Submarine Training & Systems Centre

MINUTE

S80/1/5
STSC 648/99

CASS		(CASSHQ)
CCLM		(HMAS STIRLING)
DGUWS		
Attention:	**DDGUWS**	(R2-4-C068)
	SM	(R2-4-C114)
DSM		(R1-4-B106)
DSM-N		(R1-4-C026)
DNMC-SM		(CP2-6-03)
EDSP		(R1-4-B046)
FSOO		(MHQ)
SERM		(CASSHQ)

For Information:

COS NTC	(NTCHQ)
OIC SUMU	(HMAS PENGUIN)

OCCUPATIONAL HEALTH AND SAFETY ASSESSMENT #29 (OHSA#29)

1. The enclosed OHSA#29 has been developed in order that all material, operational and medical hazards associated with Pressurised Submarine Escape Training (PSET) have been identified and adequately addressed.

2. The OHSA has been reviewed by members of the Escape and Rescue Sub Group and their comments are at Part 2 of the OHSA. SSB members are requested to review the enclosed OHSA prior to discussing it as an agenda item at the SSB meeting on 27 Oct 99.

3. POC for further information is LCDR David Jones, ph 08-95532250.

s22 [redacted]

J.M.H. TAUBMAN
CMDR, RAN
LA-SM

20 Oct 99

Enclosure:
1. OHSA#29

OCCUPATIONAL HEALTH AND SAFETY ASSESSMENT

ASSESSMENT No. 29
ISSUE 2

20 Oct 99

PRESSURISED SUBMARINE ESCAPE TRAINING

s22
Prepared b[redacted]..................................
D.T. JONES
LCDR, RAN
OIC SETF

s22
[redacted] 20 Oct 99

Endorsed by [redacted]..................................
J.M.H. TAUBMAN
CMDR RAN
LA-SM

20 Oct 99

PART 1 - THE ASSESSMENT

1.0 INTRODUCTION

1.1 Purpose

1.1.1 The SUBSAFE Board (SSB) has directed an Occupational Health and Safety Assessment (OHSA) be conducted in order that DCN might be assured that all material, operational and medical hazards associated with Pressurised Submarine Escape Training (PSET) have been identified and adequately addressed.

1.1.2 The purpose of Part 1 of this OHSA is to address all the risks associated with PSET and how they are managed. Part 2 will document the discussion and comments arising from the assessment with the final outcome and recommendations made at Part 3.

1.2 Scope

1.2.1 This assessment will evaluate all aspects of PSET against the requirements of current RAN Escape and Rescue Policy.[1]

1.2.2 The specific areas this assessment will address are:

a. RAN Submarine Escape Training;

b. RAN PSET;

c. Risks of conducting PSET; and

d. Management of the risks.

1.3 Background

1.3.1 The RAN has an obligation to provide an appropriate level of training in the use of the escape systems as part of its duty as an employer as defined in the OH&S (CE) Act. The argument can be further refined to include the requirement to take all "*reasonably practicable*" steps "*to provide and maintain a means of access to, and egress from, the workplace that is safe for the employees and without risk to their health.*"[2]

1.3.2 The concept of PSET was developed by the Royal Navy in 1946 with the associated training policy and procedures implemented in 1952. The

[1] DI(N) OPS 63-1 *[RAN Subamrine Escape and Rescue Policy]*
[2] Occupational Health and Safety (Commonwealth Employees) Act 1991, Clause 16(2)(b)(ii)

methodology was modified in 1966 with the introduction of the Single Escape Tower (SET).

1.3.3 PSET has been a component of RAN submarine training since the formation of the Submarine Squadron in 1967. Up until 1986, PSET was conducted by the Royal Navy at the Submarine Escape Training Tank (SETT) located in HMS DOLPHIN.

1.3.4 Following the decision to repatriate submarine escape training to Australia, the SETF was constructed in HMAS STIRLING in the late 1980s with operational PSET commencing in February 1989. Research by Mellon[3] indicates that "*... no such stand-alone written justification appears to exist in the RAN archives ... justification might exist in the original Naval Staff Requirement or the Naval Project Brief for the construction of the SETF, however, many of those files have exceeded their sentencing life in the Australian Archives and have been destroyed. It is entirely possible that the justification for SETF was that escape training was already part of the requirement for RAN submarines.*" The escape training consisted of a four day initial course and a two day requalification course. Both were based on the structure of the Royal Navy courses conducted in the SETT. The qualification period for this escape training was valid for three years.

1.3.5 In 1989 after a series of pressure related incidents, a short shutdown was undertaken at the SETF to address the issues and training resumed in March 1990. In 1995, after further pressure related incidents, a longer shutdown was instigated and further changes were also implemented. This saw significant differences in the conduct of PSET for both staff and submariner trainees.

1.3.6 In February 1998, after an audit by Maritime Command, the SETF was again shut down for several reasons, including incomplete training documentation. At this point a decision was made by Lead Authority – Submarines (LA-SM) to redevelop all the SETF training documentation into Competency Based Training and Assessment (CBTA) format. This documentation was subsequently approved by the relevant category sponsors (CASS and DNW). A further audit together with an ORE was conducted in late May 1999. SETF was awarded a Standard Achieved and SETF training recommenced 31 May 1999.

2.0 RAN SUBMARINE ESCAPE TRAINING

2.1 The RAN Submarine Escape and Rescue Policy identifies the mandatory requirement for all RAN seagoing submarines to have a capability to utilise Single Escape Tower and Rush Escape methods. It also identifies rescue as the preferred means of egress from a disabled submarine (DISSUB) but

3 Mellon, LEUT G.J., "Justification for the Conduct of Pressurised Submarine Escape Training", Nov 96, para 1

recognises that escape may be the only option available to the survivors. The training requirements for submarine escape are laid down in DI(N) PERS 75-6 *[Submarine Escape Training Policy]*.

2.2 As mentioned earlier, in order to rectify the training documentation deficiencies, all SETF courseware was redeveloped in CBTA format. The entire process from training needs analysis to conducting the pilot course took twelve months to complete. The review team consisted of personnel experienced in implementing Competency Based Systems and subject matter experts.

2.3 The approved documentation identified four units of competencies:

a. Communicate with Rescue Forces;

b. Perform Submarine Escape;

c. Maintain Submarine Environment; and

d. Supervise Submarine Escape and Survival.

2.4 The newly developed Submarine Escape Training Course (SETC) is of 5 days duration. It provides the necessary skills and knowledge to enable submariners to escape from a submarine. During the course, trainees are assessed both in the classroom and in the water against the required performance criteria. Only when each trainee has been assessed as competent in all four units will he/she be awarded the submarine escape qualification.

2.5 All submariners are required to undergo escape training every 3 years in order to maintain currency. To meet this requirement, a 2 day requalification course has been developed. This includes the necessary instruction and assessment to ensure each trainee is competent in the 4 units identified above.

3.0 RAN PRESSURISED SUBMARINE ESCAPE TRAINING (PSET)

3.1 Trainees only undertake pressurised training as part of the competency, Perform Submarine Escape. `An element of this competency requires trainees to conduct ascents through the water column at SETF. The two types of ascents performed at SETF are:

Buoyant: The escaper's face is in water and he/she breathes out throughout the ascent whilst wearing a buoyancy device.

Hooded: The escaper wears an escape suit and breathes normally throughout the ascent to the surface.

3.2 **Buoyant Ascents**

3.2.1 Trainee Training. Trainees conduct two buoyant ascents from a depth of 9m. Prior to their ascents they are instructed in the correct blow rate by SETF staff on the surface. Once the trainees have successfully demonstrated the correct blow rate, they are dressed in a Training Life Jacket (TLJ) and taken down to the 9m lock. The lock is flooded to chest height and then pressurised to 9m. Upon equalisation, each trainee is instructed to take a deep breath prior to being pulled into the main water column by the SETF instructors. After entering the main water column the trainee commences his/her blow. When the staff are happy with the trainee's blow rate, the trainee is released who then, aided by the TLJ, ascends to the surface blowing out all the way.

3.2.2 Staff Training. Staff also conduct buoyant ascents similar to trainees. However, as part of their training to become competent as water workers, staff conduct buoyant ascents up to a depth of 18m.

3.3 **Hooded Ascents**

3.3.1 Trainee Training. Trainees conduct one buoyant ascent from a depth of 18.5m. The trainees are dressed in the MK 10 Submarine Escape Training Equipment (ie Escape Suit) before entering the SET. The trainee connects himself to the air supply whilst a SETF instructor secures the trainee inside the SET using a retaining pennant. The air supply provides high quality diving air for the trainee to breathe as well as buoyancy for the suit. When the instructor is satisfied the trainee is breathing normally, the SET is then flooded. On equalisation, the upper lid opens and the trainee rises through the hatch to the extent of the retaining pennant. The trainee is met by two SETF instructors; one assesses his well being whilst the other connects him to the centreline jackstay. Once the instructors are assured the trainee is well and breathing normally, the retaining pennant is released and the trainee ascends to the surface breathing normally all the way.

3.3.2 Staff Training. Staff also conduct hooded ascents. During staff training and as instructors, they can conduct more than one ascent but they cannot exceed five hooded ascents per day. The procedure for the hooded ascents is exactly the same as for trainees, but less safety numbers are provided.

4.0 RISKS OF CONDUCTING PSET

4.1 This section will identify the risks associated with PSET. In most instances, the physiological risks apply to both trainees and staff. Risks for both buoyant and hooded ascents will be explored and any exceptions between trainee and staff training will be highlighted.

4.2 **Buoyant Ascents**

4.2.1 There are risks involved when trainees are subjected to pressure in the 9m lock and when they ascend to the surface wearing a TLJ.

4.2.2 During the pressurisation process, the risks for the trainee are:

a. Aural barotrauma. If trainees are unable to equalise their ears, they may suffer bruising or rupturing of the ear drum. In more severe cases, damage to the inner ear may occur.

b. Sinus barotrauma. The trainee may suffer pain and bleeding may result. In the most severe case, a nerve may be damaged and loss of sensation to part of the face may occur; this could be permanent.

c. Near-drowning/Drowning. The trainee may inhale water and drown in the lock if there is uncontrolled flooding or if a breathable supply of air is not provided or reachable.

4.2.3 During the buoyant ascent, the risks for the trainee are:

a. Pulmonary tissue damage. Widespread tearing and bleeding within the lungs can result from an escaper exhaling inadequately on the way to the surface. This condition can result in rapid death, depending on the severity of the rupture. The condition is more likely in persons with pre-existing lung defects, such as asthma, emphysema, severe or complicated pneumonia or tuberculosis scarring, etc, hence the need for excluding people who suffer (or have suffered) from these conditions from diving, escape training and submarines. Pulmonary tissue damage can lead to:

(i) Air Embolism. This is also known as Cerebral Arterial Gas Embolism (CAGE) and is the most serious effect arising from lung rupture. The disruption of the lung tissues can allow gas bubbles to enter the blood vessels where they are carried to the heart and thence to the body's organs and other tissues. The bubbles may cause blockages in the progressively smaller chains of arteries supplying various parts of the body. The bubbles also damage the capillary vessel walls, often resulting in clots within the vessel. Once deprived of oxygen, the tissues in the affected areas die or become permanently damaged. In the case of the brain or heart this may lead to death very quickly. Only very small quantities of gas are needed to cause this.

(ii) Surgical Emphysema. If the alveoli in the lungs are ruptured, air may escape into the lung structure itself and then track along loose tissues around blood vessels into the region of the chest between the lungs, breastbone and spine, called the mediastinum. This cavity contains the windpipe, heart and major blood vessels, it is sealed from the abdomen by the diaphragm and extends upwards into the neck. Air entering the mediastinum may enter the sac containing the heart and interfere with its pumping ability, it may travel up into the loose tissues of the neck where it may be displayed as subcutaneous emphysema, or it may compress various organs in the neck and mediastinum.

(iii) Pneumothorax If a rupture occurs near the lung surface, gas may be released into the thoracic (pleural) cavity and cause collapse of the lung, as the escaper's continuing ascent expands the gas now trapped between the chest wall and the lung. Bleeding into the chest may also occur.

b. Decompression Illness (DCI). DCI occurs as the result of bubble formation in body tissues during decompression. Mild cases may not show symptoms until 24 hours or so after the ascent, whilst severe cases may present during the ascent. The disease manifests itself in a number of ways, with joint, nervous system, gastrointestinal, heart and lung, skin and blood problems occurring.

(i) Joints. Symptoms may range from severe joint pains, colloquially known as the 'bends', to minor fleeting joint pains (niggles).

(ii) Nervous System. Effects on the brain arise from bubble formation in the brain tissue or any blood vessel supplying the brain The effects are similar to those induced by a stroke. Effects on the cerebellum will display symptoms of unco-ordination and this symptom is commonly known to divers as the 'staggers'. Spinal DCI occurs due to nitrogen bubbles in the spinal cord or supply arteries and can cause loss of feeling or paralysis and is often associated with the inability to pass urine. Central nervous system effects of DCI are extremely serious and can rapidly lead to death or permanent forms of brain damage and paralysis.

(iii) Gastrointestinal. Bubbles within the lining walls or blood vessels can cause nausea, loss of appetite, vomiting, cramping pains and diarrhoea.

(iv) Heart and Lungs. In severe cases large quantities of bubbles can form in the blood, often very soon after decompression. The bubbles occur in the veins returning blood to the heart and are trapped in the lungs, causing chest pain, shortness of breath and an irritating cough. Some bubbles are able to pass through the lungs and enter the heart, where they are distributed as gas emboli to the brain. Small abnormalities of the heart chamber walls can allow venous bubbles to pass into the arterial side of the heart. If such bubbles enter the coronary arteries the effect is similar to that of a 'heart attack'.

(v) Skin. Itching and rashes, or a bluish mottling of the skin may develop and are usually symptoms of severe DCI.

c. Near-drowning/Drowning. The trainee may inhale water, asphyxiate and drown if they are unable to make it to the surface or to a supply of breathable air.

4.3 **Hooded Ascents**

4.3.1 There are risks involved when trainees are subjected to pressure in the SET and when they ascend to the surface wearing an escape suit.

4.3.2 During the pressurisation process, the risks for the trainee are the same as those for the buoyant ascents.

4.3.3 During the hooded ascent, the risks for the trainee are the same as those for the buoyant ascents.

4.4 All the risks identified for both buoyant and hooded ascents also apply to SETF staff.

5.0 MANAGEMENT OF THE RISKS

5.1 Having defined the physiological risks associated with submarine escape, it is necessary to describe the procedures used to manage the risks in order that they be avoided wherever possible. Where the risks cannot be avoided, the procedures associated with the training in order to minimise the risks are discussed.

5.2 There are several factors that can affect the level of risk and they can be summarised as:

a. Medical fitness;

b. Equipment failure;

c. Trainee's failure to display the necessary skills and behaviour; and

d. Instructor's failure to display the necessary skills and behaviour;

5.3 The following paragraphs lists the risks in the same order as the preceding section, the relevant influencing factors, and the procedures used to avoid or minimise the risks.

5.4 **Aural Barotrauma**

5.4.1 All personnel who volunteer for service in submarines are required to undergo a submarine suitability (SUBSUIT) medical and a 30m dive in a recompression chamber (RCC). The medical and/or the 30m dive identifies those candidates who cannot equalise their ears and they are made PMU submarines.

5.4.2 Before trainees commence the SETC, they are assessed on the first day by a Medical Officer qualified in underwater medicine. Their medical records are checked to ensure they have successfully undertaken the SUBSUIT medical and RCC dive. Each trainee is then physically examined by the Medical Officer before being made 'Fit to Dive'.

5.4.3 During the pressurisation process for both buoyant and hooded ascents, trainees are accompanied by a SETF instructor. If at any time a trainee experiences discomfort or pain in their ears, the trainee notifies the instructor who will immediately stop the pressurisation. The instructor will ask the trainee about his well being and if the trainee is happy and can equalise their ears, pressurisation will continue. If the trainee experiences further problems, pressurisation will again be stopped and the trainee will be removed from further training. A medical assessment will be made and the Medical Officer will determine when the trainee can undergo another course.

5.4.4 If a trainee highlights a problem with their ears after they reach the surface, qualified medical staff will immediately assess the trainee. The Medical Officer, who is in the building at all times during trainee training, will be consulted after the initial examination.

5.4.5 Equipment failure is not a factor in influencing a person's risk in receiving an aural barotrauma.

5.4.6 The above procedures to avoid or minimise the risk of aural barotrauma apply equally to SETF staff.

5.5 **Sinus Barotrauma**

5.5.1 The procedures developed to avoid or minimise the risks for aural barotrauma also apply for sinus barotrauma.

5.6 **Pulmonary Tissue Damage**

5.6.1 This condition can occur during both buoyant and hooded ascents if the escaper holds their breath during their ascent to the surface.

5.6.2 Before personnel conduct any PSET, trainees receive lectures in the classroom on the physiological risks associated with PSET. Further briefs are given before the trainees commence their ascents, including a graphical presentation (using a wine bladder) of the potential lethal results in not blowing out all the way to the surface. All ascents are correctly demonstrated by SETF staff before trainees undertake PSET for themselves.

5.6.3 At the start of the buoyant ascent, the trainee's blow rate is assessed by a SETF instructor. If the trainees expels all their air they are placed back in the lock and debriefed. If the blow rate is insufficient, they receive taps to their midriff which informs them that the blow rate needs to be increased. Once the blow rate is correct, the trainee is released and ascends to the surface due to the buoyancy in the TLJ. If at any time the trainee stops blowing out, instructors in the water will tap the trainee's midriff to ensure they exhale all the way to the surface. At no time is the trainee not observed during their ascent to the surface.

5.6.4 When the trainee reaches the surface, their well being is established and they are observed by medical staff. If any distress is noted or the trainee complains of discomfort or pain, appropriate action is immediately taken by the SETF instructors and medical staff. An RCC is located at the tank top at immediate notice to dive. In the event that an incident does occur, the patient can undergo therapeutic treatment immediately with all qualified medical staff and operators in attendance.

5.6.5 The only equipment failure that may affect the trainee's ascent to the surface concerns the TLJ. All TLJs are tested by SETF staff before they are distributed to trainees. However, if the TLJ fails and does not inflate correctly, the trainee will be placed back in the lock.

5.6.6 During hooded ascents, SETF instructors ensure the trainee is breathing correctly before release. If they are not breathing correctly or shows signs of panic, the trainee is detached from the retaining pennant and pulled into a bell by the instructors. The bell is then driven to the surface where the trainee is assessed by SETF staff before a decision is made on whether their training should continue.

5.6.7 Connection to the centreline jackstay allows the trainee to ascend to the surface in a controlled manner whilst concentrating on breathing normally all the way. Upon reaching the surface, any observed distress is treated in the same manner as described in para 5.6.4.

5.6.8 If during the ascent, the escape suit fails and the trainee finds their face in water, they are instructed to breathe out all the way to the surface as per a buoyant ascent.

5.7 **Decompression Illness**

5.7.1 DCI is more prevalent in older, obese personnel. The medical screening procedures aim to eliminate these personnel. All personnel must be WS1 or WS2 before they can commence submarine escape training. Also, personnel must complete initial PSET before the age of 35 years.

5.7.2 To limit the nitrogen loading which can predispose personnel to the risk of DCI, restrictions are placed on personnel when selected to undergo PSET. These restrictions include the banning of diving activities before and after PSET. These restrictions are contained in the joining instructions and reinforced daily by instructional staff.

5.7.3 Other restrictions include the banning of alcohol and limiting physical activity whilst on course. This ensures personnel are not dehydrated during PSET and sporting injuries do not occur which could increase the risk of DCI at the injury site. In addition, personnel are not allowed to fly for 24 hours post PSET.

5.8 **Near-drowning/Drowning**

5.8.1 As PSET is conducted in a water column 20 metres deep, the risk of personnel drowning is always present. It may occur during the flooding of the lock or SET or during the ascent through the water.

5.8.2 During the flooding of the lock and the SET, the rate at which water enters is controlled by an instructor at all times. If flooding becomes uncontrollable due to equipment malfunction, both the lock and SET contain drains which can be opened to release the water. In the lock, the problem can also be overcome by pressurising the lock to stop the ingress of water. The SET and lock can be flooded and drained from both within and outside the compartment.

5.8.3 Before personnel enter the lock or SET, all systems are checked by a qualified instructor and unmanned runs are conducted. No training is allowed to occur until all safety related defects have been rectified; this includes the RCCs.

5.8.4 Although drowning during an ascent is possible in theory, it is highly unlikely to occur in the controlled environment at SETF. If personnel expel all their air prior to a buoyant ascent, they will be placed back in the lock by the SETF instructors. For hooded ascents, if their hood fails to fill with air during flooding of the SET, then the flooding will be stopped by the SETF instructor. As personnel are observed throughout the ascent, any difficulties observed will be promptly addressed by qualified staff in the water and at the surface.

5.9 **Engineering Systems**

5.9.1 All the engineering systems at SETF, including the building and its environmental controls, are certified by Det Norske Veritas (DNV). The planned maintenance activities are controlled by a computerised maintenance management system.

5.9.2 After any planned or corrective maintenance, all systems are checked correct by qualified SETF maintainers. If the work was on safety critical items, then DNV conducts an inspection to certify the work as correct.

5.9.3 Upon the completion of any work, unmanned runs are conducted by SETF staff to ensure the systems operate as specified in the operating manuals and SETF Standing Orders (SSOs).

5.10 **Operating Procedures**

5.10.1 All operating procedures associated with escape training are detailed in SSOs. The SSOs address all water work evolutions including how to deal with casualties and the procedures to be followed in the event of fire.

5.10.2 SSOs are comprehensive and all staff are assessed regularly to ensure they are competent to deal with any incident. A staff work-up period is conducted after all planned maintenance periods (usually Jan and Jul each year).

5.11 **Pressure Related Incidents**

5.11.1 Throughout the history of the SETF there have been a total of 34 pressure related incidents. 15 of these involved staff with the remainder involving trainees. Since the shutdown in 1995, which resulted in the restructuring of training and increased restrictions on water work instructors, there have been no pressure related incidents among staff or trainees.

5.11.2 After the 12 month training review and the recommencement of training in May 1999, 73 trainees have undergone PSET. Without exception, all have stated that PSET has been conducted in a safe and professional manner.

6.0 **CONCLUSIONS**

6.1 The training at SETF has been reviewed and the revised documentation approved by the category sponsors.

6.2 Without doubt, there are risks associated with PSET. Ignoring the risks or by not developing procedures to avoid or minimise these risks can lead to serious injury or death.

6.3 The risks of aural and sinus barotrauma have been examined and the procedures used to avoid of minimise the risks have been discussed. Wherever possible the risk is avoided by appropriate medical screening. During PSET, the risk is minimised by the medical examination conducted immediately prior to PSET and by qualified SETF instructors during the pressurisation process. In the event a barotrauma occurs, qualified medical staff are available to treat the patient immediately.

6.4 The risk of pulmonary tissue damage is perhaps the most cause for concern. Personnel who fail to exhale during an ascent risk serious injury or death. However, the instruction in the classroom and the demonstrations by SETF staff make the trainee fully aware of the consequences of holding their breath. Personnel are not allowed to ascend to the surface until they have demonstrated the correct breathing method, and in the case of buoyant ascents, instructors are in the water column to remind the trainee to blow out all the way to the surface.

6.5 The risk of drowning exists but the systems and procedures in place negate the possibility of an incident occurring.

6.6 All the risks associated with PSET cannot be avoided. However, there are systems and procedures in place to minimise the risks. In the unlikely event an incident occurs, qualified staff are immediately available to take corrective action.

7.0 RECOMMENDATIONS

7.1 This OHSA be reviewed by members of the SUBSAFE Board - Escape and Rescue Sub-Group (SSB-ERSG) and forwarded to the SUBSAFE Board (SSB) for endorsement;

7.2 Upon endorsement by the SSB, a presentation should be made to DCN with a recommendation that PSET continue to be conducted by the RAN; and

7.3 The RAN Submarine Escape Training Policy (*DI(N) PERS 75-6*) be updated at the earliest opportunity after consideration of the matter by DCN to reflect the outcome of that presentation and the recent changes brought about by CBTA.

OCCUPATIONAL HEALTH AND SAFETY ASSESSMENT #29

PRESSURISED SUBMARINE ESCAPE TRAINING

PART 2 - THE DISCUSSION

1.0 The OHSA was distributed to all Escape and Rescue Sub Group (ERSG) members for comment. The following details their written comments (in italics) together with the author's response on the issues being raised.

2.0 Comments from LCDR R.M. Walker, Officer-In-Charge Submarine and Underwater Medicine Unit

2.1 The reference has been reviewed. It is SUMU's opinion that this document is incomplete and does not address the pertinent issue of whether or not we should conduct pressurised submarine escape training (PSET) at all. Whilst para 1.1.1 states the purpose of the OHSA is to determine whether all material, operational and medical hazards associated with PSET have been identified and addressed, this surely must involve a review of why we do PSET, an assessment of the relevance of this training and an assessment of whether the health risk of conducting this training can be justified. No attempt has been made to consider the financial cost of this training, neither the compensation cost of injury sustained during training, nor the effect of the compulsory requirement for PSET on recruitment.

2.1.1 Although the original draft of the OHSA was produced by another author, the purpose as described in para 1.1.1 has not changed. During the redevelopment of the training documentation in CBTA format, a full job analysis was conducted by training systems personnel and subject matter experts. The final documentation suite was approved by the category sponsor (CASS). It is not considered necessary to conduct a training needs analysis (TNA) given the experience of the personnel involved in the documentation rewrite. LA-SM is responsible for the development and conduct of all submarine shore training and it is the policy that all submariners will undergo PSET as a mandatory prerequisite for the award of the submarine qualification.

2.1.2 There will always be risk involved in a seagoing career in submarines. Without trying to be subjective, there may occur a time in which the only way personnel can exit the submarine is through escape; the primary method of rescue will not always be available. Discussions with trainers and trainees indicate that the confidence gained form PSET gives them the peace of mind that they can escape successfully from a submarine if needed. This cannot be simulated through non-PSET methods. The number of times that personnel need to undergo PSET in order to retain their knowledge and skills will be reviewed when the need for PSET has been resolved.

2.1.2 It should be noted that Mr Neil Ringshaw (of Ringshaw & Associates), a specialist in OHS in the training environment with wide experience in the mining industry, has been contracted to:

a. review OHSA #29 and associated documents;

b. review existing training modules (documentation); and

c. prepare for a risk assessment of the processes.

2.1.3 Mr Ringshaw will provide a draft submission for the SSB by 27 Oct 99. It is intended Mr Ringshaw will be further employed to facilitate a job safety analysis and perform a gap analysis if required. Although Ringshaw is not being employed to conduct a training needs analysis, he will provide guidance on how many times a submariner is required to undergo PSET.

2.2 *These issues were circulated in a previous draft of this document (reference B) to which SUMU provided a detailed response (reference C). It is considered none of these issues have been addressed, just a justification for maintaining the status quo. SUMU argues there are considerable grounds for considering the abandonment of PSET and continuing with a program of non pressurised submarine escape training (NPSET).*

2.2.1 As discussed earlier, the purpose has not changed between drafts. Given the effort in producing the new training documentation and the subsequent approval to resume PSET, it is not agreed there are considerable grounds for the abandonment of PSET.

2.3 *It is SUMU's opinion the SUBSAFE board must be advised there is a substantial random component to the incidence of pulmonary barotrauma in PSET, which means there is no completely safe training depth. The SUBSAFE board must be prepared to accept a fatality may occur at SETF even if all procedures have been diligently exercised. If PSET continues they must be prepared to defend the existence of this training when the general public will be made aware the likelihood of submariners having to perform an escape is statistically extremely remote and, the RAN has a dedicated rescue capability available. No evidence has been presented in this review to show PSET is more beneficial than NPSET and no attempt has been made to perform a risk analysis.*

2.3.1 It is agreed that there is a risk of pulmonary barotrauma and there is no completely safe training depth. However, there is also a risk that a submarine may become disabled whereby the only means of egress is escape. The training currently conducted at SETF is considered the most effective to give submariners the necessary skills and knowledge to escape. It cannot be assumed that the rescue capability will always be available. It is in the RAN's interest to ensure an alternative means of leaving the submarine is possible.

2.3.2 A risk analysis has been conducted, albeit of the status quo. A further risk analysis utilising the job safety analysis methodology will be conducted by Mr Ringshaw if a further assessment is required.

2.4 Further comments relating to the document are listed:

a. *Para 1.3.2. PSET began at HMS Dolphin in 1930 (not 1952) using the Davis Submerged Escape Apparatus whilst the USN 100 foot escape tower opened in 1931.*

Para 1.3.2 to be amended.

b. *Para 4.2.3. Pulmonary barotrauma frequently occurs in individuals with a normal CXR and in whom pre-existing lung defects have been excluded. It also frequently occurs in individuals who have been observed to breathe out 'correctly' all the way to the surface. It is thought to occur due to a localised obstruction to airflow, a condition that will not be detected by routine examination.*

It is acknowledged that pulmonary barotrauma can occur in individuals who have been made fit to dive and also blow out 'correctly' to the surface. However, the event itself occurs infrequently. There have been 3 documented incidents at SETF since 1989 and none since 1993. The most recent incident when a trainee was injured after becoming separated form the centreline jackstay has not been conclusively diagnosed as a pulmonary barotrauma; conversely, a CAGE cannot be ruled out This is not meant to detract from the risk of pulmonary barotrauma occurring during PSET but to put it into context – escaping from a submarine is risky and PSET gives the trainees confidence that the escape systems fitted to the submarines will allow them to arrive on the surface.

c. *Para 4.2.3.b. DCI symptoms almost always present within the first 12 hours following a dive and frequently soon after reaching the surface. Patients often deny their symptoms or ignore them, which accounts for the delay in seeking treatment. It is known that bubbles form during all dives, whether or not they become symptomatic depends upon a multitude of factors. The new classification system specifically moves away from the previous incorrect description of Type 1 (minor) and Type 2 (major) disease. Very rarely will an individual have only symptoms of joint disease and with careful examination evidence of neurological involvement (brain and spinal cord) will be present. That is, the great majority of patients with DCI will have neurological involvement. Para iv describes bubbles in the lungs (the 'chokes') but neglects to say the bubbles may be present in such large quantities to block all forward flow through the heart and therefore is fatal.*

All staff and trainees are briefed to immediately report any feelings of ill health to the medical staff at SETF. These briefs are given at the start and finish of each training day by their SETF instructor. Trainees are also made aware that symptoms may present after completion of training and they are briefed to notify local medical staff immediately so that corrective action can be taken.

Para iv to be amended.

d. *Para 5.4. The risk of aural barotrauma exists each time an individual is exposed to an increase in ambient pressure. Novice divers are most at risk. The steps taken in para 5.4.3 do not exclude a candidate having an inner ear barotrauma which may result in permanent hearing loss.*

The risk cannot be eliminated but the trainees are accompanied by a SETF instructor at all times during pressurisation. They are briefed to notify the instructor if they experience any pain in their ear(s) at which time pressurisation is immediately stopped. The staff and trainees are also told not to forcefully valsalva during the pressurisation process.

e. *Para 5.6.1. Pulmonary tissue damage may occur if the escaper holds their breath during the ascent or fails to breathe out adequately. As mentioned previously, this may occur in a subcompartment of a lung and occur even if the individual has been observed to breath out 'correctly'.*

Addressed at para 2.4b above.

f. *Para 5.6.3. This observation of 'correct' blow rate will not prevent the occurrence of a pulmonary barotrauma.*

Addressed at para 2.4b above.

g. *Para 5.6.7. Failure of the connection to the centreline jackstay has recently occurred resulting in injury to the escaper.*

As a result of the incident and subsequent investigation, the traveller used to connect the trainee to the centreline jackstay has been redesigned. The design changes have been approved by DNV.

h. *Para 5.7. It is the instructors who are at most risk of DCI (trainees more at risk of pulmonary barotrauma). Many inter and intra-personal factors contribute to the development of DCI, not just age and body fat content.*

Para 5.7 to be amended.

i. *Para 5.11.1. This statement is incorrect. This implies since the shutdown in 1995 not one incident of aural or sinus barotrauma has occurred. I believe you are trying to say there has been no incidence* *of DCI since 1995. However, all cases must be recorded: was there not a recent case of pulmonary barotrauma during a recent requalification course?*

SETF incidents addressed in para 2.4b above.

j. *Para 6.6. I do not think you can say an 'in the case of an unlikely event occurring'. There is a very clear predictable and foreseeable risk of pulmonary barotrauma in submarine escape training.*

It has been agreed throughout the OHSA that there are risks associated with PSET. However, the ability to quantify the risk to provide meaningful results is debateable. Using the statistics to date, the event of death or serious injury during PSET is unlikely. This is not to say it will never happen.

3.0 Comments received from Mr P. Hugonnet, Undersea Warfare Systems Branch – SUBSAFE Manager

3.1 The overall structure of the OHSA is sound in so much as it has described the process, identified the risks and their management strategy however it is considered that it is basically flawed because it has not examined why personnel are being exposed to risk in the first instance. The Conclusions of the OHSA are that there are indeed risks associated with PSET. Para 6.6 specifically states that at these risks cannot be avoided however mitigation measures have been put in place to minimise them. Unfortunately no where in the document does the OHSA attempt to justify why personnel are being exposed to these risks in the first instance. It is perceived that the Scope of the OHSA at para 1.2 has been varied from earlier iterations of the OHSA to avoid any discussion of the foregoing issue. In this particular instance there is a basic presumption that the current RAN Escape and Rescue Policy is valid and that PSET is necessary because it represents past practice. While this approach could be regarded as valid, it does not sit well with the documented discussions that have already taken place in this matter and which would be available for external audit.

3.1.1 The perceived changes in purpose have not changed in between authors and no attempt has been made to avoid discussion on the issue of why PSET is conducted. This OHSA has only focused on the issues relating to the purpose at para 1.1.1. That said, the requirement for PSET has been discussed earlier in Part 2.

3.2 While OHSA # 29 (8.9.99) discusses some of the historical aspects associated with the operation of the SETF and PSET there is no indication that this particular OHSA has been under development for some considerable time noting that the first draft was distributed by the now SERM for comment on 18 December 1998 – almost 12 months ago!

3.2.1 Not considered relevant or helpful to this version of the OHSA currently being reviewed and discussed.

3.3 *Any external audit of OHSA # 29, particularly one conducted by say COMCARE in the event of any mishap in the SETF, would surely question the time taken to develop the OHSA and indeed why the final document has taken a completely different approach to the original attempts.*

3.3.1 Addressed at para 3.1.1 and para 3.2.1.

3.4 *In the development of this particular version of the OHSA 'References' have been indicated as "footnotes" and indeed only three are noted throughout the entire document. If only these three References have been consulted in developing the OHSA then its integrity must be open to question noting that in the Draft Issue # 1(29.1.99) of the OHSA Annex A listed the 14 References as shown at Annex A. Those References are all considered to be germane to the OHSA and it is considered that their visibility would be required to support any external audit of the OHSA to prove its integrity. Indeed MIL-STD-882 which represents the source document for the SUBSAFE Program, and in particular Task 206- Operating and Support Hazard Analysis, which itself provides the basic structure for any OHSA, requires an examination of, "Lessons learned, including a history of mishaps caused by human error ", and the source for this particular examination is considered to reside in the References quoted at Annex A.*

3.4.1 The 'missing' references were not included as they were not used in this version of the OHSA. To come to the conclusion that its integrity is in question is not constructive. However, they are now included in Part 2 for personnel wishing to review the background to a previous draft.

3.4.2 The COMCARE and legal aspects of the OHSA and any shortfalls are being addressed by Mr Ringshaw. This independent consultant was purposely hired to ensure the document was reviewed by a qualified OHS practitioner outside the RAN. It is recommended future OHSA assessments are not conducted by personnel who have a vested interest in the process, no matter their perceived position on particular issues.

3.5 *Since the generation of Draft Issue # 1 (29.1.99) of the OHSA the draft USN Naval Submarine Medical Research Report on "a Medical Risk Assessment of Pressurised Submarine Escape Training " by Captain M.T. Wooster MSC USN, was distributed by the now SERM for comment in March 1999. While it is considered that the USN Study Report does not add much to the RAN Corporate knowledge on the PSET issue, it does re-enforce the fact that PSET is a risky activity – how risky is yet to be determined. The OHSA needs to reflect the existence of this particular report and preferably its outcome, if it is to demonstrate that it has addressed the totality of the PSET issue.*

3.5.1 The draft USN report was not referenced as no formal copy could be located and therefore its conclusions could not be endorsed. However, noting the scope of the OHSA, it is agreed the report did not add much to the overall OHSA and there was no perceived need to include it in discussion. However, this report has been given to Mr Ringshaw as background material.

3.6 *At the SUBSAFE Board Meeting on 16 February 1999 it was agreed that the final version of the PSET OHSA was to be subjected to an independent audit to demonstrate that it would stand up to any external scrutiny. LA-SM was tasked to finding a suitable auditor and my understanding was that Curtin University would be canvassed in the first instance.*

3.6.1 Curtin University were approached and they declined as they did not believe they had appropriately qualified personnel to audit the document. It was then thought to utilise RANR legal officers but it was decided they lacked the independence required in the process. After a presentation by Mr Ringshaw on the legal aspects of OHS in the training environment, he was approached to provide an independent assessment of the OHSA and SETF training as a whole. Mr Ringshaw was contracted to provide the necessary services 8 Oct 99 and a draft report is due 27 Oct 99 for submission to the SSB.

3.7 *The foregoing decision of the SUBSAFE Board is not reflected in the Recommendations at Section 7 of the extant OHSA # 29 (8.9.99). Is it therefore to be presumed that DCN will be asked to endorse the continued conduct of PSET by the RAN before any such independent review? If this is the intention , then it is perceived that there is not much point in having an independent audit after the decision has been made.*

3.7.1 Addressed at para 3.6.1.

3.8 *Recommendation at para 7.3 of the extant OHSA # 29 (8.9.99) suggests that DI (N) PERS 75-6 should be updated to , " reflect ....and the recent changes brought about by CBTA". This Recommendation is presumably linked to the Conclusion at para 6.1 however no where in the OHSA are these changes documented. As a minimum it is considered that the CTBA initiatives should be documented as an Annex to the OHSA noting that it has been recommended that they are to form the basis for a future change to the referenced DI(N).*

3.8.1 The changes to the DI(N) as a result of the CBTA are minor and the inclusion of the CBTA documentation within the OHSA is not warranted. It is intended the revised DI(N) will be submitted to the SSB for endorsement before it is forwarded to NHQ.

3.9 *On the basis of the comments at paras 1.3.5. /1.3.6. of the extant OHSA # 29 (8.9.99) should there not be an additional Recommendation incorporated in the OHSA that requires an audit of the SETF , as an Operating and Safety Hazard Analysis ,to be conducted on a regular basis, say biannually ? Or is this catered for in the " Standard Achieved " process with which I am not familiar?*

3.9.1 As SETF is a Training Command responsibility, future audits of SETF will be conducted in accordance with Traingram 3/98 *[NTC Training Management Audit Policy].*

3.10 *It is considered that OHSA Issue # 1 (8.9.99) needs to be reworked to address the deficiencies highlighted above and preferably in time to be reviewed by the SUBSAFE board Escape and Rescue Sub Group on 25 October.*

3.10.1 Not agreed. The entire OHSA will be forwarded to all SSB members 20 Oct 99 for discussion at the SSB meeting on 27 Oct 99

3.11 Annex A: References examined in Previous Iterations of OHSA # 29

OCCUPATIONAL HEALTH AND SAFETY ASSESSMENT #29

PRESSURISED SUBMARINE ESCAPE TRAINING

ANNEX A - LIST OF REFERENCES

A. Forbes, Cdr D.M., RN, FOSM Study into Submarine Escape Training, SUBSUNK Parachute Assistance Group (SPAG) and Submarine Escape and Rescue Assistance Team (SMERAT), Jun 98

B. Occupational Health and Safety (Commonwealth Employees) Act, 1991

C. DI(N) OPS 63-1, RAN Submarine Escape and Rescue Policy, Dec 96

D. DI(N) PERS 75-6, RAN Submarine Escape Training Policy, Nov 97

E. SETF minute, Review of RAN Submarine Escape Training Facility Operating Procedures, Mar 89

F. HMAS STIRLING Health Centre minute 1/4/1 (Loxton, Surg CMDR M.J. RAN), Submarine Escape Training Facility (5ETF): Review of Operations, Sep 95

G. DSMT minute 72/27/2, Revised Submarine Escape Training, Sep 95

H. COMAUSMTNDIVFOR minute 860/98, Submarine Escape Training Facility Management Audit and Certification Report, Feb 98

I. RAN SETF Standing Orders, Volume 2

J. Pennefather, J., A Review ofRush Escape in Collins Class S/Ms, Aug 98

K. Mellon, LEUT G.J., RAN, RAN SUBSUNK Resources Study, Feb 94

L. United States Naval Submarine Medical Research Laboratories Special Report 5P89- 1, The B.A.P. PACHOCA (SS-48) Colhsion: The Escape and Medical Recompression Treatment ofSurvivors, 1989

M. Royal Navy SCOSER, Pressurisation and Ascent as an Essential Part of Submarine Escape Training, Nov 1990

N. ABR 5129, Royal Australian Navy Digest ~ Accidents and Jncidents, May 98 (latest change)

4.0 Comments received from Mr N.P. Whyatt, Directorate of Submarine Engineering

4.1 Para 3.2.1. It is considered important that the process by which the lock is pressurised to 9 metres and how that process is controlled are described. The effective descent rate achieved during pressurisation should also be stated and compared with the maximum permissible rate (it is understood that the maximum descent rate permitted in RAN diving operations is 18 metres per minute). The text implies that trainees no longer conduct deep, buoyant ascents from the submarine section (at 21 metres) at the bottom of the water column, previously practised as part of rush escape training. It is assumed that this is the case.

4.1.1 All descents and ascents are in accordance with ABR 155 and SETF Standing Orders with the processes controlled by qualified SETF instructors. It is not intended to describe the processes in the OHSA.

4.1.2 It is correct that trainees no longer conduct buoyant ascents from the submarine section. Rush escape training is non-pressurised.

4.2 Again, it is considered important that the process by which the SET is pressurised to 18.5 metres and how that process is controlled are described. The effective descent rate achieved during pressurisation should also be stated and compared with the maximum permissible rate. It is also understood that during PSET, the SET is normally operated in the 'non venting' mode instead of the "venting' mode (as instructed in the Guard Book) during the flooding and equalisation phases of the escape cycle. This has the effect of increasing the equalisation period (and decreasing the effective descent rate). It is understood that this practice was adopted to lessen the effects of rapid pressurisation, and hence improve the comfort of the trainee during PSET. If this is still the case, it should be documented in the OHSA.

4.2.1 The response at para 4.1.1 also applies to the processes associated with pressurisation of the SET.

4.2.2 Although the non-venting method does increase the equalisation period and provide more comfort for the trainee, the procedure was developed to allow the SET blister and SET to flood equally and in the shortest time possible. It was designed to take into account the engineering design of the SETF SET and not the preferred training method.

4.3 It is considered that it may be worthwhile for the OHSA to document the 'dive profile' (depth vs time) for each activity undertaken during PSET (buoyant and hooded ascents) and to compare the profiles with the limitations specified in the RAN Diving Manual (ABR 155) to provide a quantitative assessment of the risks. It is recommended that SUMU be *consulted to determine whether this exercise would add any value to the OHSA.*

4.3.1 The water work activities at SETF do not exceed the limitations in ABR 155 and SETF Standing Orders. Doppler readings of SETF staff are being collated by SUMU in order to determine the maximum number of ascents that can be performed by staff. These results will be reflected in SETF Standing Orders.

4.3.2 OIC SUMU and staff have provided advice in both the rewrite of ABR 155 and the OHSA.

5.0 Comments from LCDR S.A. Hamilton, Staff Officer – Policy, COMAUSMINDIVFOR

5.1 Concur with report. Just one point: Para 5.11.1 suggest third sentence should start off: "Since resuming training after the shut down"

5.1.1 Para 5.11.1 to be amended.

6.0 Comments received from LCDR G.M. Burton, Submarine Escape and Rescue Manager

6.1 Other than indicating it is a current requirement in accordance with DI(N) PERS 75-6, there is no discussion why PSET is used or considered necessary. Additionally, as stated in para 12 to Ref B (39th SSB meeting of 23 Sep 98), "...The assessment should also address the hazards created through not providing pressurised training."

6.1.1 The reference described was not known to this author upon handover of the OHSA. However, the purpose between the two drafts (para 1.1.1) is identical and the OHSA has focused only on these aspects. As discussed earlier, it has been decided that PSET is the effective training regime to give submariners the skills and knowledge to escape from a submarine.

6.2 Notwithstanding the purpose of the OH&SA as detailed in paragraph 1.1.1, it is considered that the scope and discussion in the document should also include:

a. further background on the rationale of submarine escape;

b. the probability, including near misses, of an accident that requires escape;

c. the risks of not conducting PSET;

d. the advantages/disadvantages PSET provides;

e. international practices, and

f. conclusion why PSET is used or necessary.

This would ensure a more rounded presentation and provide an uninformed reader, ie., a non submarine qualified member, with the required background and understanding to make a fully considered judgement on PSET.

6.2.1 Not agreed. Using the rationale already described previously, the areas identified above are already adequately addressed or do not require inclusion in the OHSA.

6.3 Whether it has intentionally been done to reduce the size of the document for review and comment purposes is not known, it is considered that the following items or sections should form the standard structure of an OH&SA:

a. Contents;

b. Distribution List;

c. Details of Issues;

d. Glossary, and

e. List of References.

6.3.1 The sections highlighted above were not considered important in the initial draft of the OHSA. These sections will be included, where necessary, in the final version of the OHSA.

6.4 While the revised version of the OH&SA provides discussion as to the conduct of PSET at this time, it does not adequately cover all aspects of PSET, including those shown in para 3 above. The underpinning requirement for the OH&SA is considered to be the presentation and discussion on the need and risks for and not conducting PSET in the RAN.

6.4.1 The need for PSET, whilst not documented in a detailed manner, has already been stated. The training requirement and competencies required to escape from a submarine have been agreed by CASS and training is conducted accordingly. The risks on conducting PSET have been discussed throughout the OHSA.

7.0 CONCLUSIONS

7.1 It is obvious from the comments received that some ERSG members believed the need to conduct PSET should have been addressed in the OHSA. Although this was not this author's expectation, the need for PSET has been addressed in Part 2, albeit possibly not to the satisfaction of some ERSG members.

7.2 The development of a TNA in order to ensure PSET is the most effective method of training submariners in escape is not required.

7.3 If further discussion is required on the need for PSET, the TNA will need to be conducted. Advice from the training experts within LA-SM and industry indicate that the analysis will require outside resources to fully document the training profiles and will more than likely involve the use of psychologists to collect and interpret the data. This process could be expected to take at least 6 months. It is quite possible that to validate the different training methods will require submariners to escape from a submarine.

7.4 It is not the intention of this OHSA to hide the risks. Conversely, all risks have been identified in Part 1 and Part 2 of the OHSA. However, the risks are managed in a controlled manner and eliminated or minimised where possible. The SSB should be left in no doubt that death or serious injury may occur at the SETF in the future. However, this author believes the training received from PSET gives the submariners the competencies and confidence to attempt an escape from a disabled submarine where rescue is not an option.

8.0 RECOMMENDATIONS

8.1 SSB members review the OHSA (Part 1 and Part 2) with their deliberations and actions, if any, forming Part 3 of the OHSA. The independent report should be used to facilitate the decision making process.

8.2 If a TNA is required then funding should be made available in order to contract out the analysis to an appropriate organisation. This organisation has not yet been identified.

8.3 The final OHSA be forwarded to DCN for approval.

8.4 Mr Ringshaw be further employed to conduct a full job safety analysis to ensure all risks associated with PSET have been identified and if necessary, training documentation and procedures amended.

OCCUPATIONAL HEALTH AND SAFETY ASSESSMENT #29

PRESSURISED SUBMARINE ESCAPE TRAINING

PART 3 - THE OUTCOME

PRESSURISED SUBMARINE ESCAPE TRAINING REVIEW 2018

EXECUTIVE SUMMARY

1. The RAN has not reviewed the underlying requirement for Pressurised Submarine Escape Training (PSET) since the inception of training in 1989. PSET carries a significant enterprise risk and the RAN should expect and acknowledge that in time a fatality will occur at the Submarine Escape and Rescue Centre and that medical screening can not completely eliminate this risk. The concept '*so far as reasonably practicable'* (SFARP) under the Workplace Health and Safety Act and Regulation considers what is possible then whether it is reasonable, in the circumstances to do all that is possible. To identify what is reasonably practicable all of the relevant matters must be taken into account and weighed up and a balance achieved that will provide the highest level of protection.

2. Historically RAN PSET serious incident rates (1.4 per 1000 ascents for trainees and 0.15 per 1000 ascents for instructors) are higher than both the US reported multi-country data (serious incident can be expected in 0.1 to 1 per 1000 ascents) and the UK (serious incident rate of 0.5 per 1000 ascents). With only 15 489 trainee ascents the RAN is within the threshold for a catastrophic or fatal episode.

3. The design of submarines and their operating environments has changed significantly since pressurised training first commenced in the UK in 1954, as has rescue capabilities. Submarine accidents are most likely to occur during activities conducted in shallower, more confined water, high traffic areas, during post maintenance trials and training exercises. It is for this reason, that during the more hazardous initial periods at sea after an extensive docking or maintenance period, RAN submarines undertake material certification and training activities with an escort vessel, and are restricted to maximum water depth of 180 m for appropriate depth and watertight integrity checks within a pre-determined geographic area should rescue services be required.

4. Potential outcomes for credible disabled submarine (DISSUB) scenarios indicate a comparable likelihood between surface abandonment, rescue or escape. For nearly all submarine disasters at sea the greatest chance of survival is when the crew remains with the submarine for as long as possible. If the crew of the DISSUB is unable to surface and stay with the submarine, the priority is to surface and conduct abandonment in preference to sinking and waiting for rescue. Escape from a DISSUB is a last choice decision.

5. The current training approach provides practical experience of the pressurised environment, yet many elements of realism are not incorporated. The benefits of escape tower pressurisation and ascending through the water column are not proven and carry significant risk. Realistic training is necessary however we have been unable to demonstrate proven benefits to justify the potential health risks under the current approach to PSET over unpressurised training techniques.

6. The Review considers that the current approach to training has a bias toward tower escape and a more balanced approach across abandonment, escape and rescue can be achieved by removal of pressurised elements. When taking into account all of the current unpressurised submarine abandonment, escape and rescue training and related activities, we assess that effective submarine training is still achieved whilst eliminating exposure to potentially fatal hazards. Improvements such as the use of 'wet' training can be made to deliver more realism in the unpressurised environment.

7. The Review has carefully noted and agreed the findings of the RN 2008 Review of PSET namely “A risk and benefits analysis of pressurised ascent training has been carried out. Neither the deterministic consideration of benefits nor the probabilistic approach demonstrate the pressurised ascent training offers sufficient benefit to justify the associated risk. It is clear that some training is required but many options exist to give more appropriate higher fidelity training without the inherent risks of SETT ascents”. The UK analysis was underpinned by statistical evidence which showed that the expected number of fatalities that occur during pressurised ascent training is over 40 times more than the added number of lives that would be saved in a DISSUB scenario having undertaken the training. It highlighted that the risk has stayed relatively consistent since 1975, and even with extreme errors in estimation, the benefit of pressurised escape training does not outweigh the risks.

8. This Review has relied extensively on data from the UK. This is considered appropriate as the RAN has, since the inception of this training, relied upon the deep expertise of the RN in escape, rescue and survivability matters. The RAN has always acknowledged the RN as the world expert in PSET with their far greater experience in training (overall numbers) and submarine medicine research.

9. It is recommended that:

a. PSET be ceased as soon as practicable and the PSET pre-requisite for submarine training be removed;

b. PSET be replaced by realistic non-pressurised training and the Submarine Abandonment, Escape and Rescue Training Needs Analysis be reviewed as a matter of urgency;

c. Medical standards for submariners be reviewed as a matter of urgency;

d. A detailed communication plan be developed to advise the submarine community and their families of the changed requirements and allied countries who have used the RAN SERC for their training requirements; and

e. A detailed implementation plan be developed to support the transition from pressurised to non pressurised escape training.

2018/3615309

PRESSURISED SUBMARINE ESCAPE TRAINING REVIEW 2018

INTRODUCTION

1. In support of a task in the Submarine Abandonment Escape and Rescue (SAER) Strategic Campaign Plan to clarify the Submarine Escape Training Facility (SETF) future requirements, DGSM commissioned a review (2018/3573584) into whether Pressurised Submarine Escape Training (PSET) conducted at the Submarine Escape and Rescue Centre (SERC) should continue, and if not, what alternative training should be considered.

AIM

2. The aim of the Review is to evaluate the future requirement for submarine escape training, to consider whether pressurised or unpressurised training achieves the assessed training need and make determinations considering the risk and benefits of conducting PSET.

3. Taking into account the guidance at Ref A, the Review Team determined there are two principal areas that need to be addressed and answered by the Review:

a. Does the benefit of PSET outweigh the risks?

b. Is pressurised training essential for effective submarine escape training?

BACKGROUND AND HISTORICAL PERSPECTIVE

4. The SETF began construction in 1987 and commenced formal PSET in 1989 (instructor training commenced in 1988). Prior to this, escape training was undertaken at the Royal Navy Submarine Escape Training Tower (SETT) facility at HMS DOLPHIN, Gosport, Hampshire. With the introduction of the Collins Class the SERC provided the RAN with a sovereign submarine escape training capability.

5. As a consequence of the OBERON Class acquisition and until mid 1980s, the RAN was heavily reliant upon the resources and corporate knowledge of the Royal Navy to provide deep expertise in escape, rescue and survivability matters. SERC infrastructure requirements, training concepts and standards were adopted from the RN and it was typically accepted their system would meet Australian requirements; however, doctrine and policy rarely included detailed information or reasons behind decisions[1]. No Australian documentation which outlines the foundation requirements for pressurised training has been revealed during this Review.

6. Training at the SERC has followed a similar form since its commencement in the UK in 1952, with a number of ascents being conducted by the trainees, intermixed with lectures and videos in the classroom environment. The current method of pressurised training was

[1] SUBSUNK Study 1996: The RAN's Knowledge Base

established by the Ruck-Keene committee in 1946 responding to the experiences of escape during and immediately prior to World War II where British submarines had a fateful record of less than 30 successful escapes in 77 submarine sinking events[2]. The committee was responsible for the recommendation to fit future submarines with escape chambers, which were already in use on US submarines, and for adopting free ascent as the primary means of submarine escape. The Ruck-Keene committee recommended building a 60 to 100 feet deep training tower to teach buoyant ascent to all submarine personnel as the primary means of submarine escape. UK training was modified in 1966 with the introduction of Tower Escape and the hooded escape suit.[3] Meanwhile, the USN selectively taught free ascent in 100 feet training towers to build confidence as a secondary means of escape; the primary means was from a rescue chamber. At the time, the US had reservations about the safety of training all personnel in free or buoyant ascent as a primary means of escape. An important conclusion from the Ruck-Keene report was successful escape did not depend only on ascent, but required procedures, equipment and training to survive in the submarine and to prepare for and initiate escape, as well as survive afterward on the surface.

7. **United States Navy PSET**. From 1962 the US Submarine Force adopted the use of the Steinke Hood escape appliance—an inflatable life vest with an integrated hood that allowed the escaper's head to remain dry throughout the ascent as they breathed normally. By 1974 the USN assessed that the lack of thermal protection, the complexity of escape tower operating procedures, and slow (20 minute) single man escape cycles made use of this method of escape debatable. Training under these constraints when also considering the dangers was considered unproductive.

8. In 1983 the USN ceased pressurised escape training due to the limited capability of the Steinke Hood, concerns with safety, and the financial cost of maintaining the submarine escape training tower. US reports around this period highlighted the significant risks such as barotrauma and decompression sickness being attributed to the buoyant method of escape and associated operating procedures. Between 1983 and 2009 USN submarine escape training was conducted unpressurised using a shallow water pool and simulated escape fittings.

9. USN PSET was reintroduced in 2009 after nearly a 30 year absence. In 2001, as part of an assessment of submarine escape and rescue capabilities and requirements, the USN Submarine and Rescue Review Group recommended accelerating the installation of a new escape suit on all submarines (the same suit in use at the time by many other countries including Australia and the UK). The USN considered that only a pressurised escape tower provided adequate training to ensure successful escape from a disabled submarine. Furthermore, the USN assessed that the most critical attribute involved with use of the new escape suit occurs during the pressurisation phase in the escape tower and during the subsequent escape through the submarines upper hatch. The USN deemed that training should include the effects of the escape tower flooding process and resultant pressure on the escape suit itself, together with the effect of buoyancy during this process as the escapee progresses through the escape hatch. Part justification for pressurised training included this method being used by other countries including Australia and the UK at the time.

---

[2] Submarine Escape And Rescue; An Overview CDR Jay C Sourbeer, MC, USN
[3] Royal Navy 1998 Review of Submarine Escape Training

10. USN PSET is not mandatory. Unpressurised training is the minimum requirement for completion of the basic submarine course and submarine qualification. Requalification of PSET is voluntary. Failure to meet the physical standards for USN PSET does not disqualify a member for submarine duty and PSET students are not disqualified from submarine service should they fail to complete PSET. USN escape training data reported in 2014 reveals only 32 percent of recruits received the PSET qualification; the remainder undertook unpressurised training[4]. This represents approximately 20% of the entire afloat submarine force. No incidents were reported to have resulted in lost duty time, permanent disability or death. However, since the 2014 report one case of AGE has been recorded where the student returned to full duty[5].

11. **Royal Navy PSET**. The RN ceased pressurised escape training in 2009 after studies were unable to provide a definitive conclusion that the benefits of pressurised training outweigh the risk of death or serious injury such training carries. Furthermore, the escape training tower was judged to not fully deliver the pressurised escape experience required[6]. While the aim of the RN review was to provide evidence regarding the justification for pressurised training and to consider the risks and benefits, it was placed in context by the *Management of Health and Safety at Work Regulations 1999* and the then recently introduced *Corporate Manslaughter and Corporate Homicide Act 2007*.

12. Prior to 2009 much of the medical and diving research that underpins the current global PSET body of knowledge was conducted at the UK training facility. The UK report highlighted the difficulty in making a case to support pressurised ascent training; the majority of hard benefits were considered to come from the non-ascent elements, such as equipment familiarisation and understanding the drills and procedures for ascent. Furthermore, the UK review identified the main soft benefit of pressurised training is its contribution to submarine ethos and corporate identity. The report drew attention to the claim that pressurised training may contribute to increased confidence levels in the event of a disabled submarine (DISSUB), but this benefit might be reduced by lack of realism in the current training, such as temperature and visibility[7].

13. The UK analysis was underpinned by statistical evidence which showed that the expected number of fatalities that occur during pressurised ascent training is over 40 times more than the additional number of lives that would be saved in a DISSUB scenario having undertaken the training. It highlighted that the risk has stayed relatively consistent since 1975, and even with extreme errors in estimation, the benefit of pressurised escape training does not outweigh the risks.

14. The UK report noted that submarine operations had become safer and that there is less reliance on escape compared to rescue. The argument comprised the considerable advances in submarine escape and rescue and the introduction of much enhanced rescue capability which is predicted to be viable for 40% of DISSUB scenarios.

---

[4] Initial review of the US Navy's pressurized submarine escape training outcomes. UHMS, Inc 41(1):33-40 March 2014
[5] Correspondence between PSET Team Leader – JFD Australia and US Naval Submarine School Escape Training Program Manager 22 February 2018
[6] Cessation of Pressurised Training at Fort Blockhouse: Personal Message from CINCFLEET 29 February 2009
[7] Royal Navy Pressurised Ascent Training Review 24 Jul 2008

15. **History of Submarine accidents**. While the current RAN pressurised escape training concept has mostly remained aligned to the early lessons from WWII era submarines, analysis of submarine accidents post-WWII since 1946 highlight that the number of these incidents has declined three-fold between the 1946 to 1974 period, and from 1974 even fewer accidents have occurred[8]. Fewer new submarines have sunk during the period 1975 to 2018 when compared to the post war period 1946 to 1974, supporting the view that improvements in submarine design and operating procedures have decreased the probability of an incident. A 1988 report highlighted the probability of a submarine sinking in peacetime is extremely low; the world rate for accidental sinkings being less than 0.001 per submarine year.[9]

REAL WORLD SUBMARINE ESCAPE AND RESCUE

16. Analysis of submarine accidents that would have benefited from an escape, rescue or abandonment response reveals 57% were caused by collision, grounding or loss of control; with collision the single most cause at 33%[10]. 57% of incidents occurred in escapable depths of water (0-200 m); a further 10% occurred in water depth available for rescue (200-610 m); while 33% of incidents occurred in water too deep to support rescue. Incidentally, these numbers are analogous to the operating profile of the Collins Class submarines whereby the amount of time spent in escapable water depths is 43%; and 40% of the time is spent operating in water depths to deep for rescue. Of the 96 incidents analysed the majority were major submarine incidents since 1960. 37% led to loss of some or all of the crew or loss of the submarine.

17. For nearly all submarine disasters at sea the greatest chance of survival is when the crew remains with the submarine for as long as possible. If the crew of the DISSUB is unable to surface and stay with the submarine, the priority is to surface and conduct abandonment in preference to sinking and waiting for rescue. Escape from a DISSUB is a last choice decision.

18. Royal Navy modelling used to determine credible DISSUB scenarios and the range of potential outcomes indicates a comparable likelihood between surface abandonment, rescue or escape. Surface abandonment is the most advantageous option in 23% of DISSUB scenarios; rescue is most advantageous in 23% of scenarios; and escape is the most advantageous in 32% of scenarios[11]. Analysis of the 33 potential scenarios in the RAN SAER Operational Concept Document broadly supports these findings; with the Time To First Rescue (TTFR) and the many variables accompanying the potential condition of the disabled submarine being key factors in determining the prospect of escape before rescue forces arrive. For instance, TTFR in a best case scenario close to Fleet Base West will be almost 44 hours, while a DISSUB in deeper waters near Indonesia the TTFR will be 122 hours[10].

19. The foremost reasons for escape are uncontrollable flooding or deterioration of the atmosphere. Both situations could result in the requirement to perform surface abandonment, or escape whilst submerged or bottomed on the seabed. If escape is required, the options are

---

[8] Submarine Accidents: A 60-year Statistical Assessment: Christopher Tingle
[9] Escape and Rescue from Royal Navy Submarines. Report on Submarine Credible Accidents, 1988;41-58
[10] SEA1354 SERAS Time To First Rescue Scoping Study: TTFR Scoping Report Frazer-Nash Consultancy Ltd
[11] Review of the 'Duty of Care' Implications Associated with Proposed Options for Future RN Submarine Escape, Rescue, Abandonment and Survival Training Provision. J A Byrne, A H Whittaker, M Waters & A Head. 09 Jan 2009

Tower Escape or Rush Escape; both methods are hazardous and come with significant constraints, particularly physiological hazards and the limited maximum depth at which escape is possible. Tower escape is more likely if watertight integrity of the submarine has not been breached, in which case the submarine crew can remain within the submarine, continue efforts to surface the submarine, and prepare for rescue or escape. If the pressure hull has been breached then rush escape may be required.

20. In situations where escape is the only option the senior survivor[12] will need to decide whether to commence tower escape or wait until rescue forces arrive with a dedicated rescue vehicle. While rescue is the preferred method, the course of action is influenced by the depth of water, pressure and other internal environmental concerns. This could result in survivors being forced to escape prior to the arrival of rescue forces.

21. Submariners will be required to draw on their experience during training and follow the procedures in order to successfully escape from the submarine. Since the pressurised elements of training is only associated with escape, the following sections provide an overview of these techniques but will not include detail of rescue and abandonment.

22. **Tower Escape**. The escapee wears an escape suit with the hood assembly fully enclosed and enters the escape tower. The top hatch is wound to 'idle' and kept shut by sea pressure, and the bottom hatch is shut. The escapee plugs an inflation line from the suit into a connection within the tower in order to breathe diver quality air while the escape suit also inflates. The tower is flooded manually (normally from the escape compartment or from inside the tower if it is the last person escaping), and when the tower pressure reaches external water pressure, the tower equalises and the upper hatch opens with the assistance of a counterbalanced spring. The escapee unplugs from the tower connection in a buoyant state and egresses the tower to commence the ascent. The air inside the suit continues to expand during the ascent and the excess air is vented through relief valves in the hood, keeping the hood inflated and allowing the escapee to breath normally all the way to the surface. The rate of ascent wearing the Submarine Escape Immersion Equipment (SEIE)[13] is over 2.5m/sec.

23. Due to technical constraints of the Collins Class escape system combined with the physiological limits of the human body, the maximum recommended depth for Tower Escape is 180 m. This depth is well short of the maximum operating depth of the Collins Class Submarine, which spends approximately 40% operating in water depth less than 180 m.

24. It is for this reason, that during the more hazardous initial periods at sea after an extensive docking or maintenance period, submarines undertake material certification and training activities with an escort vessel, and are restricted to maximum water depth of 180 m for appropriate depth and watertight integrity checks within a pre-determined geographic area should rescue services be required. This offers insight into the approach taken during the more hazardous periods of submarine material certification to reduce likelihood of having to employ escape techniques in the event of a DISSUB.

---

[12] The senior submarine qualified member of the ship's company present in the compartment
[13] The SEIE is a whole-body suit and one-man life raft which provides extensive protection for the submariner on reaching the surface until rescued

25. **Rush Escape**. This method of escape is only used when Tower Escape is not suitable, such as an uncontrollable flood or when the tower is defective. For Rush Escape to commence the forward compartment must be flooded until the pressure inside the compartment equalises with that outside the submarine. The escapee wears the escape suit but with the hood assembly partially closed so that clean air can be supplied from mouthpiece breathing units attached along air lines in the compartment. Upon equalisation of the compartment the first escaper on a long breathing unit opens the Upper Accommodation Space hatch, checks the casing cover is clear and starts an ascent. The Rush Escape sequence is commenced with personnel 'fleeting' towards the tower, then removing the mouthpiece and zipping up the hood just before ducking under the escape trunking to exit the submarine. Rush Escape has a high casualty rate except from the shallowest of depths.

26. The Collins Class Submarine Guard Book states Rush Escape is depth limited between 48 m and 60 m. This is calculated to be the depth bracket of the submarine's keel at which internal and external pressures equalise, when the internal water level is at the base of the Escape Trunk. Difficulties with flooding the submarine's forward compartment if required make Rush Escape a challenging proposition—as well as the impact of increased pressure exposure and resulting acid, chlorine gas, electrocution and potential explosion hazards. At time of writing the SUBSAFE Board was conducting analysis in order to further understand the feasibility of Rush Escape.

27. The SEA1354 Phase One Operational Risk Analysis for Submarine Rescue Report contains extreme risks for Tower Escape and Rush Escape. Any casualties with limb injuries or those who cannot function unaided will not be able to egress via the escape tower as there is no means for injured survivors to enter the tower and remain engaged with the air charging connection. Injured DISSUB survivors are unable to conduct Tower Escape and can only be recovered by rescue. For Rush Escape the extreme risk statement underlines the limitations with this technique and calls into question the effectiveness of this capability.

28. **Escape Hazards**. In escape scenarios cerebral arterial gas embolism (AGE) with pulmonary barotrauma (PBT) and exposure hypothermia are two credible life threatening medical conditions likely to affect survivors. Decompression sickness (DCS) is also likely, particularly when the ambient pressure of the submarine is greater than 1 ATA[14] or delays to the cycling of the escape tower allow greater saturation at external water pressure.

29. DCS is also more likely if survivors have endured the escape compartment for extended periods at increased ambient pressure, existing in a cold, dark and very humid environment. Oxygen will be reduced with elevated carbon dioxide concentrations in the atmosphere, along with possible elevated levels of other contaminants. There may be food and water restrictions, resulting in fatigue and dehydration and elevated anxiety levels. RN User Requirements Documentation for Submarine Escape, Rescue, Abandonment and Survival (SMERAS) states the expected rate of decompression illness for escapes at 180 m is around 5%, but acknowledges that there may be more or less at this and other depths.

30. PSET has no impact on whether or not a submariner will develop DCS on escape. For those survivors who have been saturated in air who make an ascent from over 1.7 ATA,

[14] Atmospheres Absolute (ATA) is defined to be one standard atmosphere of pressure at sea level

rescue and transfer under pressure is the preferred means of egress from the submarine. The risk of life threatening DCS increases with depth. PSET is conducted from a health perspective solely to prevent the occurrence of PBT.

31. **Summary**. Submarine accidents are most likely to occur during activities conducted in shallower, more confined water, high traffic areas, during post maintenance trials, and training exercises. It is for this reason, that during the more hazardous initial periods at sea after an extensive docking or maintenance period, RAN submarines undertake material certification and training activities with an escort vessel, and are restricted to maximum water depth of 180 m for appropriate depth and watertight integrity checks within a pre-determined geographic area should rescue services be required. Licensing activities are graduated to take into account the water depth and proximity of rescue services. Historically, 67% of submarine sinkings have been within rescuable or escapable depths. Generally Collins Class submarines operate 40% of time in waters too deep for either escape or rescue. Injured survivors can only be recovered by rescue.

RAN PSET

32. The RAN Submarine Escape and Rescue Policy is contained in Defence Instruction (General) (DI(G)) OPS 35-2, which outlines the objectives, requirements and responsibilities of the SAER organisation. This document identifies the requirement for all RAN submarines to have a capability to utilise Single Escape Tower (SET) and Rush Escape methods. It identifies rescue as the preferred method for saving submariners from a DISSUB but recognises that escape may still be required if rescue forces are unable to react before conditions in the submarine deteriorate. The DI(G) provides direction for the conduct of training of submarine personnel in abandonment, escape and rescue techniques but does not stipulate the requirement for PSET.

33. The requirements for escape and rescue training are detailed in DI (Navy) PERS 75-6 – *Submarine Escape Training Policy*. This DI(N) was cancelled in Dec 2017 due to amendments to the *Defence Act 1903* that came into affect on 1 July 2016 which removed the authority for Service Chiefs to issue or amend Defence Instructions. The Submarine Force Headquarters advised they are in the process of reviewing the most appropriate format to retain submarine escape training policy material.

34. The DI(N) outlines the mandatory prerequisite of successful completion of the PSET course prior to trainee submariners being posted to a submarine. Requalification of submarine escape training competencies must be undertaken every three years; personnel 35 years of age or older may elect to complete unpressurised training to re-qualify, but initial trainees over the age of 35 must complete PSET. The 35 year age limit was based on the knowledge that the biggest age related decreases in lung compliance occurred in the 30-39 year age group with a theoretical increase in risk of PBT.

35. Following formal training, Verification of Competency (VOC) activities include escape related tasks that are required to be completed by trainee submariners using the SMSQ Taskbook (Submariners Sea Qualification – Common and Escape Taskbook), and by submarine qualified personnel who have not been posted to a seagoing position for over 18 months using the SSATB (Submarine Safety Assessment Taskbook). Furthermore, all submarine crew members must complete submarine escape modules (dry escape training) as part of annual submarine crew continuation training, and pre-workup training evolutions for abandonment. The completion of taskbooks and formal crew continuation training

requirements certify that all members of the crew demonstrate 'current competency' and possess the knowledge and skills to safety operate and utilise the escape and supporting systems.

36. **PSET Waivers**. PSET waivers are common, mostly due to SERC defects and course cancellation, short notice postings or when submarine programs change. At the time of this Review there were 25 waivers granted to seagoing submariners requiring requalification, and one waiver for an initial trainee in order to allow training progression after cancellation of PSET due to SERC defect. The current management of PSET waivers is considered sound, though the pragmatic approach of waivers for trainees does lead us to question the tangible import assigned to the pressurised component. Two qualified submariners were made Permanently Medically Unfit (PMU) for PSET following two serious incidents while undertaking requalification in 2017. In both cases the individuals were provided with a waiver due to previous successful completion of PSET.

THE POSSIBILITY OF HARM WHEN EXPOSED TO PSET

37. The health hazards associated with PSET are outlined in Annex A. The most serious life threatening health hazards are PBT with or without AGE in both trainees and instructors with the additional risk of DCS in instructors.

38. **Hazard Controls**. The PSET Safety Case Report outlines the hazard controls to reduce the probability of occurrence, and mitigations to reduce the severity of potential consequences. They are step-by-step measures along a potential injury path, and commence at initial submariner medical screening where personnel are examined through chest x-ray, lung spirometry, body mass index, ECG test and a recompression dive familiarisation. Thereafter submariners are subjected to periodic medical and annual dental examinations.

39. For the period 24 hours prior to commencing PSET alcohol consumption is limited and trainees are not permitted to undertake strenuous exercise, flying, dental work, blood donation, and diving. Immediately prior to PSET, the trainee is medically examined to ensure they are 'fit to dive'.

40. Controls during training activities take into account the progressive structure of training, requiring trainees to demonstrate performance prior to progressing to the next stage of training. Training procedures include medical briefings, safety briefings, and observation of practical demonstrations. All in-water training involves close monitoring and supervision during accents, with instructor intervening if required at various depths in the water tank.

41. Post PSET controls include direct observation by medical staff immediately after completing ascents for any onset of symptoms of pressure related injuries. This is followed by an indirect observation period where trainees are not permitted to leave the training facility. A Medical Officer trained in Underwater Medicine is required to be within the facility during all training activities with at least one recompression chamber available to ensure prompt treatment. For 24 hours after undertaking PSET the same limitations as pre-PSET are enforced in order to reduce the risk of a pressure related injury developing.

42. **PBT and AGE**. Despite diligent employment of existing hazard controls, manifestation of PBT or AGE is possible during PSET. PBT and AGE still occur in individuals who have been declared medically fit and assessed by instructors to breathe correctly during the ascent. This is most likely related to areas of increased lung compliance

at a microscopic level. The RN Institute of Naval Medicine in 1998 reported that any level of pressurised training will lead to casualties, and it is not possible, by medical screening, to reduce the casualty rate further[3]. Moreover, there can be no complete accounting for the incidence of PBT or AGE, other than to acknowledge that it may exist and serious injury or fatality may occur.

43. **International PSET Incidents**. In 1997 the US Naval Submarine Medical Research Laboratory (NSMRL) completed a quantitative risk assessment of medical hazards encountered in submarine escape training[15]. Eleven nations including Australia provided input and statistics of training incidents. The report noted that the most serious hazard is AGE (including cerebral AGE) which may occasionally result in the death of the trainee. The report concluded:

"The data shows that serious incident (lung rupture with evidence of gas embolism to the brain) can be expected in 0.1 to 1 per 1000 ascents. Of those with a serious incident, between 1% and 10% will probably die despite the best available treatment. There is a substantial random component to the incidence of pulmonary barotrauma such that we cannot predict very well when an incident or death will occur."

44. Interestingly, the RAN data (from 1988 to late 1995) which contributed to this report reported a relatively high incidence of 3.0 incidents per 1000 escapes. An explanation for this difference was not provided although it is noted that contributing nations used differing depths for PSET. It is postulated that the increase in RAN serious incidents related to the rate of DCS in instructors, which later reduced with a change in practice.

45. Following the USN report, a 1998 RN review of submarine escape training conveyed that the serious incident rate over 20 years was 0.5 per 1000 ascents and the fatality rate was 0.009 per 1000 ascents (1 in 110 000)[3]. The 20 year period is significant because the UK training techniques employed during this time are the closest international comparison to the current RAN PSET curriculum that we have been able to make, although the UK PSET escape depth was 30m (vice 20m in the RAN).

46. A higher UK injury rate was experienced prior to 1975, at which time a 30m buoyant ascent was eliminated following a major safety review. Of note, the USN and RN reports only include trainee casualties; US instructor casualty rates are unknown, however UK instructors suffered 24 serious incidents including one fatality during the period up to 1997.

47. A 2008 RN review which led to the cessation of pressurised ascent training concluded that the probability of a death attributable to RN PSET equaled 0.13, compared to the 0.003 per annum estimated number of lives saved as a result of training[7]. That is, a fatality from training can be shown to be more than 40 times more likely that the saving of a life in a DISSUB scenario through carrying out the training.

48. Following the resumption of voluntary PSET in the USN in 2009, there has been 11 395 ascents using the SEIE and one AGE has been recorded where the student returned to full

---

[15] A Medical Risk Assessment of Pressurized Submarine Escape training: US Navy Internal Working Document prepared for CNO-879 4 June 1997

duty[16]. A 2014 report that reviewed the first 39 months of operation shows that 2859 candidates qualified for PSET, yet 642 trainees failed to complete training with the most common medical issue being middle ear barotrauma[17].

49. **RAN PSET incidents**. The SERC has provided a consolidated list of historical PSET related injuries however there is a strong belief that this is not complete with a particular emphasis on under reporting in some years.

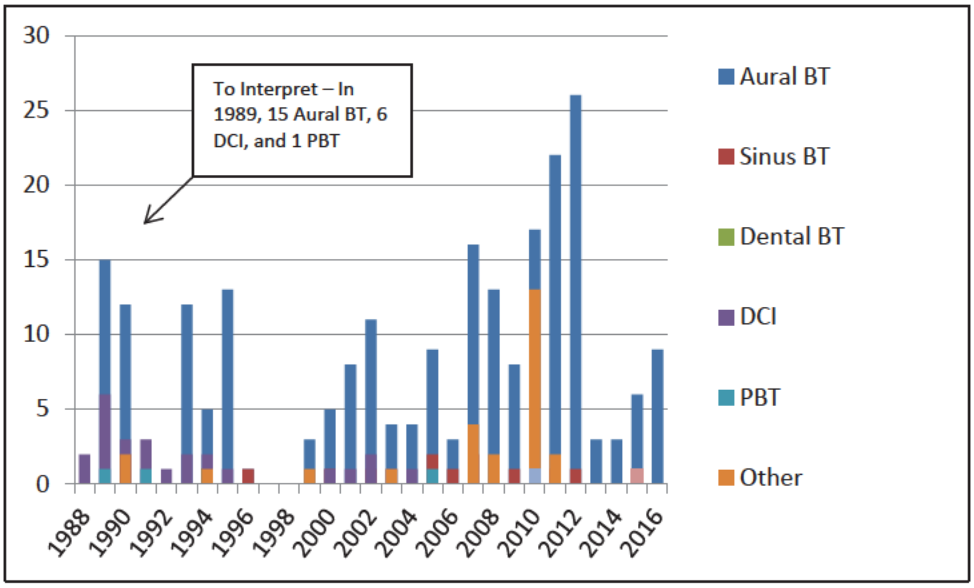

Figure 1: Historical PSET Related Injuries

50. During the period 1988 to 2016 the SETF has recorded 26 cases of decompression illness and 3 cases of PBT (interpretation of this data is difficult due to a change in medical nomenclature where a delineation between DCS and PBT was not considered essential and both conditions were included under the one disease category of decompression illness). There was an additional serious injury as a consequence of an instructor suffering a hypoxic blackout (not enough oxygen to the brain).

51. A review in 2014 noted 160 PSET incidents were reported as Defence Workplace Health and Safety incidents between the period 2007 and 2014 of which 129 (81%) were aural barotrauma. Over the period 2007 until 2013 inclusive, the incidence of middle ear barotrauma varied between 5-34%, with the average being 15% per year. Most are assessed as grade 1-3 (retraction of the tympanic membrane; slight or gross haemorrhage within the tympanic membrane) although grade 5 (burst eardrums) has occurred in 1.6% of cases[18]. Once a middle ear barotrauma has occurred the trainee is unable to continue with training on that course.

---

[16] Correspondence between PSET Team Leader – JFD Australia and US Naval Submarine School Escape Training Program Manager 22 February 2018
[17] Initial Review of the US Navy's pressurized submarine escape training outcomes: UHM 2014, VOL. 41, No.1
[18] RAN PSET Review 2014 CMDR D.L. Stevens RANR

52. The RAN PSET Safety Case Report contains data on serious personal injuries to staff and trainees. It classifies serious injury to include DCS, Cerebral AGE, PBT, Head Injury and other serious trauma related causes.

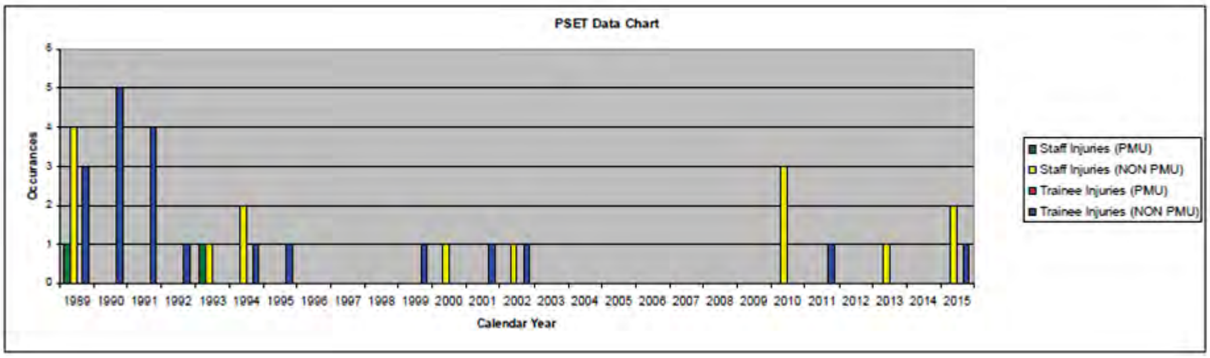

Figure 2: PSET Safety Case Report 2016 statistics of serious personal injuries

53. At time of writing, 5163 trainees have undertaken pressurised training and performed approximately 15 489 ascents. The total number of ascents during PSET has been recorded; however they do not differentiate between instructor and trainee, or what compartment the ascent was from. A realistic estimate has been made by applying the training syllabus and number of ascents per trainee since commencement of PSET in 1989. 22 serious injuries against trainees are recorded in the PSET Safety Case plus two personnel were made PMU PSET in 2017. There have been no fatalities.

The serious incident rate for trainees undertaking RAN PSET is 1.4 per 1000 ascents

54. Since commencement of the RAN PSET, 100 instructors have completed 115 347 accents. The PSET Safety Case records 17 serious incidents; of these, two personnel were medically categorized as PMU Diving, Submarines and Aircrew as a result of pressure related injuries. There have been no instructor fatalities.

The serious incident rate for instructors conducting RAN PSET is 0.15 per 1000 ascents

55. **Recent RAN PSET Incidents**. The most recent serious incidents during PSET occurred on 3 and 31 Oct 2017 both as a result of buoyant ascent from 9 m. Both trainees were undertaking requalification having previously successfully completed PSET on two or more occasions. For one member the final diagnosis remains uncertain, however PBT (pneumomediastinum) could not be excluded completely. The other member was diagnosed with definitive PBT with cerebral AGE. Both trainees have made a full recovery and have been made PMU PSET.

56. Post-event clinical review assessed that all screening was appropriately and competently conducted, and both members were fit to conduct PSET in accordance with ADF standards. The cases were well managed by on-scene medical and support staff with appropriate recompression therapy applied. The review noted that this was the "classic scenario…unambiguous and represents the rare but potentially catastrophic event".

57. **Treatment of pressure related injuries**. PSET mitigation includes prompt and appropriate treatment by trained medical staff including the use of recompression therapy which may reduce the consequences of a serious pressure related injury. However, the

response to recompression treatment is not consistent and many individuals are left with significant neurological impairment despite prompt recompression.

58. In view of the indiscriminate factor of a PBT episode, the availability of medical treatment including recompression therapy appears to carry substantial weight in the current determination to deliver pressurised training. However, a Submarine and Underwater Medicine Capability Review in 2017 highlighted the inexperience of the SERC medical staff in treating serious hyperbaric injuries, a lack of ongoing professional development opportunities to increase their competence, and constraints in using the on-site recompression chambers (RCC operating treatment depth limited to 20m, no ability to mechanically ventilate a patient in the RCC and no ability to undertake best practice vital signs monitoring) [19]. Fortunately the two most recent cases did not require extensive cardiovascular or respiratory support.

59. **Summary**. RAN serious incident rates are higher than both the US and UK and with only 15 489 trainee ascents we are within the threshold for a catastrophic or fatal episode. Central to this Review is the consideration of whether PSET should be conducted with any likelihood of PBT or AGE, not the extent to how we might treat an occurrence if realised.

CURRENT PSET APPROACH

60. An individual is in date for submarine escape training when proficiency is awarded on completion of either the pressurised or unpressurised training. This provides the option for an individual above the age of 35 to elect not to undertake the pressurised component of the course. The pressurised training course contains the same modules as the unpressurised course but includes an extra module (Buoyant Ascent Training).

61. Prior to undertaking PSET trainees are required to sign a 'Statement of Risk of PSET' which is not designed to waiver the Commonwealth's responsibility for health and safety, but rather inform the trainee of the potential risk of injury and death and be fully informed of the associated risks. The statement of risk highlights the possibility of PBT and AGE and informs the overall death rate worldwide is approximately 1 in 98 000 and overall rate of significant injury worldwide is approximately 1 in 10 000 ascents.

62. During pressurised escape training two ascents are performed from the SERC 9 m lock with head in water wearing a training lifejacket and one ascent from the SET wearing the SEIE with head in air (breathing normally). The head in water ascents are performed to teach the trainee submariner in a 'worst case' scenario; that is, continuous exhalation during ascent when their head is in water. This could occur as a result of a hood rupture or incorrect dressing of the SEIE (failing to completely zip up the hood). Included as a 'worst case' scenario is the possibility of conducting a rush escape before being able to don the SEIE (e.g. an uncontrollable flood), which would result in a head in water ascent. We have previously noted the limited effectiveness of the Rush Escape technique from Collins Class submarines.

63. Trainees are required to complete one ascent from the 20m SET wearing the SEIE. The 9 m head in water ascent is also performed as mitigation for the SET ascent in the event of a hood rupture. There have been no observed or reported occurrences of hood burst

[19] Submarine and Underwater Medicine Capability Review 2017 by RADM R Walker RANR

including during RAN ESCAPEX activities, although trainees use a more robust suit designed especially for PSET. The training suit is bench tested and has a visual inspection every 20 runs in addition to inspection by instructors before the ascent. The MK11 SEIE operational suit is only used by instructors during the Rush Escape demonstration; the suits are removed from submarines which provides a quality assurance process and allows the RAN to remove suits by batch number should a significant defect be identified.

64. During unpressurised and pressurised training, students conduct in-water training and are assessed on the correct blow rate required for buoyant ascent with the head in water. We note that during all submarine escape training activities the *Golden Rule* is emphasised and is a well known adage amongst submariners—*breathe normally all the way to the surface, and never hold your breath, if however for some reason you have to make an ascent with your head in water blow out all the way to the surface, and never hold your breath.*

65. **Discussion**. The current training provides an experience of the pressurised environment, yet interactions with pressurised elements of SET escape are mostly outside the control of the trainee. For example, when tower equalisation occurs and the upper hatch opens the trainee will automatically start to float out of the tower and become disconnected from the stole charging valve—all they are required to do is breath normally during the ascent to the surface and not hold their breath. Important aspects of SET escape include correct entry into the tower while protecting the stole charging connection, then remaining plugged into the stole charging valve (this inflates the stole and hood, providing fresh air to breathe). SERC 2017 records show that unplugging is the most common procedural intervention by instructors when trainees are in the escape tower. It is possible for this aspect of training to be undertaken unpressurised during realistic simulation of flooding the escape tower.

66. A literature search has failed to find any reports which provide evidence that there is long term retention of the water skills taught during PSET. The three year requalification period currently undertaken appears to be an arbitrary decision; no evidence exists to support the concept training remains effective even one month or one year, let alone 3 years after it is undertaken.

67. The training depth of 9 m and 20 m provides the trainee with the experience of ascent for 6-7 s and 7-8 s. The value of this is questionable but it does provide the trainee with some experience of continuous exhalation during ascent when the head is in water (buoyant ascent) and some level of confidence in the escape system (hooded ascent).

68. The 9 m ascent with head in water training will not guarantee that an escapee will commence breathing out in the event of a hood burst, particularly in a real life escape when exposed to other factors such as contaminated and cold water, dark lighting, fear and anxiety, and rapid ascent. Taking into account the small chance of hood burst and the considerable pressurised training risks, we suggest that an appropriate level of experience may be achieved through the current 'wet' unpressurised training module where trainees are required to demonstrate competency in the correct blowing rate.

69. Confidence in the escape system can be demonstrated and reinforced through the combination of all escape training elements as well as conduct of the current escape tower functionality trials which are completed to the maximum functional depth on all submarines during post maintenance trials. We recognise the advantage any experiential learning may provide, but we have seen little evidence to support the benefits of escape tower

pressurisation and ascent through the water column, particularly when contemplating considerable health risks to trainees and instructors.

70. The SETF Operations Manual outlines the purpose of training is to provide submariners with the "theoretical knowledge and practical skill to escape from a DISSUB" with activities in the water tank allowing trainees to "practice and gain confidence with the equipment and escape techniques" [20]. In our quest to identify exactly what elements of the escape sequence would benefit from pressurised training we note that training material provides little insight into the specific required learning outcomes; the buoyant ascent training lesson management guide states the learning objective is to "perform ascents from the SERC 9 m lock with head in water wearing a Training Life Jacket" and "Perform an ascent from the SET with head in air".

71. Not all elements of realism are incorporated during buoyant ascents; training is conducted in warm fresh water, the DISSUB may have contaminated, cold salty water; the SERC water column and tower displays 100% lighting, the DISSUB could have no lighting or be dimly lit using cyalume sticks; training is performed with an 'even keel', the submarine could be on any angle; the training atmosphere is clean, at sea the survivor may be under pressure where one breath from the compartment could be fatal; and, training is undertaken as a controlled evolution, at sea both fear and panic are likely.[21] We submit that other experiences not represented in the current training may be just as important as the pressurised aspect—realistic training is necessary, but the benefits of escape tower pressurisation and ascending through the water column are not proven and carry significant risk.

72. UK SETT Instructors who have conducted escapes from 180 m support this notion: "even if you have in the past done hooded ascents…the real experience will be quite different"[22]. During PSET trainees are taught to breathe normally throughout tower flooding, equalisation and ascent phase. This is achieved effortlessly in the SERC SET since ascents are only conducted from 20 m using non-vented runs; that is, tower pressure increases are mostly steady from the moment the tower commences flooding. In a real tower escape situation, the guard book instructs vented runs are to be used (except for the last man). This results in pressure commencing at the last couple of feet when the water level reaches the top of the tower vent pipe (the vent valve is then shut), at that point tower pressure will rapidly start to increase. This is intended to minimize the amount of time the escapee is under pressure and reduce the risk of DCS, but at deeper escape depths *normal breathing* becomes progressively more difficult to maintain as pressure is doubled approximately every 4 s (attributable to the design of the tower flood valve orifice). For example, pressure would increase from half the escape depth pressure (90 m) to full escape depth pressure (180 m) in the last 4 s; an escapee breathing normally (e.g. on a 4 s cycle) just as they would in the training SET, would find they have hardly any air to breathe out which could lead to serious injury or fatal consequences. The deviation from real tower escape procedures has been established to reduce the risk of aural barotrauma during training and allow quick intervention if required by the instructor located in the SET Blister, however this aspect of current PSET is not fully representative of what the escapee may experienced during tower escape from a real DISSUB.

---

[20] ABR 6799 Volume 1 SETF Operations Manual – Submarine Escape Training Facility Garden Island WA
[21] Training Material Lesson Management Guide – Buoyant Ascent Training SMSET 0006
[22] BR241(6) Submarine escape Rescue Abandonment & Survival: Command Guidance and Senior Survivor's Guide

73. **Contrary opinion**. A UK DSTL report[11] used the example of an escape from the *BAP PACOCHA*[23] DISSUB incident in 1988 to recommend that practical experiential RN PSET training should be retained. This was based upon evidence that submariners trained only in the theory of submarine escape are likely to perform poorly and suffer an incident rate of PBT during ascent from a DISSUB far in excess of PSET international training facilities. A 2009 DSTO assessment of the conclusions in the DSTL report concurred with the methodology used and agreed that training should include some form of experiential pressurised ascent training[24]. We assess this reasoning to be unconvincing; a USN review undertaken at the invitation of the Peruvian Navy shows a broad range of recommendations that reveal issues inherent in the overall SAER system played a major part in the outcome[25]. Moreover, the *BAP PACOCHA* supported rush escape only with the Steinke hood and a high injury rate was to be expected. The submariners were correct in not having confidence in the escape system. The level of non pressurised escape training received by the crew was also not documented. Notably the RN did not accept this viewpoint with the cancellation of PSET in 2009.

74. A South African 1998 report stated a reduction in anxiety levels with a form of pressurised escape training (rush escape with a hood for buoyancy) [26]. The report demonstrated a reduction in anxiety levels immediately following the training compared to pre-training levels. Care should be taken with generalizing this data due to the small number of participants, absence of a control group, short term follow up and the use of subjective self reporting.

75. At commencement of the Review we ascertained that no previous RAN submarine abandonment, escape, rescue and survival Training Needs Analysis (TNA) or equivalent study had been completed. Training Authority - Submarines (TASM) was requested to undertake formal analysis of the training requirement for PSET.

76. The analysis revealed that ceasing all pressurised training is considered “feasible but not preferable” due to the increased workplace risk created by not providing trainee submariners with the benefits of experiential learning[27]. However, the report recommended PSET be completed only once by trainee submariners and pressurised requalification should be removed in favor of unpressurised training. It was considered the benefits of experiential learning at pressure are most evident during the initial experience with diminishing return as the number of experiences increase, and at some point the health and safety risks outweigh the benefits of continuing to provide the experience.

77. The TASM report is a valuable reference, although we note the key assumptions used in the report are from the PSET Safety Case Report (SCR). The Review however

---

[23] In 1988 the Peruvian Navy submarine *BAP Pacocha* was sunk after a surfaced collision with a Japanese fishing trawler shortly after sunset as it was transiting to home port. The submarine sunk in 43 metres of water with a 9 degree bow up. Approximately half the crew were rescued after surface abandonment before sinking. 22 survivors were trapped in the forward torpedo room and escaped using buoyant ascent
[24] Document Review DSTO-CR-2009-0553 Peter J. Henley
[25] NSMRL Special Report SP89-1: The B.A.P Pacocha (SS48) collision: The Escape and Medical Treatment of Survivors
[26] Submarine Escape: The Effect of Training on Anxiety. C van Wijk. Military Medicine, Vol 163, February 1998;68-71
[27] TASM L&D Strategy to address pressurised submarine escape training requirements April 2018

considers the PSET SCR (Annex B) to be incomplete and outdated. In particular, the undeveloped appreciation for the life-threatening indiscriminate nature of AGE, and some elements of realism are not incorporated in current training. We observe the report is centred on the pressurised training module and does not offer performance gaps when considering the combined effect of all escape training and associated activities (including those conducted outside of SERC).

78. The reintroduction of USN PSET in 2009 whilst appearing to support the continuation of PSET was in part justified by this training being conducted by other countries including Australia and the UK at the time. The UK has of course since ceased PSET. In addition the voluntary nature of USN PSET has resulted in only 20% of the entire afloat submarine population having undertaken the training which does not support the statement that only PSET provides adequate training to ensure successful escape from a DISSUB.

79. **Summary**. The current training approach provides practical experience of the pressurised environment, yet many elements of realism are not incorporated. For example, contaminated, cold salty water and low light levels are not represented in training but may be just as important as what the current pressurised components are believed to be. The tower ascent experience is of limited duration (7-8 s) and is mostly outside the control of the trainee—all they are required to do is breathe normally during the ascent to the surface and not hold their breath. The real experience during tower flooding and equalization in a DISSUB could be quite different from that experienced during PSET, especially at deeper depths where the current training methodology of *breathing normally* becomes difficult or may not even be achievable (due to the inherent design of the tower flooding arrangement and the escapees *normal* rate of breathing). TASM analysis of PSET identified cessation of PSET is “feasible but not preferred” however it does not fully contemplate the considerable risks associated with PSET. Also, it does not take into account the elements of realism which are not included, or the value of other escape and rescue training and activities that are undertaken outside of SERC

80. We recognise that the 9 m head in water ascent does provide a unique experience of continuous exhalation during ascent, however it will not always guarantee an escapee will commence breathing out in the event of a hood rupture. We are uncomfortable with the significant health risks associated with this form of training, particularly when the prospects of a hood rupture and having to employ this technique is doubtful, and training on correct exhalation rates is already taught and assessed during unpressurised training.

81. The benefits of escape tower pressurisation and ascending through the water column are not proven and carry significant risk. Realistic training is necessary however we have been unable to demonstrate proven benefits to justify the potential health risks under the current approach to PSET over unpressurised training techniques.

PROVISION OF EFFECTIVE SUBMARINE ABANDONMENT, ESCAPE AND RESCUE TRAINING

82. We have considered all aspects of RAN submarine abandonment, escape, and rescue training and associated activities including those undertaken outside of SERC. These include:

a. Submarine crew continuation training (annual dry escape lectures);

b. Pre-workup training (practical 'wet' equipment demonstrations of escape suits and individual life rafts, and crew abandonment training and assessment); and

c. Completion of Verification of Competency (VOC) task books that include escape related tasks required to be completed by trainee submariners and by submarine qualified personnel who have not been posted to a seagoing position for over 18 months.

83. These activities external to SERC pressurised training ensure that all members of the crew demonstrate 'current competency' and possess the knowledge and skills to safety operate and utilise the escape systems. Participation in the biennial exercise Black Carillon and other international exercises also provide opportunities to refresh individual and crew skills, and consolidate teamwork during submarine abandonment, escape, rescue and survival drills. Live ESCAPEX drills will also provide further evidence of the functionality of the escape systems.

84. Escape tower functionality trials are completed to the maximum functional depth on all submarines during post maintenance trials and provide important crew consolidation in the operation of the escape system as well as providing confidence in its performance should it ever have to be used.

85. In the previous section examining real world submarine escape and rescue, we determined that the range of potential outcomes for credible DISSUB scenarios indicates a comparable likelihood between surface abandonment, rescue or escape. However, we consider current training has a bias toward tower escape (despite rescue being the preferred form of egress), and given the considerable risks a more balanced approach in proportion to the probability of having to use each method would deliver an equitable and pragmatic training program.

86. Taking into account the current whole of unpressurised submarine abandonment, escape and rescue training and related activities, we consider the removal of all pressurised elements will still deliver effective training. Pressurised is but one component when considering the totality of abandonment, escape and rescue training.

87. Realistic training is important and improvements could be made to unpressurised modules. The current RN approach uses a 'wet' trainer in which the students don the SEIE and enter the tower which is flooded to the height one would expect at sea. The flood rates are realistic and the trainee experiences the sensations and difficulties of holding the stole charging connection into the tower charging valve. The only difference is that it is not pressurised and once flooding ceases the trainee climbs out of the escape tower upper hatch. The UK facility uses cold water and darkness to provide greater realism, whilst avoiding the risks associated with pressurisation.

88. **Summary**. We consider that the current approach to training has a bias toward tower escape and a more balanced approach across abandonment, escape and rescue can be achieved by removal of pressurised elements. When taking into account all of the current unpressurised submarine abandonment, escape and rescue training and related activities, we assess that effective submarine training is still achieved whilst eliminating exposure to potentially fatal hazards. Improvements such as the use of 'wet' training can be made to deliver more realism in the unpressurised environment.

RISK TO PERSONNEL IN EVENT OF HAVING TO ESCAPE WITHOUT HAVING CONDUCTED PSET

89. As discussed previously the *BAP PACOCHA* incident highlighted the overall lack of a serious escape and rescue strategy rather than supporting the argument for PSET.

90. The 2008 RN Review of PSET which led to the cessation of pressurised training states "A risk and benefits analysis of pressurised ascent training has been carried out. Neither the deterministic consideration of benefits nor the probabilistic approach demonstrate that pressurised ascent training offers sufficient benefit to justify the associated risk. It is clear that some training is required but many options exist to give more appropriate higher fidelity training without the inherent risks of the SETT ascents. A fatality from training can be shown to be over 40 times more likely than the saving of a life through carrying out that training. Sensitivity analysis confirms that the benefits of training do not outweigh risks even given extreme errors in assumptions".

91. The RN CINC further noted in 2009 "The design of submarines and their operating environments has changed significantly since pressurised training commenced in 1954 as has our rescue capability. I remain fully convinced that the cessation of pressurised training reflects an appropriate balance of risk assessment with no significant degradation in any individual's ability to escape from a modern distressed submarine. Moreover I am confident that investment into a more realistic simulator represents a reaffirmation of the RN's commitment to its people and provides an attractive headmark for future safety training"[28].

92. Similarly the RAN has not reviewed the underlying requirement for PSET since inception of training in 1989. PSET carries a significant enterprise risk—the RAN should expect that in time a fatality will occur at SERC and this risk must be acknowledged at the highest level. With recent changes to Workplace Health and Safety legislation there is a change in the consideration of risk from ALARP (as low as reasonably practicable) to SFARP (so far as reasonably practicable). This means that all reasonable measures must be considered and taken where reasonably practicable.

93. Under the new legislation the RAN must consider whether it is 'reasonable, in the circumstances' to continue with PSET (the worst case scenario being a fatality expected to occur over the life of training) if all other non-pressurised escape training when combined is considered effective and appropriate. In other words: should the RAN be conducting this training if there is an unacceptable risk of an AGE occurring and a low likelihood of a DISSUB incident at sea? Put another way: why would we expose trainees to risk of an AGE during PSET if their training is unlikely to be put to use at sea.

POTENTIAL CONSEQUENCES OF CEASING PSET

94. The 2008 RN Review of PSET highlighted that a soft benefit of pressurised training was its contribution to submarine ethos and culture and that whilst subjective, such a benefit could be replicated by alternative training without carrying the same risks. It has also been argued that pressurised training may contribute to an increased confidence in the event of a

---

[28] Personal Message from CINCFLEET Cessation of Pressurised Escape Training at Fort Blockhouse 26 February 2009

DISSUB. This benefit however may be decreased by the lack of realism in the current training. If a decision is made to cease PSET there will need to be a considered communication strategy to reassure submariners and their families that this does not represent a reduction in Navy's duty of care or a cost cutting measure but is a considered decision based on improvement in submarine safety, rescue systems and an overarching non pressurised submarine abandonment, escape and rescue training package.

95. This Review has relied extensively on data from the UK. This is considered appropriate as the RAN has, since the inception of this training, relied upon the deep expertise of the RN in escape, rescue and survivability matters. The RAN has always acknowledged the RN as the world expert in PSET with their far greater experience in training (overall numbers) and submarine medicine research. Any criticism of this approach or decision to cease PSET (if so decided) can be balanced on these grounds.

96. A decision to cease PSET may impact on allied countries who use the facility for their training requirements (Since 2015, 30% of all PSET trainees were from Singapore). Careful messaging will be required to inform them of any decision to cease PSET.

97. Currently RAN medical standards require all submariner applicants to meet the medical standards for diving so that PSET can be undertaken. These standards primarily relate to respiratory conditions and in particular childhood and current asthma, previous history of collapsed lung and scarring of the lungs. If PSET is no longer a prerequisite for submarine service there may be additional personnel available for submarine service who were previously rejected on medical grounds (as the risk of having to escape from a submarine is unlikely). The RN have not been able to quantify the number of additional personnel who have been declared fit for submarine service since the cessation of PSET however approximately 10% of new entrant submarine volunteers were returned to General Service or discharged from the RN because they were permanently unfit to undergo pressurised training and therefore prevented from joining the Submarine Service unless a waiver was granted[7].

98. The RN has confirmed that there have been savings in time and money from a health system perspective by not requiring all submariners to be diver fit (no requirement for additional lung function testing)[29].

99. The SERC elements and facilities that support pressurised escape training are expensive to maintain and has been subject to numerous defects and shutdown periods since the inception of training. A decision to cease PSET may lead to financial savings with respect to maintenance of the water column and would negate the need for recompression chambers at the facility and contracted training services.

CONCLUSION

100. The RAN has not reviewed the underlying requirement for PSET since the inception of training in 1989. PSET carries a significant enterprise risk and the RAN should expect and acknowledge that in time a fatality will occur at the SERC and that medical screening can not completely mitigate this risk. With recent changes to Workplace Health and Safety legislation

---

[29] Personal Correspondence RN Head of Submarine and Radiation Medicine

the required consideration of risk is to SFARP requiring all reasonable measures must be considered and taken where reasonably practicable.

101. Historically RAN serious incident rates are higher than both the US and UK; with only 15 489 trainee ascents we are within the threshold for a catastrophic or fatal episode. Central to this review is the consideration of whether PSET should be conducted with any likelihood of PBT or AGE, not the extent to how we might treat an occurrence if realised.

102. The design of submarines and their operating environments has changed significantly since pressurised training commenced in the UK in 1954, as has rescue capabilities. Submarine accidents are most likely to occur during activities conducted in shallower, more confined water, high traffic areas, during post maintenance trials and training exercises. It is for this reason, that during the more hazardous initial periods at sea after an extensive docking or maintenance period, RAN submarines undertake material certification and training activities with an escort vessel, and are restricted to maximum water depth of 180 m for appropriate depth and watertight integrity checks within a pre-determined geographic area should rescue services be required.

103. The current training approach provides practical experience of the pressurised environment, yet many elements of realism are not incorporated. The benefits of escape tower pressurisation and ascending through the water column are not proven and carry significant risk. Realistic training is necessary however we have been unable to demonstrate proven benefits to justify the potential health risks under the current approach to PSET over unpressurised training techniques.

104. The Review considers that the current approach to training has a bias toward tower escape and a more balanced approach across abandonment, escape and rescue can be achieved by removal of pressurised elements. When taking into account all of the current unpressurised submarine abandonment, escape and rescue training and related activities, we assess that effective submarine training is still achieved whilst eliminating exposure to potentially fatal hazards. Improvements such as the use of ‘wet’ training can be made to deliver more realism in the unpressurised environment.

105. The Review has carefully noted and agreed the findings of the RN 2008 Review of PSET namely “A risk and benefits analysis of pressurised ascent training has been carried out. Neither the deterministic consideration of benefits nor the probabilistic approach demonstrate the pressurised ascent training offers sufficient benefit to justify the associated risk. It is clear that some training is required but many options exist to give more appropriate higher fidelity training without the inherent risks of SETT ascents”. The UK analysis was underpinned by statistical evidence which showed that the expected number of fatalities that occur during pressurised ascent training is over 40 times more than the added number of lives that would be saved in a DISSUB scenario having undertaken the training. It highlighted that the risk has stayed relatively consistent since 1975, and even with extreme errors in estimation, the benefit of pressurised escape training does not outweigh the risks.

106. It is recommended that:

a. PSET be ceased as soon as practicable and the PSET pre-requisite for submarine training be removed;

b. PSET be replaced by realistic non-pressurised training and the SAER TNA be reviewed as a matter of urgency;

c. Medical standards for submariners be reviewed as a matter of urgency;

d. A detailed communication plan is developed to advise the submarine community and their families of the changed requirements and allied countries who have used the RAN SERC for their training requirements; and

e. A detailed implementation plan be developed to support the transition from pressurised to non pressurised escape training.

Robyn.Walker

Digitally signed by Robyn.Walker
DN: c=AU, o=GOV, ou=DoD, ou=PKI, ou=Personnel, cn=Robyn.Walker
Date: 2018.06.21 14:17:00 +10'00'

Digitally signed by Brett.Sampson
Date: 2018.06.21 11:39:37 +08'00'

RM Walker, AM
RADM, RANR

BM Sampson
CAPT, RAN

22 June 2018

ANNEXES:
A. PSET Health Hazards
B. Appraisal of the PSET Safety Case Report (Version 6)

PSET HEALTH HAZARDS

1. The health hazards associated with pressurised training in escape from a disabled submarine are considerable.

2. The accepted PSET training philosophy adopted by the UK, USA and Australia historically involves escape exposures from 20-30 m (3-4 ATA) followed by a rapid decompression phase. Whilst these training exposures do not realistically approximate the worst case depth scenario the associated medical risks with greater pressure exposures (largely decompression sickness) were considered unacceptable.

3. RAN PSET is based upon the Collins Class escape system. Only single escape tower training is conducted under pressure with compartment or rush escape training conducted unpressurised.

4. PSET trainees are exposed to short duration ascents from relatively shallow (but still hazardous) depths and subjects trainees to the greatest rates of lung gas volume increase that would be experienced during a real submarine escape. Whilst to the lay person it might be expected that very deep ascents may be more dangerous, the greatest air pressure/volume changes in the lungs and other gas filled organs occurs in the final ascent from 1 metre to the surface. Therefore the risk of pulmonary barotrauma remains real for an escape from any depth.

5. Instructors supervise and assist trainees during all aspects of training throughout the water column. They primarily utilise highly skilled ‘breath hold’ diving techniques combined with breathing from built-in breathing supplies, or from various air filled compartments. Decompression sickness is an additional hazard for instructors.

6. Trainees perform buoyant ascents from 9 m with ‘head in water’ wearing a training lifejacket (requires the trainee to blow out constantly all the way to the surface), and from 20 m wearing the Submarine Escape Immersion Equipment (SEIE) which is fitted with a hood that allows normal breathing during an ascent. Head in water buoyant ascents have been included historically for fear the SEIE may rupture during pressurisation, yet there have been no recorded hood ruptures during training or escape exercises. During the pressurisation process and ascent, the hazards for buoyant and hooded ascent are the same, and apply to both instructors and trainees.

7. Barotrauma refers to tissue damage resulting from changes in volume of gas spaces, which is due to changes in environmental pressure. During ascents trainees and instructors are subject to a pressure of 3 ATA (hooded ascent) and 1.9 ATA (buoyant ascent) which can cause the following conditions:

a. Aural Barotrauma – middle ear and inner ear

b. Facial Nerve Barotrauma

c. Sinus Barotrauma

d. Dental Barotrauma

e. Decompression Sickness (DCS) – gas bubbles absorbed into body tissue

f. Drowning

g. Pulmonary Barotrauma (PBT) – lung over inflation syndrome

h. PBT with Arterial Gas Embolism (AGE) – gas bubble blockage(s) within the arterial system

8. Middle Ear Barotrauma is the most common medical incident during PSET attributable to insufficient equilibrium of the middle ear. It can result in slight bruising of the tympanic membrane (ear drum) to rupture of the tympanic membrane (burst ear drum). This problem has moderate severity and minor barotraumas usually heal with symptomatic treatment with no long term effects. Some ruptured eardrums will require surgical repair. Inner ear barotrauma is rare and is caused by over pressurisation. It may result in permanent hearing loss, tinnitus (ringing in the ears) and vestibular disturbances such as nausea, vomiting, vertigo, disorientation and unsteady gait. Surgery may be required but may not relieve all symptoms. Inner ear barotrauma will usually result in a permanently medically unfit to dive or undergo PSET medical categorisation.

9. Facial Nerve barotrauma is rare and is usually associated with middle ear barotrauma and presents as a one sided facial weakness (unable to frown, eye unable to close, drooping of the lower eye lid, mouth pulled to the normal side). Usually, but not always, symptoms will resolve with time.

10. Sinus Barotrauma is the second most common complication. If the sinuses are not equalised during descent, congestion and haemorrhage compensate for the contraction of air within the sinus cavity resulting in pain. Most cases resolve over time but the individual may need surgery to repair the underlying problem.

11. Dental barotrauma is caused by the impact of rapid pressurisation and /or depressurisation on poor or damaged fillings or due to recent dental work with residual air pockets trapped within the tooth or tooth socket. This usually presents as a pain in the tooth, but in extreme cases it can result in tooth implosion.

12. DCS and PBT with or without AGE are potentially the most fatal, although prior medical screening reduces (but does not eliminate) the prospect of an episode. Drowning, while also potentially fatal, is less likely due the close level of supervision by instructors when the trainee is in the single escape tower or the main water column.

13. DCS is typically more relevant to instructors than to PSET trainees who spend very little time at depth. With increasing time spent at depth there is an increased uptake of dissolved nitrogen into the blood stream. With ascent, nitrogen may come out of solution to form bubbles in the blood and tissues causing decompression sickness. Since bubbles can form in or migrate to any part of the body, DCS can produce many symptoms, and its effects may vary from joint pain and rashes, to paralysis and death. Individual susceptibility can vary from day to day, and different individuals under the same conditions may be affected differently. During the 1990s there were a number of PSET instructors who suffered DCS. A review of their depth-time profiles and subsequent changes in practice led to a reduction in episodes and DCS in instructors is now considered less likely. Trainees usually do not spend enough time at pressure to absorb enough nitrogen to cause DCS.

14. **Pulmonary Barotrauma.** PBT is the result of over distension and rupture of the lungs by expanding gases during ascent. There are four manifestations of PBT of ascent which may occur singly or in combination (pulmonary tissue damage, mediastinal emphysema, pneumothorax and arterial gas embolism). Predisposing factors include any medical condition that promotes gas trapping or airway obstruction e.g. cysts, asthma, fibrosis and infection. The typical description of PBT is in a trainee who makes a rapid ascent to the surface, forgetting to breathe out on the way. Whilst cases of PBT may be due to inadequate exhalation during ascent, there are also individuals with no predisposing medical condition and who have been observed to exhale correctly who have also suffered PBT. This is thought to reflect localised areas of reduced lung compliance (or stiff lungs).

15. A diver whose lung volume is 6 litres at 20 m (the depth of the RAN PSET water column) will need to exhale 12 litres of gas surface equivalent during the ascent in order to maintain his total lung volume of 6 litres at the surface. If for any reason air that is inhaled at depth is trapped within the lungs during ascent, there will be an enhanced potential that pulmonary barotrauma will occur. This is a particular risk as the escaper rises through the last 10 m before reaching the surface because the relative lung expansion is greatest near the surface.

16. **Arterial Gas Embolism**. PBT with AGE presents when gas from the lungs escapes into the bloodstream, forming bubbles which enter and block the arterial circulation. The dominant pathology occurs when bubbles reach the brain, known as cerebral arterial gas embolism (CAGE). CAGE usually presents as a medical emergency with loss of consciousness, convulsions, paralysis and sensory disturbance and visual disturbance. The patient my stop breathing and have a cardiac arrest.

17. The next most problematic PBT condition is pneumothorax, where gases enter the space between the lungs' two outer linings, expand and cause the lung to collapse. With mediastinal emphysema, air escapes and enters the space between the chest and lung, expands and places pressure on the lungs, heart, or blood vessels. Air may also track underneath the skin in the subcutaneous tissues, typically around the neck, resulting in voice changes, crackling sounds underneath the skin, and difficulty with swallowing. The pressure changes may lead to complete rupture of the lung tissue itself although this is very rare in PSET.

18. **Training Depth of Water**. There is no evidence to suggest training in shallow water is safer than deep water. A USN medical risk assessment of PSET has documented AGE from as shallow as 1m, and numerous serious injuries have occurred internationally from at least 9 m, and possibly shallower since the exact depth of casualty was unable to be determined because 9 m was the approximate start depth prior to ascent. Owing to Boyle's law the maximum changes on volume occur in the last 10 m of ascent close to the surface, therefore it is reasoned that training from a shallow depth does not substantially lessen the risk. Instructors may be able to focus more on the safety of trainees when training from deeper depths due to increased time to monitor and intervene (for example, to correct trainee blow rates or monitor breathing), however this will not guarantee the avoidance of PBT or AGE. There is no completely safe training depth.

19. **PSET techniques**. USN comparison of international training techniques over time highlight that various types of pressurised escape training have different risk profiles. Free ascent training is more hazardous than buoyant ascent training using a lifejacket, and hooded escape devices which allow the trainee to breathe normally provide a degree of safety over free or buoyant techniques. Applying this to the RAN PSET, the 20 m tower escape using the

SEIE (where the trainee breathes normally) offers a measure of safety over the 9 m buoyant ascent wearing a training lifejacket. The ability to breathe normally whilst wearing the SEIE diminishes the risk of a trainee holding their breath or incorrect exhalation rates.

20. **Indiscriminate factor**. A large body of research and data exists to comprehend the substantial random probability of PBT or AGE during PSET. Despite the existence of mitigations such as medical screening, instructor monitoring and control, training technique or depth, the possibility of PBT or AGE remains stochastic in nature. Fundamental to the recommendations of this Review we recognise that despite controls, PBT and AGE incidents during PSET will occur, and they will occur even when controls for the known factors have been applied.

21. **Summary**. PSET is associated with the risk of barotrauma to all gas filled organs, the severity of which ranges from inconvenient to life threatening. There is a substantial body of research that confirms there is no completely safe pressurised training method and that there is a foreseeable risk of PBT that can not be mitigated completely. Instructors carry the additional risk of DCS that can be mitigated (but not completely) with shallower depth profile.

ANNEX B TO
PRESSURISED SUBMARINE
ESCAPE TRAINING REVIEW 2018

APPRAISAL OF THE PSET SAFETY CASE REPORT (VERSION 6)

1. **Background**. The PSET Safety Case Report (SCR) was developed in 2001 and has undergone five reviews currently at version 6, March 2016. The SCR is managed as a dynamic document by COMSUB through SERM and the SUBSAFE Submarine Abandonment Escape and Rescue Sub-Group (SAERSG) and is reviewed periodically by the SUBSAFE Board.

2. SUBSAFE Board records show in 2001 CN acknowledged the hazard of an arterial gas embolism (designated HRI of 8 'unacceptable') then, given the balance of risk and benefit, directed PSET to continue. He instructed the SAERSG to monitor PSET activities with oversight by DGNCSA and the SUBSAFE Board. The SCR was last presented to the NSRC in 2007 with an HRI (P) of 8 for PBT-AGE; tolerable with continuous review. The NRSC accepted the residual risk and noted it was *as low as reasonably practicable* (ALARP) providing the hazard remained open and is reviewed at each SAERSG.

3. At time of writing the PSET SCR was under review by SERM with particular emphasis on the interpretation and application of *so far as reasonably practicable* (SFARP) in considering the standard of health and safety under the *Workplace Health and Safety Act 2011*.

4. **Safety Case Report evaluation**. During the course of this Review we have encountered nil documentation that explicitly describes why the RAN undertakes PSET. The PSET SCR start point assumes that PSET will be delivered, but does not answer the question of why the RAN needs to do it, nor does it show why the risk of not doing PSET is worse.

5. While the SCR describes the hazards, hazard controls and mitigations; the specific relationship between them and analysis to fully understand the effectiveness of existing mitigations is lacking. For example the extent to which the occurrence of PBT or AGE is mitigated is not clear, and no reference is made to the analysis of past incidents.

6. We discovered that the Hazard Log Item for PSET (HLI 1238 – Risk of pressure related injury due to Pressurised Escape Training) was closed 24 Aug 2016. Entries until 2016 provide inadequate evidentiary component of PSET safety management. ABR6303 describes the hazard log as one of the most important tools for managing safety. We consider that it should be complementary to the safety case and show that all PSET hazards and accidents have been considered, and be the audit trail providing the reasons why harm to PSET instructors and trainees has been eliminated and/or minimised *so far as reasonably practicable*. Notwithstanding this shortfall, PSET certification activities show that risk controls have been implemented.

7. The SCR includes hazard controls to address maintenance and material certification. We note that the training facility is aging and has experienced poor reliability over several years. Systems and equipment may not always perform as anticipated and therefore the mitigated risks may not be as low as indicated. Medical support experience and chamber limitations should also be considered.

8. The SCR lists the total number of ascents conducted at the facility but does not itemise instructor and trainee. While they are both subject to the same hazards, trainees present a higher risk profile and are more susceptible to PBT or AGE as most are novices with no diving or escape experience. Record keeping showing the breakdown of trainee and instructor ascents will allow more detailed analysis and comparison of serious incidents, including comparison with international data. Of the 130 836 ascents to date, trainee ascents comprise approximately 15-20%.

9. **Safety Case Report discrepancy**. Since the first SCR in 2001 the inherent risk associated with AGE has been assessed as Intolerable (HRI 2), then mitigated to High (HRI 8) after application of documented controls and mitigations. In 2014 the risk (probability) of AGE was reduced to Medium (HRI 12) however we were unable to ascertain the reason for this substantial change.

10. How this decision was justified is not clear; there is limited detail in SUBSAFE Board and SAERSG records and the extent to which the medical community was engaged is not apparent. Previous versions of the SCR include considerations such as the random occurrence of AGE, ineffectiveness of medical screening, and situations may exist where the injuries sustained may not be treatable. However these statements are no longer included in the current SCR. It is likely that the serious incident rate during that period was low enough for inexperienced personnel to be dismissive of the risk. To address this we suggest future SCR appraisals include this inconsistency in the scope of review.

11. **Summary**. We assess that the PSET SCR is incomplete and out-dated and the PSET HLI 1238 has been incorrectly closed. The PSET SCR requires contemporary revision from the concept of ALARP to SFARP in accordance with the WHS Act 2011. It must look for the gaps in safety as well as seeking to demonstrate that PSET is safe, and address the real and life-threatening indiscriminate nature of AGE. The PSET HLI should be reopened and complement the SCR as a key evidentiary component of PSET safety management.