APPROACH TO DELIVER A SAFE TYPE 218SG SUBMARINE

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ABSTRACT

The Type 218SG submarine from ThyssenKrupp Marine Systems, Germany, is the first newly built submarine acquired for the Republic of Singapore Navy (RSN). Due to the challenging environment that the submarine has to operate in, ensuring that the Type 218SG submarine design is safe is an important aspect of the programme. Differing from previous acquisition programmes for the CHALLENGER-class and ARCHER-class submarines, the Type 218SG submarine programme required that the Integrated Programme Management Team (IPMT) adopt a system safety framework – one that incorporates the best elements of the Naval Sea System Command SUBSAFE programme and the United States Department of Defense System Safety approach (MIL-STD-882E) – to provide maximum assurance of the submarines' safety. The IPMT comprised members from DSTA and the RSN. This article shares the system safety framework and approach adopted to ensure the Type 218SG submarines' operational effectiveness and safety.

Keywords: system safety, Type 218SG, SUBSAFE

INTRODUCTION

The Republic of Singapore Navy (RSN) submarine journey started in 1995 with the acquisition of the CHALLENGER-class submarines. To ensure that these submarines are safe for operations, the RSN implemented the Submarine Maintenance Safety Programme (SMSP), which is based on the US Naval Sea System Command (NAVSEA) SUBSAFE programme. The SMSP is a stringent quality assurance programme for the maintenance work carried out on RSN submarines (RSN, 2015). The RSN has accumulated over 20 years of valuable experience operating and maintaining first the CHALLENGER-class and then the ARCHER-class submarines. These experiences have helped DSTA and the RSN build up the required knowledge and technical competency to embark on the new acquisition of the Type 218SG submarines. To ensure that these submarines are safe to operate and maintain, it is important to have a system safety framework that can allow the Integrated Programme Management Team (IPMT) to sieve out hazards and non-compliances, and to address them adequately in a timely manner at the different phases of the programme.

UNIQUENESS IN SAFETY FOR SUBMARINES

Although a submarine operates at sea, its behaviour is more akin to that of an aircraft than a ship. It is subjected to high compressive pressure from seawater when submerged and operates three-dimensionally in the deep ocean. For a submarine of 1,800 tonnes operating at a depth of 300m, a 100mm-sized hole at the hull can easily flood the submarine in 10 minutes, breaching the typical 10% reserved buoyancy of 180 tonnes and rendering her unable to surface. Therefore, the submarine design and construction must be safe to ensure it surfaces after every dive. The loss of USS THRESHER with 112 crew and 17 contractors in 1963 illustrates this danger (NHHC, n.d.). This painful lesson for the United States Navy (USN) led to the launch of the NAVSEA SUBSAFE programme (USN, 2000).

Moreover, a submarine cannot "see" its surroundings when it is underwater and relies heavily on its sensors such as sonars to visualise what is around it. Due to its operation in a three-dimensional space while underwater, a submarine is subjected to more risks than a surface ship. The surfacing of a submarine is a risky manoeuvre clearly demonstrated by the collision of the Royal Navy's HMS AMBUSH with a tanker during a training exercise in 2016 (Robinson, Mclelland, & Robinson, 2016). This lesson shows that not only do the sensors need to be put through stringent tests during construction, the crew also needs to be trained to handle advanced equipment to ensure the safe operation of the submarine.

The environment within the submarine is enclosed and confined. It is more like a space station than a ship. Life on board has to be sustained by careful control of the atmospheric conditions such as air quality and toxicity. The air within needs to be refreshed continuously to ensure liveability in extended underwater operations. In addition, fire or flooding incidents – if not arrested in time – will endanger the submarine and lives on board. Failure to take care of the atmosphere in the submarine will have dire consequences as shown in the MING-class 361 of the People's Liberation Army Navy in 2003, where all 70 crew on board died of oxygen asphyxiation (BBC News, 2003).

For a submarine in a distressed situation where it cannot surface, submarine rescue becomes a complicated and difficult endeavour. To rescue a submarine in distress, not only does it require the correct rescue assets that are compatible with the submarine, but time is also critical as emergency supplies that sustain the lives on board could run out in about seven days. In the case of the Russian submarine K-141, KURSK, the rescue operation could not be mounted in time and all 118 crew perished (RT, 2015).

With a harsh and unforgiving environment, submarine safety is paramount. The consequence of any safety breach is unacceptable and would have catastrophic impact. It is therefore imperative to have a safe boat from design to construction and testing before commissioning for service. Clearly, a system safety management framework is needed to ensure the safety of the Type 218SG submarines.

COMPLEXITY IN SUBMARINE DESIGN

From another perspective of the complex nature of submarine building, it is also important to have a system safety framework to help the IPMT balance the safety and operational requirements with cost and schedule management. Figure 1 shows the complexity of building a submarine compared with other technology products such as an aircraft. Based on the parts count and the manufacturing time, it is clear that the construction, integration and testing of submarines takes many man-hours. It is therefore important to get it right from the onset as any design or production changes to address safety shortfall late in the programme will be costly to implement or may not be implementable at all.

Therefore, a robust system safety framework is needed to surface any safety issues early in the programme, ensure the submarine design can be ascertained to be safe at the design phase, assure that the manufacturing work to be carried out meets the high quality required, as well as ensure that safety requirements are robustly tested to provide maximum assurance. In short, the system safety framework aims to reduce the residual risks at all stages of the programme to

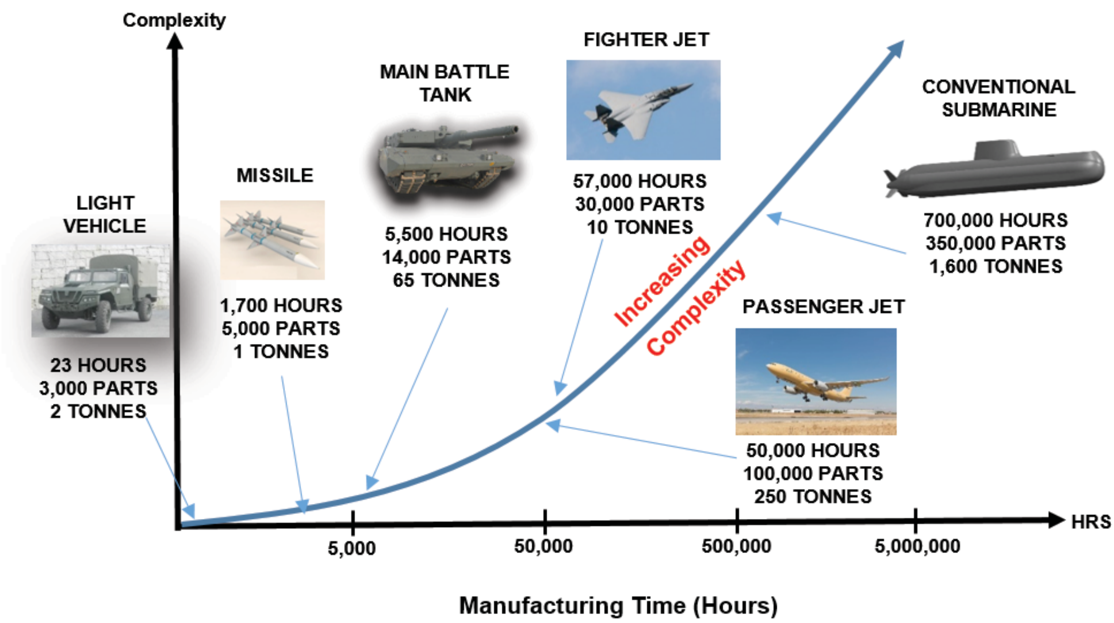

Figure 1. Relative complexity of commercial and military equipment (Firebaugh, 2001)

as low as reasonably practicable (ALARP) and minimise the undesired impact to project cost and schedule, as well as subsequent unsafe submarine operation resulting from safety non-compliance.

SYSTEM SAFETY ASSURANCE FOR TYPE 218SG SUBMARINES

The safety framework adopted for the Type 218SG submarines is anchored on three pillars of German Military Standards (Bauvorschriften fur Schiffe, or BV in short) (Federal Office for Defense Technology and Procurement [BAAINBW], n.d.), NAVSEA SUBSAFE programme (US Navy, 2000) and Department of Defense (DoD) standard of practice for system safety (MIL-STD-882E) (DoD, 2012) to address system safety in design, construction and robust testing. This framework utilises the strength of each of the constituents to address the safety needs throughout the different phases of the entire programme.

In other words, the IPMT utilised the best of system safety requirements to ensure that the Type 218SG submarine is safe. This is the first time the IPMT has incorporated all three elements of system safety into an acquisition programme.

System Safety Working Group

The approach to achieve a safe submarine requires a dedicated system safety management structure with a clear delineation of responsibilities (Ministry of Defence [MINDEF], 2012). The safety assurance structure for the Type 218SG submarine programme is depicted in Figure 2. A tripartite partnership involving DSTA, the RSN and submarine manufacturer ThyssenKrupp Marine Systems (tkMS) is essential for the successful implementation of the system safety framework for the Type 218SG submarine. Each entity focuses on different areas of safety to ensure that all potential safety hazards are addressed at all stages of the programme. The DSTA IPMT focuses on technical safety while the RSN crew focuses on operation safety. The tkMS engineers are responsible for the safe design and the implementation of the safety measures. The tripartite partnership allows a robust discussion on design safety, and checks and balances on the implementation of the safety measures.

System Safety Framework for Type 218SG Submarines

The implementation of the system safety framework is shown in Figure 3. It captures the broad activities required to ensure that safety hazards are identified and mitigated as practicable as possible at different phases of the programme. The safety requirements as well as lessons learnt from previous RSN submarine acquisition programmes and past submarine safety incidents are incorporated into the acquisition contract with tkMS at the programme's onset. Defining the safety requirements alone is insufficient because these requirements need to be translated into design, implemented and tested to ensure that the submarine is indeed safe for operations. At the different phases, the IPMT ensures that the design of the Type 218SG submarine is safe, constructed according to design, and that the final product is verified through a series

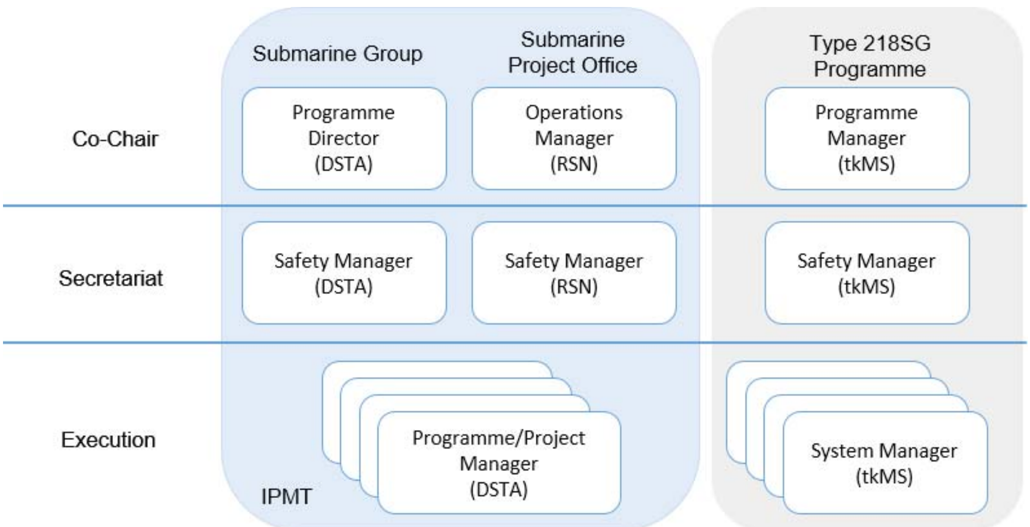

Figure 2. Structure of the Type 218SG Submarine Programme system safety working group

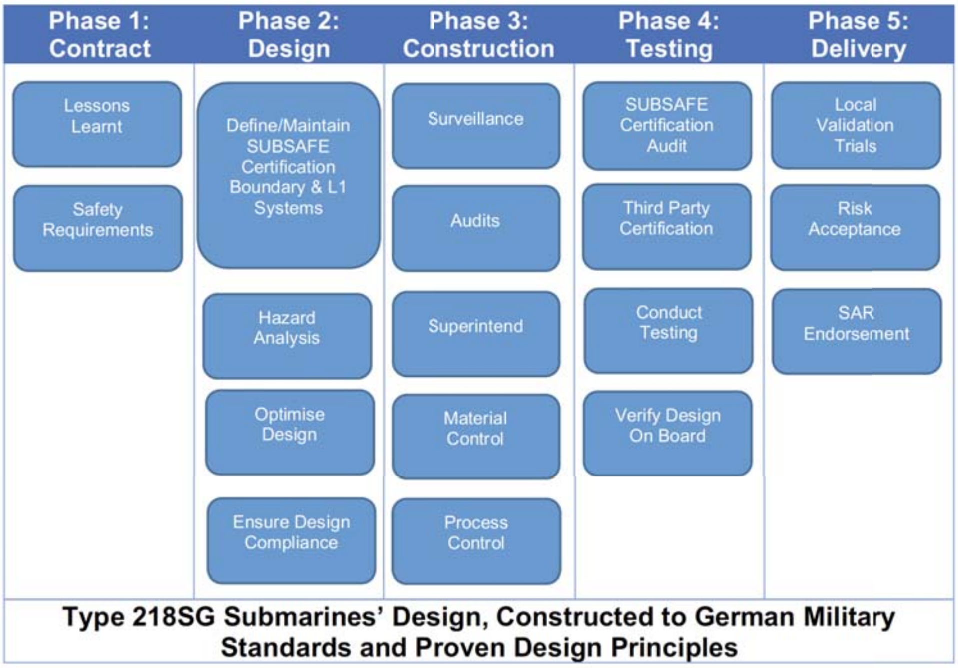

Figure 3. System Safety Framework

of comprehensive testing. In addition, the submarine will be inspected and certified by a third party before the submarine is allowed to commence sea trials. Before its introduction into service, local validation trials and the residual risks of operating the submarine must be deliberated and accepted by the appropriate safety risk acceptance forum in the RSN.

Safety During Design Phase

The design of the Type 218SG submarine was anchored on the proven and established German Military Standards BV issued by the German BAAINBW. To complement the areas where BV does not stipulate requirements, other supporting standards such as the German Defence Material Standard (Verteidungs Gerate Normen) (BAAINBW, n.d.) and the North Atlantic Treaty Organization (NATO) Standardised Agreement (NATO, 2017) were used to ensure the Type 218SG submarine design was based on technical requirements which have been fully validated.

To check the robustness of the designs, the IPMT conducted thorough design reviews of all the systems' designs. A focus of these design reviews was to ensure that the systems' design meet the contractual and user's specifications for safety and performances. Using the framework stipulated in the MIL-STD-882E, the IPMT performed safety risk analysis of all the associated risks of the design and single point failure modes (DoD, 2012). At this stage, the SUBSAFE programme was also implemented to define the SUBSAFE Certification Boundary (SSCB)[1] and Level 1 systems[2] to provide (a) maximum reasonable assurance to prevent flooding; (b) enhance recoverability in such an event and; (c) enhance reliable submerge control (USN, 2000). Special attention was given to Level 1 parts to ensure that the material selected was suitable against corrosion, fatigue and pressure. The IPMT also checked the design compliance of the safety systems (such as firefighting and damage control systems, and rescue and escape systems) to ensure that they were built with adequate redundancies. Optimisation using MIL-STD-882E was then carried out to design the risk to ALARP within cost and schedule (DoD, 2012). The safety assessment outcomes from the safety analysis are submitted to the safety advisory board progressively to facilitate the acceptance of the design's residual risk.

Safety During Construction Phase

tkMS is an established submarine builder with more than 100 submarine deliveries since the 1960s, and is certified by the classification society Germanischer Lloyd in accordance with ISO 9001:2008 for the design and construction of submarines. In addition, the SUBSAFE programme provides another layer of robustness to ensure the compliance of material used, the construction is in accordance with the design, and the accountability and traceability of the works completed on the submarine. At this stage, the IPMT is carrying out audits and surveillance every six months to ensure that designs are implemented properly during construction. The IPMT has also deployed a team of engineers to Germany to superintend the construction of the submarine. As an added assurance, the RSN SMSP office will audit the IPMT in Germany to ensure that they execute their safety role adequately (RSN, 2015). This certification serves as a bedrock for the IPMT to verify the traceability of design and construction processes implemented for the Type 218SG submarines.

Safety During Testing Phase

During this phase, the IPMT will verify the implementation of the mitigating measures for the hazards identified earlier during the design and construction phases. Test protocols will include testing the safety requirements to demonstrate adequately that the mitigating measures have been implemented properly into the systems. The tests include Factory Acceptance Test (FAT), Preliminary Interface Test (PIT), Shore Base Integration Test, Harbour Acceptance Test and Platform Acceptance Test (PAT). These tests are progressive, i.e. PIT will not proceed if FAT of the systems does not pass. Through these tests, the IPMT is assured that safety implementation at the equipment, system and finally the submarine level are accounted for. Separately, the IPMT will also perform a SUBSAFE Certification Audit (SSCA) before the submarine's first launch into the water to verify all SSCB works are satisfactorily closed and Level 1 material are properly accounted for and implemented on board (USN, 2000). The successful completion of the SSCA as well as the formal residual risk acceptance by the RSN safety advisory board will provide assurance that the submarine can be launched safely.

In addition, the German Transport Authority will inspect the Type 218SG submarines after all the shore tests have been completed to provide an independent third party safety assessment before the submarine can be certified fit for sea under the German flag. This is important as it assures that the Type 218SG submarines' construction and safety requirements meet the German regulations and are fit for sea trials.

Safety During Delivery Phase

After the successful completion of the PAT, the Type 218SG submarine would have been verified to meet all requirements, including safety requirements. Before the submarines return to Singapore, a minor overhaul will be carried out at tkMS to address any remaining issues from the PAT. Upon arrival in Singapore, a series of local verification trials will be conducted to validate the performance of the systems, especially those that are sensitive to environmental conditions such as salinity and temperature. After passing the local trials, the submarine will be considered operationally safe in Singapore waters. At this stage, all the safety assessments would have been completed and all residual risks documented and accepted by the RSN (MINDEF, 2012). The Type 218SG submarines will then be considered operationally ready.

SYSTEM SAFETY DURING OPERATIONS AND SUPPORT

After handing over the Type 218SG submarine from the acquisition phase to the operations and support (O&S) phase, the system safety assurance for the submarine will be undertaken by two key entities: Operations Safety will be under the charge of the Fleet Commander, and Engineering and Maintenance Safety under the charge of Head Naval Logistics (see Figure 4).

are safe to operate and while the submarine is undergoing maintenance programme, SMSP is compliant with and certified fit for operations after the programme.

Both the Fleet Commander and Head Naval Logistics will ensure that the Type 218SG submarines are safe for operations and during maintenance.

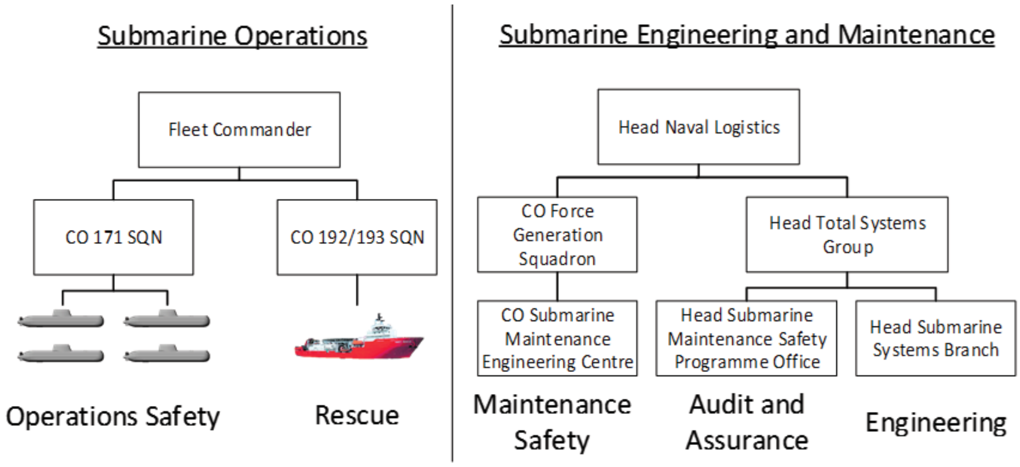

Figure 4. System safety during O&S

The Fleet Commander is the Safety Authority that authorises the submarine safe for sailing and diving under his charge. The submarine rescue vessel, MV SWIFT RESCUE, is also under the Fleet Commander's command and control. MV SWIFT RESCUE will be deployed for search and rescue missions for any distressed submarine (including foreign submarines) within the region.

Ensuring the engineering and maintenance safety of the submarine is Head Naval Logistics. He is supported by Commanding Officer (CO), Submarine Maintenance Engineering Centre under Force Generation Squadron in Naval Logistics Command for Maintenance Safety; Submarine Maintenance Safety Programme Office to audit and assure compliance with the SMSP protocol; and Submarine Systems Branch for engineering assessments especially on Deviation of Specifications from the actual systems' performance. Head Naval Logistics ensures that the submarine systems on board

CONCLUSION

Submarines operate in an unforgiving environment. Ensuring the submarine is safe is an important task for the IPMT. The submarine system safety assurance framework implemented for the Type 218SG submarine programme offers a robust methodology to ensure that the submarine design is safe, properly constructed and thoroughly tested to provide maximum assurance, yet providing a balance to ensure timely delivery within cost. In addition, a robust safety assurance structure is also necessary during O&S to ensure that the Type 218SG submarine is safe for operations throughout its life cycle.

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REFERENCES

This article was first presented at INEC@IMDEX 2017 conference held in May 2017 at Singapore.

BBC News. (2003, May 5). *China sub victims 'suffocated'*. Retrieved from http://news.bbc.co.uk/2/hi/asia-pacific/3001099.stm.

Department of Defense (DoD). (2012, May). *Standard practice: System safety* (MIL-STD-882E). United States: Author.

Federal Office for Defense Technology and Procurement (BAAINBW). (n.d.). *Bauvorschriften fur Schiffe* (BV). Germany.

Federal Office for Defense Technology and Procurement (BAAINBW). (n.d.). *Verteidungs Gerate Normen*. Germany.

Firebaugh, M. S. (2001, August 30). *eBusiness Knowledge Fair* [Infographic]. Retrieved from http://www.sms1835.no/arkiv/Sjoemaktseminar%2012%20Jacobsen.pdf

Ministry of Defence (MINDEF). (2012, June). *MINDEF system safety guidebook* (Version 1.2). Singapore: Author.

North Atlantic Treaty Organisation (NATO). (2017). *NATO Standardised Agreement* (STANAG). Retrieved from www.nato.int/cps/su/natohq/publications.htm

Naval History and Heritage Command (NHHC). (n.d.). *USS Thresher* (SSN-593). Retrieved from https://www.history.navy.mil/browse-by-topic/ships/uss-thresher-.html.

Ong, C. Y., Ong, L. K. & Chee, Y. M. (2017). Approach to deliver a safe type 218SG submarine. *Proceedings of the INEC@IMDEX Asia 2017*, Singapore. Retrieved from http://www.imdexasia.com/pdf/inec/Approach-To-Deliver-A-Safe.pdf

Republic of Singapore Navy (RSN). (2015, December). *Submarine maintenance safety program: Logistics directive* (3rd ed.) (RSN-NLD-LOG-0691-03). Singapore: Author.

Robinson, M., Mclelland, E., & Robinson, J. (2016, July). *Oops periscope: British £1.1bn nuclear submarine which crashed into a tanker is pictured in port in Gibraltar with the damage hidden by a tarpaulin and its Union Jack flying forlornly*. Retrieved from http://www.dailymail.co.uk/news/article-3700175/British-nuclear-submarine-forced-dock-Gibraltar-crashing-merchant-vessel-training-mission-Med.html

RT. (2015, August). *The day the Kursk sank: 15 years on, Russia remembers one of worst-ever submarine tragedies*. Retrieved from https://www.rt.com/news/312234-kursk-submarine-tragedy-anniversary/

United States Navy (US Navy). (2000, June). *Naval Sea Systems Command (NAVSEA) submarine safety (SUBSAFE) requirement manual* (Revision C) (0924-062-0010). United States: Author.

ENDNOTES

[1] SSCB is defined as the boundary of pipings and components of critical systems and structures vital to the ability of the submarine to prevent flooding and in case of flooding, to regain control and surface.

[2] L1 is a designation assigned to a system or components installed on board the submarines that require a high degree of assurance that the chemical and mechanical properties of the installed material meet the specified requirements.

BIOGRAPHY

Military Expert 6 (ME6) **ONG Chee Yang Terence** of the Republic of Singapore Navy (RSN) is currently on secondment to DSTA as a Senior Principal Engineer (Naval Systems). He is responsible for delivering the local support capability for the Type 218SG submarines. ME6 Ong had held various appointments in the RSN's Naval Logistics Command (NALCOM) and Naval Logistics Department, supporting both surface vessels and submarines. Prior to his secondment, he was the Commanding Officer for Platform Readiness Engineering Centre in Force Readiness Squadron, NALCOM, RSN. He graduated with a Bachelor of Engineering (Electrical Engineering) degree from Nanyang Technological University in 2002 and obtained a Master of Science (Engineering Acoustics and Electrical Engineering) degree from Naval Postgraduate School, USA, in 2006.

ONG Li Koon is a Programme Director (Naval Systems) responsible for the Type 218SG submarine programme. He has experience in the acquisition as well as the operations and support of the CHALLENGER-class and ARCHER-class submarines. He received his Bachelor of Engineering (Naval Architecture and Ocean Engineering) degree and Master of Science (Naval Architecture) degree from University College London in 2000 and 2001 respectively.

CHEE Yu Ming is a Senior Principal Engineer (Naval Systems), and has worked on the acquisition of the ENDURANCE-class Landing Ships Tank, CHALLENGER-class and ARCHER-class submarines. Yu Ming is involved in the raising and sustainment of system safety competency within the naval systems domain. He graduated from the National University of Singapore with a Bachelor of Engineering (Mechanical Engineering) degree and a Master of Science (Industrial and Systems Engineering) degree in 1993 and 1998 respectively. Yu Ming also obtained his Master of Science (Naval Architecture) degree from University College London in 2000.