levels of skill and motivation required of a submarine volunteer means that visible means of securing their survival need to be in place. Even for navies which still rely on conscription, the potential damage to reputation in losing a submarine and her crew would be considerable. For all of these reasons, a global, interlinked network of submarine rescue forces exists, which constantly strives to refine procedures and equipment. This is in response to the primary lesson learned from every submarine sinking: speed of response is king.

In this chapter, 'escape' refers to survivors exiting a DISSUB and ascending to the surface in either escape suits or escape bells. 'Rescue' refers to survivors being shuttled off the DISSUB by manned or remotely-operated rescue submersibles. 'Abandonment' refers to survivors exiting a DISSUB on the surface, and 'survivability' refers to any measure that maintains and extends a habitable environment on-board the DISSUB.

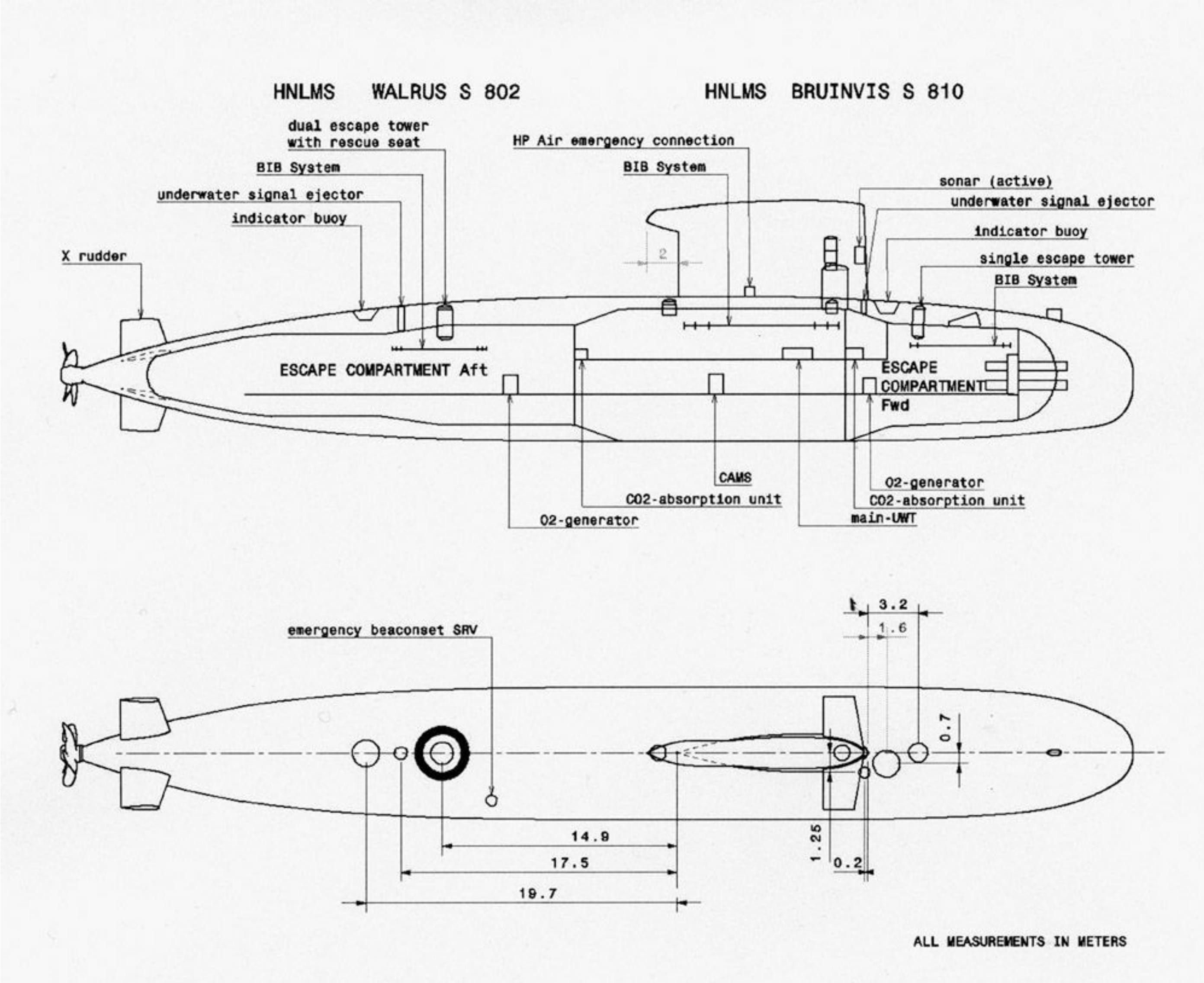
The Royal Norwegian Navy's *Ula* class submarine *Utvaer* pictured operating on the surface off the Norwegian coast in May 2015. As can be imagined, the crew on board a downed submarine face far more hazards than the crew of a distressed surface vessel. *(Petter Brenni Gulbrandsen/Norwegian Armed Forces)*

SURVIVABILITY – SELF-HELP MEASURES

Before looking at external search and rescue processes, it is worth noting that many submarine incidents are resolved by the internal resources of the boat and her crew. Submarines are constructed and equipped to demanding standards, and have high levels of survivability built in to them. Submarine hulls are immensely strong constructs, faired-in for much of their surface area under an external 'casing' that acts as an effective 'crumple zone' in event of frontal collisions. Watertight integrity is paramount; every submariner should be able to isolate every bulkhead valve on their own submarine as a matter of routine. Multiple, highcapacity bilge and ballast pumps can be quickly lined up to pump out floodwater.

In the case of a fire, it should be noted that submarine firefighting systems make more use of high-expansion foam than seawater so as to avoid compromising a submarine's buoyancy or trim. This is especially the case forward and aft: areas that tend to house the torpedo spaces and propulsion machinery, both areas of high fire risk. Moreover, if the internal atmosphere is compromised by fire or another contaminant, many submarines are fitted with a ring-main of pressurised, diver-quality air – referred to in the Royal Navy as the ‘Emergency Breathing System’ (EBS) – that can be accessed via hundreds of quick-disconnect couplings using fullface masks as used by firefighters. This will allow the crew to function effectively, if not comfortably, to provide time for the boat to be surfaced or brought to periscope depth so as to allow ventilation of the hull to be carried out. However, sometimes external support will be needed, this is considered further below.

All aspects of underwater search and rescue are more complex than the equivalent situation on the surface. Consequently thorough preparation and training – as well as effective international cooperation – are required to ensure the speedy and effective response needed to bring an incident to a satisfactory conclusion. The ‘Black Carillon’ exercise series allows Pacific Rim members of the International Submarine Escape and Rescue Liaison Organisation (ISMERLO) to test their submarine rescue capabilities. In this image, the RAN *Collins* class submarine *Farncomb* is acting as the exercise distressed submarine. The view is what either a submersible or – as in this case – the ROV pilot would see. Note that, for exercise purposes, the submarine has lights illuminated and high-visibility markings have been placed around the escape hatch to aid docking training for new personnel. *(Royal Australian Navy)*



The standard submarine search and rescue reference for NATO navies – and the 'de facto' global standard – is the open source NATO Allied Tactical Publication 57 – *ATP 57: The NATO Submarine Search and Rescue Manual.* This includes technical rescue profiles for as many submarines as possible, including diagrams showing the position of escape hatches and other equipment. This is the diagram contained in the manual showing relevant details for the Dutch submarines *Walrus* and *Bruinvis. (NATO)*

SUBMARINE TRACKING

In common with all search and rescue operations, the shorter the search phase, the greater the prospect of survivor recovery. To this end, peacetime submarine movements are closely controlled and monitored, in a manner similar to a scheduled airline flight. Operating water is allocated, along with prearranged diving and surfacing times and routine signal transmission times. In the event of several missed signals in turn – a submarine may not be able to come to a transmitting depth owing to surface traffic or sea state, or may have a defect or damage to her communications equipment – this narrows down the search area. IAMSAR procedures for a missing or overdue vessel define three phases, viz.

- **Uncertainty:** The vessel is overdue. The parallel SMERAS phase is SUBLOOK and the exercise equivalent codeword SMASHEX 1.
- **Alert:** The parallel SMERAS phase is SUBMISS and the exercise equivalent codeword SMASHEX 2.
- **Distress:** The parallel SMERAS phase is SUBSUNK and the exercise codeword SMASHEX 3.

It will be immediately apparent that a submarine deployed on operations – particularly if they are covert – will have less freedom to communicate regularly, surface or come shallow to 'snort' to either run auxiliary power or to clear out the internal atmosphere. As such, rescue forces will have less idea of the distressed submarine's position and may well not have access to conduct escape or rescue operations.[2]

The Royal Canadian Navy submarine *Chicoutimi* – the former Royal Navy *Upholder* – berthing at Faslane in Scotland in October 2004 following a fire at sea that resulted from water ingress whilst running on the surface. The fire resulted in the death of one of her crew as a result of smoke inhalation. Submarines' low freeboard means that down-flooding through open hatches is a risk that has to be guarded against. *(Canadian Armed Forces)*

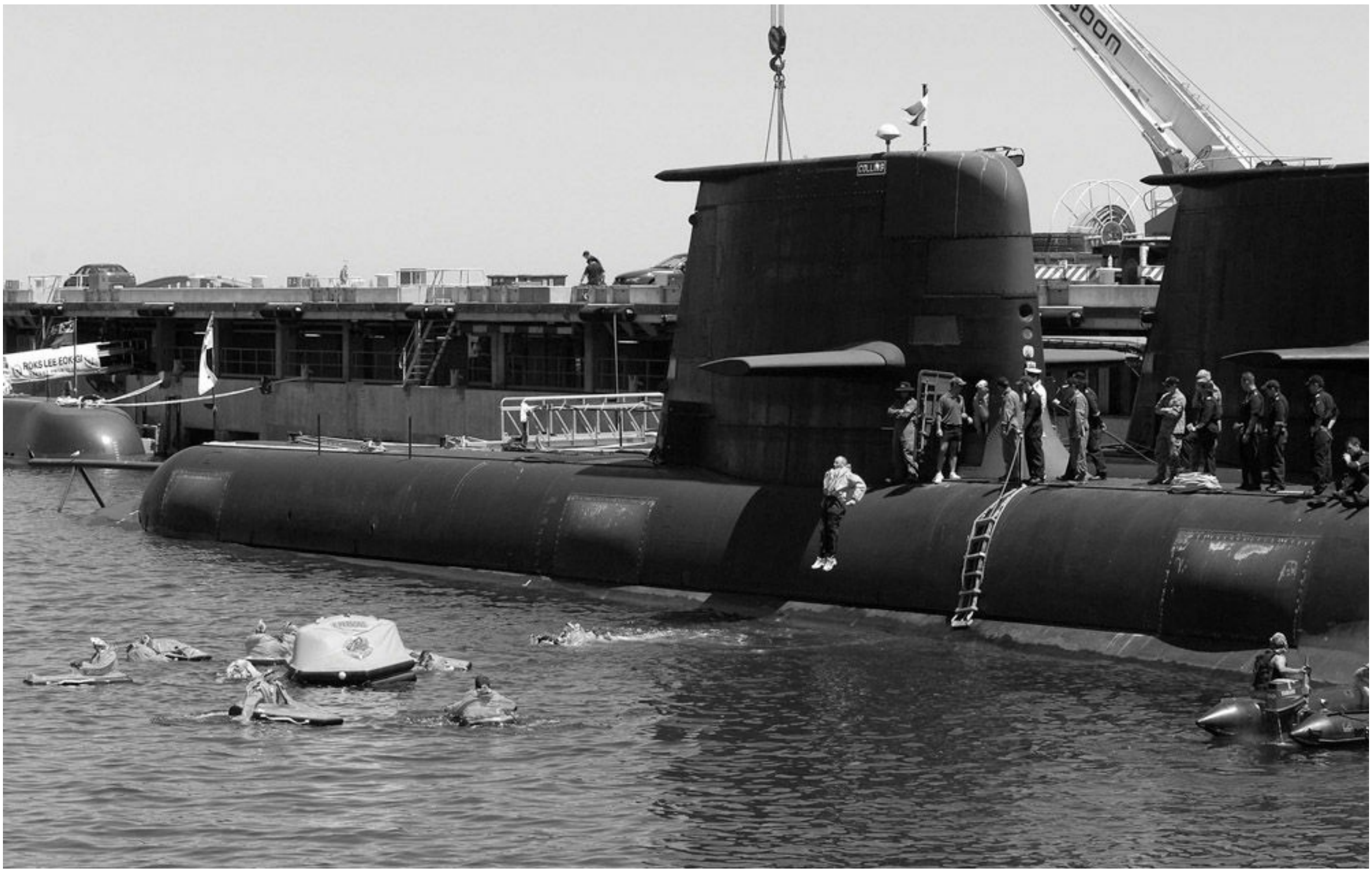
SUBMARINE SEARCH AND RESCUE: GENERAL PRINCIPLES

A key principle of SMERAS is national primacy: the nation that has sustained the loss retains operational and tactical control of the search and rescue effort. In peacetime, the nation will declare a SUBMISS/ SUBSUNK Phase through the International Submarine Escape and Rescue Liaison Organisation (ISMERLO). This maintains a protected website that allows global monitoring of unfolding situations as well as the status of declared submarine escape and rescue assets. A national submarine operating authority declaring a DISSUB situation can post updates and request assets as required.

The standard submarine search and rescue reference for NATO navies – and the 'de facto' global standard – is *NATO Allied Tactical Publication 57 (ATP 57)*, the NATO Submarine Search and Rescue Manual. This is an open-source document that sets out all the key procedures to be followed. It also maintains technical rescue profiles of as many submarines as possible, relying on navies and manufacturers making available unclassified rescuespecific data. This information typically includes internal volume, crew numbers, estimated crew endurance before air is exhausted, type and location of onboard escape stores, and external submarine plans showing positions of escape and access hatches, potential obstructions and salvage valves.

When dealing with a submarine search and rescue operation, the key initial questions to be answered by rescue forces are (i) where is the distressed submarine and (ii) in what depth of water does she lie? Modern rescue submersibles can effect a rescue from depths of up to 600m. Live, successful escape exercises have been conducted from depths of up to 200m.

It will be readily appreciated that most of the open ocean floor, the abyssal plains, rises, seamounts and trenches, all lie at far, far greater depths than this. Clearly, a distressed submarine that cannot maintain neutral buoyancy, establish positive buoyancy or drive to the surface is going to sink until the pressure hull implodes or a hull penetration fails, causing a catastrophic internal flood. However, a review of peacetime DISSUB incidents shows that the bulk occur not over the abyssal plains but over the shallower coastal margins of the continental shelves – within the rescuable and escapable depths of water. These areas are also where surface vessels are concentrated and collisions are therefore more likely.



Royal Australian Navy submariners practice a surface abandonment exercise from the lead *Collins* class submarine. Surface abandonment offers much lower risks to survivors than other forms of escape and rescue. *(Royal Australian Navy)*

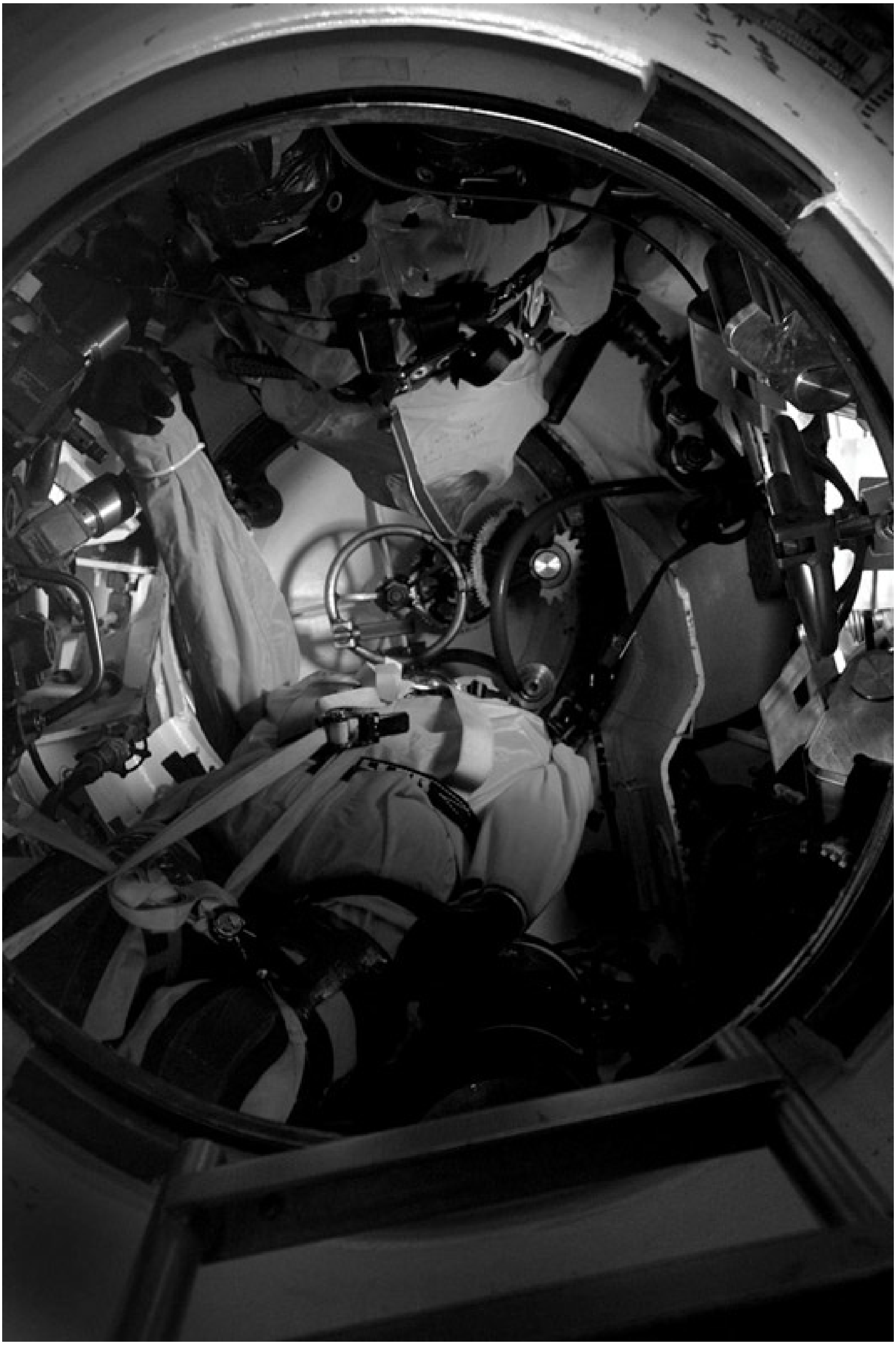
SURFACE ABANDONMENT

In event of an emergency, and assuming it is safe to do so, a submarine will aim to surface and run up auxiliary power generators and blowers to ventilate the internals and to recharge compressed air banks. This also allows crew to be protected from internal hazards – such as radiation, fire or atmospheric contaminants – by rotating personnel out of the pressure hull and onto the casing. Given that submarines have low freeboard when they are surfaced, there is a risk of down-flooding if hatches are opened in heavy seas. The near-loss of the Royal Canadian Navy's *Chicoutimi* (the former Royal Navy *Upholder*) on her delivery voyage in 2004 was a result of this. Inflatable freeboard extenders can be fitted in build or retrofitted to existing submarines' escape towers to mitigate this risk.

It may be, however, that the submarine is losing buoyancy or is otherwise untenable. In this case, the commanding officer may order a surface abandonment. Recent developments have provided specialist equipment to support this survival mode. For example, some submarine arms, such as the Royal Netherlands Navy have dispensed with indicator buoys and have used the available under-casing volume to install life-rafts that can be deployed either on the surface or when dived. Surface abandonment offers much lower levels of risk to survivors. It is becoming the preferred option in SMERAS.

SURVIVAL ON A DISTRESSED SUBMARINE

If, however, the distressed submarine is on the seabed, continued survival on board requires management of four overriding priorities. In descending order of importance, these are (i) protection, (ii) location, (iii) water, and (iv) food. Dealing with these is a complex task for distressed survivors. To simplify the process – and to aid effective, timely decision-making – a 'Guardbook' is included in onboard escape equipment. This is a sequenced process flowchart that is backed up by graphs, tables and survival instructions. The Guardbook defines what actions need to be taken in terms of making a compartment as safe as possible, how key parameters such as internal pressure, radiation and contaminants are to be monitored, how and when to release detection equipment such as pyrotechnic signals and indicator buoys, and when preparations need to be made for escape, if this is practicable



Instrument mannequins dressed in Submarine Escape Immersion Equipment (SEIE) seen inside the engine-room escape trunk of the US Navy submarine *Virginia* (SSN-774) in August 2004 during a series of pre-commissioning trials. SEIE is designed to allow safe escape from a submarine up to depths of around 200m. Survivors on a distressed submarine will become progressively more debilitated over time and this can make escape more difficult. *(US Navy)*

Protection: The survivors on board will need to try to arrest any flooding or leaks of pressurised air mains. These will drive up the internal boat pressure and, over time, saturate the bodily tissues of the survivors in a similar manner to saturation divers. Controlled decompression becomes more and more critical to survival and recovery as the duration of exposure to pressure increases. In addition, any fires, ruptures to pressurised gas systems such as nitrogen, or damage to weapons will contaminate the submarine's internal atmosphere. This could render it untenable for life, especially if the internal pressure is high. On a submarine carrying any nuclear materials, monitoring to ensure that containment systems are intact will also be required to ensure that survivors do not start to accrue a radiation dose.

To minimise oxygen consumption and carbon dioxide build-up, physical activities will be reduced as much as possible. Artificial means to keep both of these parameters within safe levels will be established from escape stores. The distressed submarine will rapidly become a cold and damp environment as its temperature equalises with the surrounding sea and condensation builds up on all surfaces.

Artificial means – such as the use of carbon monoxide absorbent materials like these ExtendAir lithium hydroxide curtains manufactured by America's Micropore – can be used to help control carbon monoxide buildup on a distressed submarine. *(Micropore Inc.)*

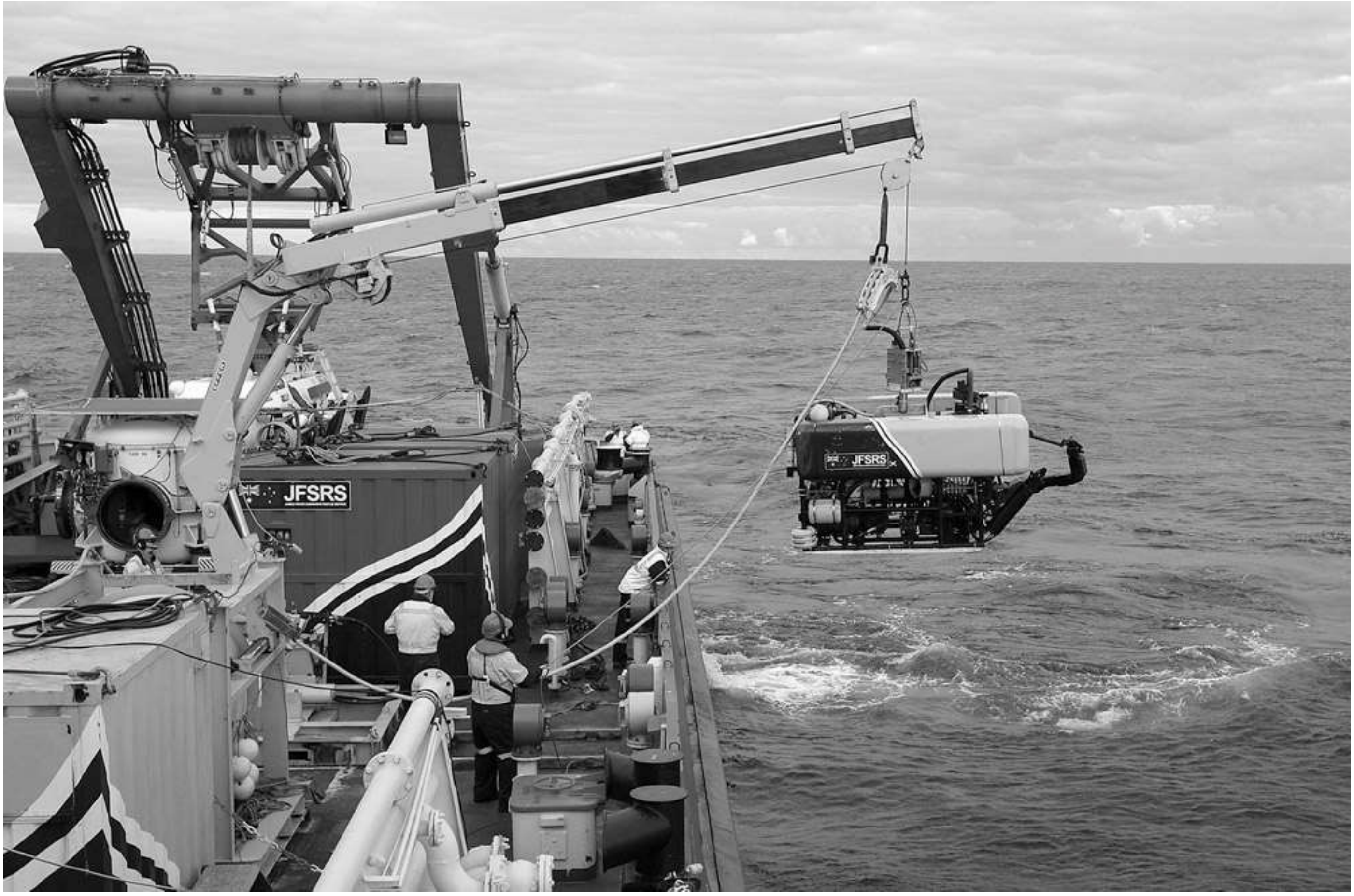
Location: Getting the location of the distressed submarine known by others is often correlated with the time delay between the last position report and the incident. Once on the bottom, survivors may be able to release buoyant communication devices, in addition to submarine smoke signals. Escape compartments are fitted with independentlypowered underwater telephones that can be used to alert search forces equipped with sonar to the distressed submarine's location. During previous submarine accidents, survivors have improvised various means to attract the attention of rescuers. These have included releasing buoyant materials from the submarine, as well as hull taps.

Water: Escape compartments can be fitted with an emergency fresh water tank to sustain life. Survivors will look to augment this by any means, from salvaging the submarine's internal fresh water reserves to collecting internal condensation.

A member of the Royal Navy's Submarine Parachute Assistance Group (SPAG) carries out a maritime parachute descent during an exercise over the Bay of Gibraltar in 2011. The SPAG can rapidly deploy a team with specialist escape and rescue knowledge to provide assistance to the crew of a distressed submarine; survivors on the surface and/or other forces involved in the rescue effort. The entry into service of the new A-400 Atlas transport aircraft – much larger than the current C-130 Hercules – is likely to expand the amount of equipment the SPAG can deploy. *(Crown Copyright 2011)*

Food: Escape food stores are similar to liferaft/lifeboat stores on surface vessels. They need to provide as much energy as possible, whilst absorbing as little water as possible while being digested.

It is to be noted that a prolonged stay in these conditions will leave survivors more and more debilitated, both physically and mentally. Ultimately a point will be reached when they are unable to function.



The initial reaction to the occurrence of a distressed submarine will be carried out by rapidly deployable response assets, such as lightweight intervention remotely operated vehicles (ROVs) such as this Australian Scorpio 45. A British Scorpio, deployed half-way round the world by a C-17 Globemaster strategic transport, was responsible for the successful recovery of the trapped Russian *AS-28* submersible in 2005. *(Royal Australian Navy)*

If escape from a distressed submarine needs to be supported, an escape gear ship will be equipped and dispatched to the distressed submarine's datum (location). Once on-scene, the ship will take over the co-ordination role from initial intervention units. The rescue ship needs to have sufficient deck space to accommodate all the relevant rescue equipment; an offshore platform support vessel will often be used. This image shows the Norwegian *Ram Star* carrying the NATO Submarine Rescue System (NSRS) during a 2011 training exercise. *(Torgeir Haugaard/ Norwegian Armed Forces)*

THE INITIAL REACTION

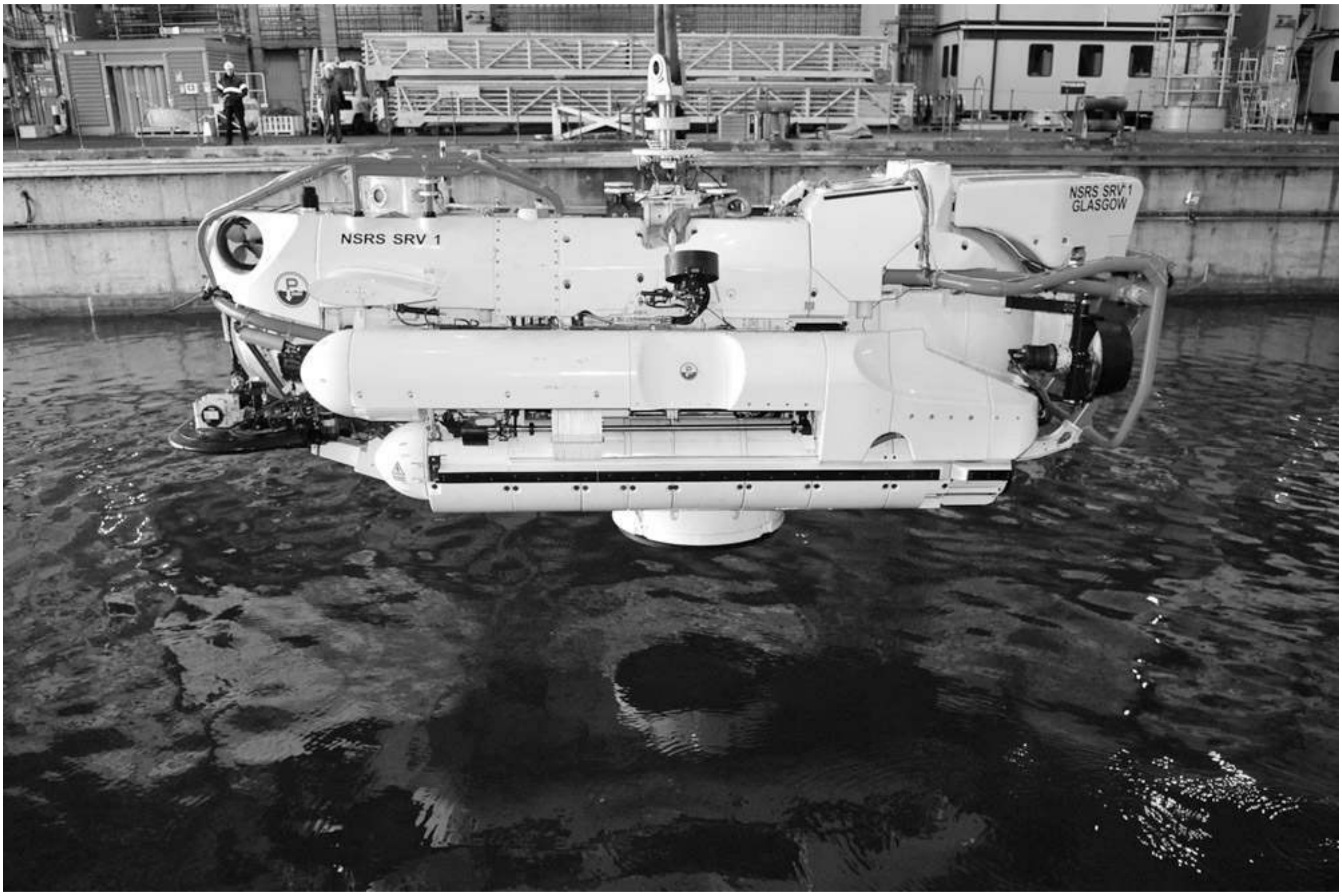
The initial reaction to the emergence of a distressed submarine will be carried out by response assets. These are small, lightweight and rapidly-deployable. They can therefore be on-scene quickly to establish communications with the distressed submarine, support an escape, and report as much information as possible on the situation back to the submarine operating authority. Response assets typically include air-portable remotely-operated vehicles, their operators and support equipment. These can be rapidly transferred to a vessel of opportunity (VOO).[3] VOO location and status is held within an ISMERLO VOO database to allow rapid identification, contact with the owners, and chartering should a distressed submarine situation so demand.

Once the vessel of opportunity and the equipment embarked reach the distressed submarine, they will first undertake an initial assessment of the situation. This will include establishing signs of life on board, the depth of water, the angle at which the distressed submarine is lying, and the condition of the escape hatches. The last-mentioned need to be able to make an effective seal with a rescue submersible in order to allow transfers of personnel or equipment. On occasion, a deployed remotelyoperated vehicle can carry out additional actions. An example is the response to the underwater entrapment of the Russian *AS-28* 'Priz' class submersible in August 2005. In this case, the rapid deployment of the UK SCORPIO remotely operated vehicle team, by means of a Royal Air Force C-17 Globemaster strategic heavy-lift transporter, allowed the team to use the vehicle's manipulator arms to cut entangling sonar array cables away from the *AS-28*.[4] The submersible was then able to surface and its crew exit the vessel.

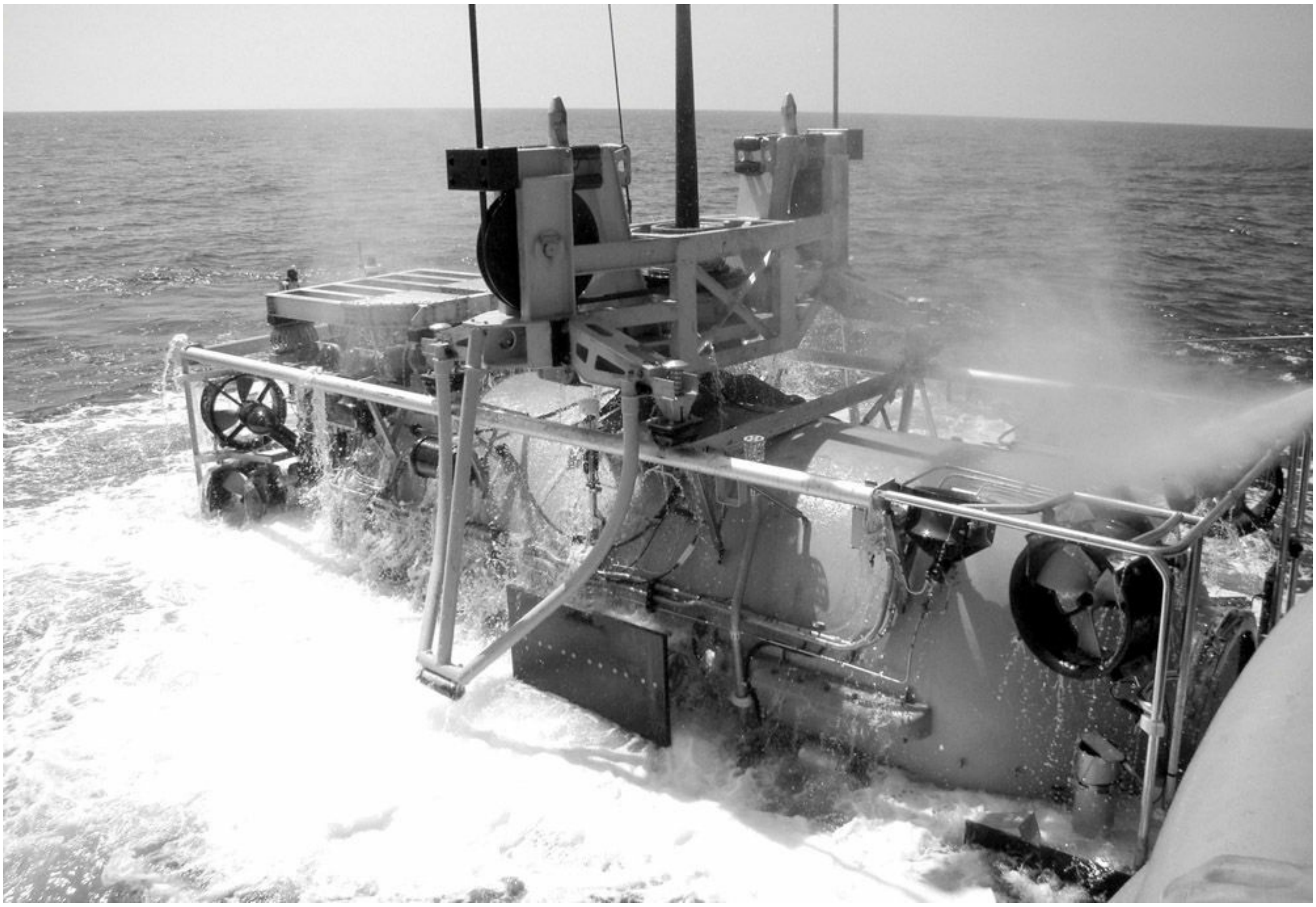
Several submarine operating authorities can also call on a 'Submarine Parachute Assistance Group' (SPAG) capability, either as a permanent asset declared to ISMERLO or as an ad-hoc capacity. SPAGs and their equipment can be deployed on to the ocean surface at the distressed submarine's datum (location) either by parachute or by a suitable helicopter. In accordance with IAMSAR procedures, the SPAG will assume the role of incident On-Scene Co-ordinator by establishing communications with onshore rescue authorities and the relevant submarine operating authority, taking over this role from the submarine's senior survivor

An interior view of NSRS during a training exercise with the Royal Norwegian Navy. A crew member can be seen examining the connection between the submersible and the exercise submarine's escape hatch; the submersible's separate control area can be glimpsed through the hatch in the background. Use of a specialised submersible or rescue bell is the only effective response when a distressed submarine is lying in deep waters*. (Torgeir Haugaard/Norwegian Armed Forces)*

SPAG team members are trained to establish underwater communications with the survivors on board the distressed submarine and to assess the overall situation. They should have sufficient SMERAS expertise to provide guidance and support to both the senior survivor and the submarine operating authority; the latter to ensure that priority is given to the correct assets in the operation. The SPAG will be equipped with underwater telephones, satellite communications and VHF/UHF radio sets to assist effective communication. A key decision is whether to attempt an escape in the knowledge that shelter and specialist care awaits directly overhead, or to remain on the distressed submarine and await submersible rescue. Air-portable inflatable boats and life-rafts, diving medical supplies, food and water are all included within immediate reaction stores inventories, although the location and specifics of the incident will dictate what is drawn for use. The lightly-equipped SPAG will deploy when environmental conditions permit, but will require additional support from a larger responding vessel as soon as possible. Even with aerial resupply, conditions on board a heavily-loaded life-raft with debilitated survivors will be bad. The risks involved in deploying a SPAG must be weighed up against the benefits. The loss of many survivors from the British submarine *Truculent* in the River Thames in 1950, for example, provide a vivid illustration of a case where lack of on-scene shelter or support led to postescape fatalities.[5]



NSRS undergoing crane launch trials at RNAD Coulport during 2011. Jointly owned by France, Norway and the United Kingdom, it is regarded as one of the world's most advanced rescue submersibles and can operate to a depth of over 600m. Its survivor compartment can be mated directly to a recompression chamber once recovered, avoiding the worsening of barotrauma or decompression illness that might result from fleetingly exposing survivors to surface pressure. *(Crown Copyright 2011)*



The US Navy Pressurised Rescue Module (PRM) element of its Submarine Rescue Diving Recompression System (SRDRS) is recovered during an exercise in the Pacific. The PRM, based on the former innovative but troubled Australian *Remora* system, is driven remotely from the associated rescue gear ship. The system has replaced the pair of manned deep submergence rescue vehicles (DSRVs) of the *Mystic* class. *(US Navy)*

SUBSEQUENT INTERVENTION

If escape is a possibility, an escape gear ship will be equipped and dispatched to the distressed submarine datum. This will be loaded with stores and equipment, such as medical supplies, fresh clothing and bedding for survivors, and a portable recompression chamber. Additional medical and escape and technical personnel will also be embarked. Once on-scene, the escape gear ship will take over the role of on-scene co-ordinator and start the recovery, triage and treatment of survivors. Escapees are likely to be suffering from diving-related signs and symptoms, such as barotrauma and decompression illness, sustained during the rapid pressure increase in the escape tower and the equally rapid pressure decrease sustained during the free ascent to the surface. The likelihood and severity of these conditions will increase with escape depth. The escape gear ship's medical personnel will screen and triage escapees. If a recompression chamber is available on the EGS, priority for the limited spaces within will go to casualties who are most likely to respond positively to hyperbaric treatment. Escapees may present to the medical personnel with other injuries or conditions sustained during the initial downing of the submarine, such as the effects of smoke inhalation or burns. However, escapees are likely to be 'walking wounded' as more severe casualties will probably have been left in the distressed submarine.[6]

The former Russian submarine *Juliett 484* breaks the surface of the waters of the Providence River, Rhode Island in June 2008 after a successful salvage operation led by US Army and Navy divers. The submarine – a Cold War relic turned into a museum ship – had sunk in around 10m of water. Most submarine salvage operations are considerably more complicated; often being contracted out to specialist firms. *(US Navy)*

Rescue – transfer from the submarine to the surface by means of a specialised submersible or rescue bell – is the definitive solution to a distressed submarine situation and the only response when the vessel is lying at greater depths. The equipment required to conduct a rescue can be considerable and the designated rescue gear ship is likely to be an offshore platform support vessel with sufficient deck space to accommodate all necessary materiel.[7] Rescue units train regularly to ensure that they can rapidly mobilise, transport their equipment and fit it to a rescue gear ship. Included in this process is personnel call-out, calling for strategic airlift, setting up road haulage and clearing road routes, nominating suitable airports for departure and arrival, identifying suitable port facilities able to accommodate the rescue gear ship alongside and mate rescue equipment to the deck, and clearing all administrative hurdles along the way. This is clearly a complex process and there is a constant risk of delay.

CASE STUDY 1: BAP *PACOCHA*/*KIOWA MARU*, CALLAO ROADS, 1988

The Peruvian Navy's *Pacocha* was a US-built patrol submarine (the former *Atule*) that had been modernised under the 'Guppy' programme. She was running on the surface, in the vicinity of Callao, in August 1988 when involved in a night-time collision with a Japanese ice-strengthened fishing vessel, the *Kiowa Maru*. The *Pacocha*'s pressure hull was penetrated and the submarine rapidly sank, illustrating the vulnerability of a submarine running on the surface. The low profile and freeboard of a surfaced submarine do not lend themselves to ready identification by a tired and overworked officer of the watch or lookout, and collision damage can easily remove the small reserve of buoyancy that a surfaced submarine has available.

Of the forty-nine crew aboard *Pacocha*, the commanding officer and three others died in the immediate aftermath of the collision and sinking. Twenty-three were able to abandon the vessel, twenty of whom were subsequently recovered alive. This left twenty-two survivors mustered in the forward torpedo room. One officer's success in shutting the forward torpedo room hatch could not be attributed to anything other than a miracle, given its weight and the inrush of water; this miracle was later officially ratified by the Vatican!

The *Kiowa Maru* apparently made no official notification of the event – larger vessels such as the current generation of 200,000-tonne container ship or Very Large Crude Carrier may run over a submarine and not even notice the impact. In this case, the alarm was raised when the *Pacocha* became overdue for arrival. Radio communications between *Kiowa Maru* and her port agent, suggesting the possibility she had been involved in a collision, were intercepted and passed to the naval base. A tug was despatched to the scene in time to see a red distress flare from the downed submarine ignite on the water, illuminating the crew who had abandoned the submarine on the surface.

The Peruvian Navy had equipped all submarines with the Steinke Hood Escape Apparatus, but in common with the US Navy, had elected not to provide practical, 'wet' escape training.1 A decision to remain on-board the distressed submarine pending rescue had to be altered as the atmosphere began to deteriorate rapidly. Instructions on the operation and use of the Steinke Hood were passed to the survivors. Lacking confidence in the use of the equipment and unfamiliar with the associated hazards in escape, several crew members hesitated while exposed to increased escape depth pressure in the escape tower. This, coupled with steadily rising atmospheric pressures in the torpedo room, led to a range of decompression injuries and illness symptoms. Pressure-related 'barotrauma' was also sustained due to correct ascent drills not being followed. There was one further fatality at this stage.

US Navy Undersea Rescue Command personnel monitor a recompression chamber during a hyperbaric treatment. Note the CCTV, which along with audio communications, provides constant surveillance of both patients and inside attendants. Diving and hyperbaric-trained doctors are also required to provide continuous subject-matter expertise, and all personnel will be trained to at least IMCA Diver Medical Technician level. As demonstrated by the Peruvian *Pacocha* rescue, the likely number of patients, and potential severity of their condition mean that submarine survivor recompression is likely to be a different proposition to either saturation divers or recreational divers. Faster decompression tables and ruthless triage are likely to be applied. *(US Navy)*

LESSONS LEARNED

Pacocha was lost in close proximity to Callao, near to a concentration of rescue assets but also in congested waters. Her loss demonstrated the vulnerability of a hard-to-see submarine with a low margin of buoyancy in such conditions.

The rescue saw both surface abandonment and tower escape, the latter ably supported by diver intervention when they were able to re-seat the escape tower’s jammed external hatch. The speed of the incident resulted in persons in 14° Centigrade water, lacking flotation or thermal protection. Close proximity to *Pacocha*’s homeport allowed rescue forces to be on-scene swiftly. There is some debate as to the utility of distress pyrotechnics in a modern age of satellite-based search and rescue; in the case of *Pacocha*, the red distress flare saved lives, as it provided positive confirmation of a SUBSUNK, the approximate datum of the DISSUB and clear indications of persons in the water.

The response also displayed commendable initiative on the part of rescue forces, as well as the need for regular training in the particulars of submarine escape and rescue. Small, cost-effective steps towards safety include effective pre-planning, notably ready access to submarine plans showing hatches and salvage fittings, as well as stockpiles of critical connectors and adaptors. Lack of crew confidence and familiarity in the escape equipment led to delays in escape, and the aforementioned barotrauma injury. The stresses inherent in making a submarine escape are not to be underestimated, and to maximise chances of survival, crews need as much confidence and experience as they can in the operation and use of the equipment. Local recompression facilities were rapidly overwhelmed by the large numbers of casualties. Time was lost tracking down naval divers owing to lack of means of communication and these in turn lacked specialist knowledge and had to learn on the job. Studies had to be made of one of the *Pacocha*'s sister submarines to note details of escape fittings, submarine hatches etc. Once on-scene, hull taps from inside were noted and replied to, but no agreed code was in place to allow effective communications. Messages had to be passed between survivors and rescuers via the submerged signal ejector, increasing the boat pressure with each operation. A decision was made to blow fresh air through the submarine via its salvage connections, but when this operation started, the survivors quickly shut the hull valve as – to their eyes – water present in the line was an indicator of flooding.

1 A Steinke hood – named after its inventor Lieutenant Harris Steinke – is an inflatable life jacket with a hood that completely encloses the wearer's head, trapping a bubble of breathing air. The Steinke hood takes up little space when stowed and is well-suited for tropical waters, but if water temperature and resultant survival times are a factor, then full-length escape suits are required.

CASE STUDY 2: K-141 *KURSK*

The Russian Navy's *Kursk* was a Project 949 (NATO reporting codename 'Oscar') nuclear-powered cruise missile submarine. In August 2000, with 118 crew on-board, she was a key participant in the Russian Northern Fleet's high-profile 'Summer X' exercise. One of the exercise's main evolutions was to have been a torpedo live-firing by the *Kursk*.

Kursk's outfit of weapons included Type 65 torpedoes fuelled by high-text peroxide (HTP), a highly volatile fuel that is explosive when it comes into contact with water. It is likely that – despite the best efforts of Russian submarine personnel – compromised build quality, maintenance routines and/or a degraded material state of equipment led to HTP coming into contact with seawater. Whatever the root cause, the effects were clear; an initial blast that flooded the forward part of the *Kursk*'s pressure hull and put the submarine on the bottom of the Barents Sea in about 110m of water. A second and much larger blast then took place. All the ship's company forward of the reactor compartment would have died instantly during the first blast. However, the sheer strength of modern submarines is proved by the survival of twenty-three personnel in the aft machinery spaces.

These men were utterly reliant on rescue, as there was no means of escape fitted to these compartments. The reaction of the Russian Navy in the crucial first hours after the sinking was slow, as they had become accustomed to delays in communications from submarines and did not make a link between reports of underwater explosions in the area and lack of signal traffic from *Kursk*. Once it became apparent that an incident had occurred, the Russian Navy initially relied on its own submarine rescue forces, ‘Priz’ class submersibles operated from *Mikhail Rudnitsky*, a converted former timber carrier pressed into naval service. *Mikhail Rudnitsky*’s main attribute was her heavy-lift crane system to launch and recover her submersibles: other than that, she was a standard merchant vessel lacking the dynamic-positioning capability to remain precisely on station. The submersibles found themselves operating at the limits of their battery endurance and despite truly heroic efforts in locating and taking imagery of the submarine, the rescue forces were unable to carry out any further actions.

By this time, external offers of assistance had been made and refused, and it was to be five days after the sinking before a commercial dive support vessel, the Norwegian *Normand Pioneer*, was able to negotiate manifold bureaucratic hurdles and arrive on-scene with the British SRS submersible *LR5*, a team of divers and a remotely-operated intervention vehicle. These determined that there were no signs of life on the submarine, and the operation now became a salvage instead of a rescue. Subsequent analysis of the bodies of the survivors in the aft compartments suggested that they had commenced survival routines and had burnt oxygen generators to keep the atmosphere within breathable limits. The pressure in the compartments had steadily risen to the point that the oxygen-rich air had been ignited. There has been debate as to how long the survivors endured. Certainly, *Kursk* lay in both an escapable and rescuable depth of water.

The Russian ‘Priz’ class submersible *AS-28* pictured surfacing in the Bering Sea in the afternoon of 7 August 2005 after a British Scorpio 45 remotelyoperated vehicle had released it from entrapment by the aerial of a sonar array off the Kamchatka Peninsula. It appears lessons had been learned from the Russian Navy’s slow response to the

2000 *Kursk* submarine disaster and a prompt international response meant that this incident had a much happier ending, with all seven crew members of *AS-28* surviving. *(US Navy)*

Given this, additional intervention capabilities can be used to extend the survival time onboard a distressed submarine until rescue can be effected Emergency life support stores are particularly important. Large watertight and pressure-tight pods with critical items such as oxygen generators, carbon dioxide removal equipment, and water and medical supplies will be loaded on the rescue gear ship. These are transferred to the distressed submarine by a remotely-operated vehicle. The distressed submarine's survivors will rig an internal pod posting bag inside the escape tower, shut the inner hatch, flood the tower, equalise its pressure and open the outer hatch. The pod will then be loaded into the bag using the remotely-operated vehicle's manipulator arm, and the tower then shut and internally vented to allow the survivors to receive the stores. Every time this operation is carried out, the internal pressure in the distressed submarine will increase.[8] Other internal leaks are also going to contribute to this; for example the crew who had survived the initial explosions on board the Russian submarine *Kursk* were in this situation, as the propulsion shaft seal leaked when the shaft was stationary. To this end, some ISMERLO members hold emergency ventilation and decompression systems within their intervention inventories. Connected to a distressed submarine's hull valves using remotely-operated vehicles or a diver in an atmospheric diving suit (ADS), these can provide fresh, clean air as well as allowing controlled decompression *in situ*.

Once rescue commences, triaged personnel will be evacuated in batches for treatment at the surface. Recompression therapy may be required. The SMERAS world has begun to adopt the commercial saturation diving system of transfer under pressure (TUP). Submersibles such as the NATO Submarine Rescue System (NSRS) can have its survivor compartment mated directly to the recompression chamber once recovered, preventing worsening of symptoms by fleetingly exposing survivors to surface atmospheric pressure. Other lines of technological development include remotely-operated rescue submersibles. The Australians led the way with their *Remora* project and this has now been taken further and matured by the US Navy. They have replaced their long-serving crewed deep submergence rescue vehicles (DSRVs) with the remotely-operated pressurised rescue module element of the Submarine Rescue Diving Recompression System (SRDRS). Medical treatment of survivors is likely to involve ruthless application of triage, as the high number of casualties is likely to swamp limited resources.

The Royal Australian Navy submarine *Farncomb* departing Sydney with the Australian Defence Vessel *Ocean Shield* – a former offshore support vessel serving as rescue gear ship for the purpose of the exercise – at the start of 'Black Carillon' 2013. There have been enough examples of successful rescues from distressed submarines to make investment in SMERAS techniques a wise one. *(Royal Australian Navy)*

SALVAGE

There is a general presumption in favour of salvage of a distressed submarine's hull and the material contained within it where this is practicable, in order to minimise environmental impacts from weapons, fuel, lubricants and other potentially hazardous materials on board. The submarine's national operating authority will lead on the recovery, although this is likely to be subcontracted out to specialist survey and salvage companies with the requisite skills and equipment. The state of the submarine's hull will dictate recovery methods: most submarines are fitted with external hull 'salvage blow' valves that will allow internal floodwater to be pumped out, and compressed air to be pumped in. Other factors, such as how many other hull penetrations have been compromised, whether the boat is deeply embedded in sediment, and the fine buoyancy control required to safely surface the hull and keep it stable throughout the lift all play a vital role. It may be that the trauma of the initial event has fatally compromised the hull, perhaps due to an internal explosion, an excursion below hull crush depth, or from the collision with the seabed.

CONCLUSION: COMMUNICATION AND TEAMWORK

A submarine rescue effort is a complex effort where many specialist disciplines have to come together and deliver against the clock, in the full glare of global media. ISMERLO has led the way in pooling the actual and potential SMERAS assets of many countries, and then exercising them in accordance with a regular cycle. The capabilities and limitations of SMERAS assets also remain firmly within the OSINT or Open-Source Intelligence sphere, aiding understanding and rapid decision-making when the occasion arises. In peacetime, the submarine community will aim to work together to assist their fellow submariners. This mind-set needs to be fostered on a continuous basis.

SMERAS specialists often have to work hard to overcome a fatalistic perception that in event of a distressed submarine situation arising, there are never any survivors. There have been enough examples in the 125 years of submarine operations to make SMERAS a wise investment in event of a SUBSUNK situation. One of those could even be evolving as the reader completes reading this article.

Notes

1. See the regularly updated *IAMSAR Manual Volume 3* (London: IMO Publishing).

2. For security reasons, this chapter focuses on a scenario taking place during an overt operation, such as training within territorial waters.

3. Vessels of opportunity are merchant vessels, often drawn from the offshore energy sector, that have SMERAS-specific capabilities such as dynamic positioning, and sufficient deck strength and area to embark SMERAS equipment.

4. Strategic heavy transport aircraft, such as the C-5 Galaxy, C-17, A-400 Atlas and Antonov AN-125/225, are crucial elements of the ISMERLO declared asset database.

5. *Truculent* was struck by the Swedish tanker *Divina* whilst returning on the surface from post-refit sea trials. Most of the crew managed to escape the sunken vessel but the absence of support when they reached the surface meant many were swept away and drowned.

6. The senior survivor, when conducting escape tower runs, has to consider the risk of an escapee internally blocking the tower and rendering it unusable by those left inside the distressed submarine.

7. For example, the tripartite NATO Submarine Rescue System (NSRS) includes a submersible, a submersible portable launch and recovery system (PLARS), a flyaway recompression chamber, an intervention remotely operated vehicle (IROV), emergency life support stores and a rigidhulled inflatable boat (RHIB) on an integral davit and cradle.

8. During an escape, those at the back of the queue to escape are far more likely to sustain a ‘bend’ owing to this effect.