UDT 2019 – How to provide safety assurance for new and in-service submarines and the challenges it creates.

Abstract — Submarines are high value assets that require material integrity and equipment reliability, to operate in an extremely hostile environment. Physical and financial constraints, as with any design and build, require an assessment of the acceptable level of risk that allows a submarine to operate safely and be affordable. These risks need to be robustly managed from identifying and quantifying the associated risk in the design stage, to assessing the risk associated with build quality and in-service degradation.

Surface ships and submersibles, both commercial and naval, have a well-defined and prescribed product verification process in the form of Class Society Rules, adoption of which will provide assurance of the design safety, build quality and in-service capability in an industry accepted approach.

This paper looks at whether that assurance processes can be successfully applied to a submarine design, build & in-service programme in a modified form. A submarine assurance process must adequately recognise and address: the operating environment, risks that are unique to a submarine and the physical constraints imposed on a submarine.

The number of submarine operating navies, capable submarine designers and builders in the world are limited. There are restrictions on the sharing of technology, design and build methods. This presents a challenge to the development of a common traditional prescriptive rule-based assurance process that would be internationally acceptable and available to all.

This paper looks at how a goal-based assurance approach can provide a solution to these problems and provide examples of how this can be achieved, highlighting the advantages and limitations of such an approach.

1. Introduction

Submarines are high value assets that require material integrity and equipment reliability, to operate in an extremely hostile environment. Physical and financial constraints, as with any design and build, require an assessment of the acceptable level of risk that allows a submarine to operate safely. These risks need to be robustly managed from identifying and quantifying the associated risk in the design stage, to assessing the risk associated with build quality and in-service degradation, and service extension well beyond the original design life.

The question facing Builders, Designers and Owners is how to provide assurance for new and in-service submarines. This paper explores the current and inherent difficulties of using a prescriptive rule or a regulation based approach with respect to the design, build and maintenance of a submarine. A major complication being that design and operating information is not made available to industry due to the sensitive nature of the subject matter. This restricts the sharing of technology, design and build methods.

Further problems arise from the limited number of submarine operating navies, capable submarine designers and builders. The submarine industry's knowledge and experience base is relatively small in comparison to the shipping industry. The lack of cross industry communication and limits on suitably qualified and experienced personnel, (SQEP), present a challenge to the development of a common traditional prescriptive rule based assurance process, that would be internationally acceptable and available to all.

The above points imply a large responsibility on the Owner, who will need help with the assurance functions because they retain responsibility for safety. Commercial shipping Owners have used Class Societies in assurance roles for many years, developing processes, sharing knowledge and gaining experience through incidents, accidents and failures. More recently navies have been moving to a class based system for warships for economy, to set common safety standards, and to share best practice. This has proved much more difficult for submarines as design rules are difficult to derive when performance and adequacy of safety are closely guarded secrets.

Lloyd's Register (LR) believe a goal-based approach to submarine assurance is the way forward as it not only allows for greater freedom in standards selection and design innovation, but also empowers the designers to have a pro-active input. Where standards do not exist or are not appropriate, it also provides a basis for a tailored solution.

Integral with design and build is the assurance process that confirms design intent is met. For surface ships, adoption of Class Society Rules provides a set process for assurance of the design safety, build quality and in-service capability in an industry accepted, well-defined, prescribed regulatory approach.

The question is, can a similar regulatory assurance processes be successfully applied to a submarine design, build and in-service programme without significant modification. Any submarine assurance process must adequately recognise and address the operating environment and requirements, combined with the physical constraints, that make for the hazards and associated risks that are unique to a submarine.

This paper looks at how goal-based assurance could provide a solution to these problems and highlights both the advantages and limitations of such an approach.

2. Differences between Ships and Submarines

Ships and submarines do share some technologies. It is, however, important to recognise that whilst some sharing of technologies exist, the operation and operational environment of naval ships and naval submarines are fundamentally different.

This may come across an obvious statement, but this is a major consideration when creating a goal-based, or any other, process that seeks to define an assurance philosophy for naval submarines. It becomes the key issue when discussing if ship standards can be applied to naval submarines. Some of the key differences between naval ships and naval submarines are:

- Submarines are designed for stealth first and everything else second. This is a major design consideration but also a design constraint. Trade-offs must be made in the performance of equipment and materials, e.g. noise, space, to maintain the stealth characteristics of the submarine. For naval ships stealth is a less of a design constraint due the to the size of the ship and space to fit the equipment inside.
- An obvious difference between naval ships and naval submarines is that ships operate on the surface. This has obvious direct consequences and some indirect consequences.
- Submarines have two steady state modes of operation, surfaced and submerged. The transition phase from surface to underwater being one of the most safety critical times for a submarine.
- When submerged the submarines crew actively manage stability, buoyancy and the environment. To support these functions, all equipment on board the submarine needs to be fully operational in both steady states as well as when transitioning between the two.
- A submarine has an enclosed atmosphere, which requires constant management with reduced tolerance for failure. A fire on board a submarine is more likely to have significant consequences. This is a key consideration, when selecting material standards to be used on naval submarine projects.
- A submarine can be considered as one machine far more so than a naval ship. Consequences of a single failure can be greater due to this interrelation of systems and equipment, demonstrated in figure 1. If we consider 10 safety goals with 25 safety functions for 40 concepts of operations involving 80 systems, the permutations of interrelations are around 500. Highlighting that apparently inconsequential failures may lead to loss of the submarine.

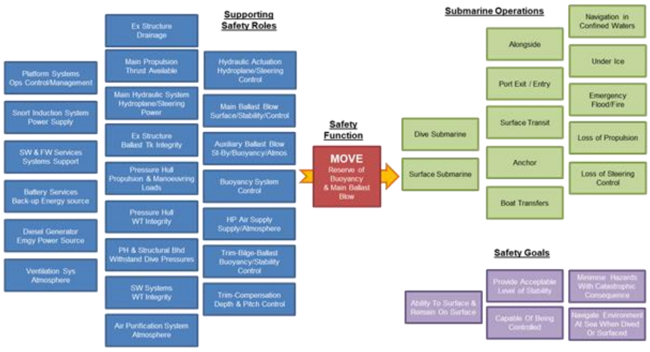

Fig 1. Interconnection and dependency of systems

- Submarine systems have a high level of redundancy, but there is less tolerability for operating with defects or equipment issues. A surface ship has greater capacity to continue to operate with defects or major equipment out of action
- Space and weight limits for a submarine provide greater constraints on the design. Naval ships are designed with space and life extensions in mind. Any additional equipment to the submarine has major consequences for the stability and buoyancy of the submarine, and this needs to be considered during the design phase. The ergonomics of adding and changing equipment is far more difficult for a naval submarine due to space and access limitations.

3. Build & Manufacturing Quality

The increased consequences of failure associated with a submarine require a higher level of build quality and greater assurance that the design intent has been met.
This level of assurance must be maintained throughout the submarine's operational life. In-service assurance requires verification that the design intent continues to be met by the material state and following repairs or modifications. All these aspects are key to through life operability, reliability and availability of a submarine.

Submarine build processes differ significantly from that of a ship as they start with building the fully enclosing external structure followed by internal fitting and installing of equipment, systems and modules. This creates logistic problems that impact on the quality requirements of supplied equipment and components.

A significantly high level of equipment becomes "lock out" during early stages of the build as shipping routes become compromised. Locked out equipment may not be used for years after fitting but will require care and maintenance. It means their 'operational' life includes a portion of the build period. This must be carefully managed, but it also drives higher quality requirements, as any future faults found will require 'in-situ' repairs. Cutting holes in the completed pressure hull is rarely an option due to the impact on pressure hull circularity and fairness of curvature, which could compromise the diving depth of the submarine.

Build quality is based on a foundation of supplied material, equipment and component quality. Assurance of both supplied product and build quality is not wholly achieved through an inspection regime. Quality cannot be "inspected" into a product it must be built in from the start. Assurance of supplied product quality requires a robust independent verification process, which includes Quality Control inspections, conducted by SQEP personnel who understand the product and manufacturing process. Their task being to question the effectiveness of the processes used to manufacture the product as it progresses, to ensure both design intent and build quality are mutually achieved.
A process employing SQEP, at the suppliers, verifying the design assumptions and intentions, as well as product quality, remain valid during manufacture, provides assurance to the builders that the design intent is being met.

This verification process, that questions the product's manufacture, can also be applied to the build, fabrication and system installation at the shipyard and also in-service maintenance. Employing this process end to end provides assurance to all stakeholders that design intent and quality requirements are met and maintained through life.

Build quality requires appropriate instructions to work from whether standards, rules, regulations or tailored solutions. The issue with using Standards and Regulations from a different area of industry, however, is whether they are fully compatible with submarine design intent and quality needs. A goal-based assurance process can be used to identify and test whether standards are appropriate to support design, build and in-service verification.

Getting the correct level of assurance for equipment and components for new building, in-service maintenance or planned refit programmes, is extremely important for naval submarines. It requires a correctly specified and unambiguous set of requirements derived from the design specification that can be readily communicated to the builder and in turn their suppliers.

Correct specification means the correct function or design intent can be achieved, but the specifications also need to set the requirements for the level of assurance and scrutiny to be applied during build so that the quality of the product satisfies the design intent, safety functions and programme expectations.

4. Ship Rule Based Assurance

Ship Rules have been developed and have evolved over many years based on experience, records and investigations of many thousands of surface vessels. For LR its Rules have developed over the past 259 years for surface ships. This has created a vast database of empirical information on which to build rule requirements. The global commercial ship industry also has a vast pool of knowledge available to designers and builders, to satisfy safety and ship owner requirements.

Prescriptive regulations are best for well-established and well-understood processes where methods are based on collective knowledge. They provide a datum for steadily improving standards and a reference point for compliance. Ship Rules are robust and well understood across the marine industry including ship builders, equipment and component suppliers. They effectively capture and preserve the design intent from the builder to the Owner.

Ship rules have a rich history being developed over time during which statutory, commercial and financial pressures have, through the knowledge and experience gained, demanded independent verification of ships through such rules to protect cargoes and assets.

4.1 So why not apply them to Submarines?

Ship rule sets work for the shipping industry because they are well established, understood and known by all parties, and accepted across the whole of the shipping industry. They have been built and developed on a vast knowledge base and driven by commercial demand. They provide a robust framework from which owners, builders, operators and suppliers can achieve, and demonstrate compliance to governing and legislative authorities.

Naval ships have adopted a classed ship rule set because of financial and resource pressures in maintaining their own standards. Naval submarines and submarines standards also suffer.

As naval ships share many common features with commercial ships it makes it simpler to align them with commercial practices for assurance purposes. With the translation of commercial ship rules to naval ships being often easy and direct. The large number of naval ships provides sufficient data and feedback to support the applicability of commercial ship rules to naval ships. Conversely there are no large numbers of commercially operated submarines.

Naval submarines, in comparison to ships, are a specialist sector of the marine industry, built in small numbers and secretive in nature. So, there is a reduction of opportunities, and a lack of appetite, to share design concepts and learn from experience across the submarine industry. This impedes the access to knowledge that would support a prescriptive submarine rule approach.

Submersible rules are available and are prescriptive, but they have evolved from a need to provide a compliance path that allowed a specific service to be performed within a highly regulated industry. Their performance requirements are therefore focussed on safety, well documented. In the industry the standards are shared as are their design and build technologies.

That lack of shared knowledge and experience, and the lack of commercial or statutory pressure within the submarine industry has not created a similar demand for common submarine rules. The lack of demand can also be attributed in part to a submarines value as a weapon and the advantage of its unknown capability. Retaining as much secrecy as possible conflicts directly with the gaining of knowledge and experience across the industry. Sharing such information could be perceived as compromising a submarines operational effectiveness, which in turn could undermine the case for asset investment.

A modified ship rule set could be used to provide a general basis for submarine rule set. However, the rules would need to be questioned at each step, why does the rule exist? what is its intention? Is the safety margin contained within it fully understood? does it still work in the submarine operating environment?

Ship Rule sets tend to have, in terms of ships, a conservative catch all safety margin. There is a need to understand if these safety margins and rule intentions, while appropriate for a ship, are suited to a submarine.

These factors limit the efficient and effective use of ship rules to set the necessary design requirements for submarine safety.

Such arguments may indicate why a submarine rule set has only recently been considered and also suggests why such a rule set would struggle to be maintained and hence remain relevant.

Rule requirements, whether ship or submarine specific, are prescriptive and need to be relevant to the design and known risks. They do not, however, address consequences or unknown hazards, a goal-based system allows you to establish the levels of tolerable risk against consequences. Such risk management through prescriptive rules requires constant maintenance to embody emerging risks, new designs and new manufacturing methods. This is a reactive process, which can cause development delays and drive a conservative minimum level safety management approach. It is impracticable to write a rule for every eventuality and very difficult to keep up to date with developing technology.

The timeliness of prescriptive rules addressing known emerging hazards creates a known flaw in any regulation. It also inhibits the use of innovative design, materials or methods. Innovation in submarine design being essential to combat the ever-changing operational requirements as counter measures are developed

Full maintenance of a comprehensive rule set requires significant in-house design expertise. However, in the case of submarine design and build this expertise is in limited supply due to it being a relatively small sector.

With regulation there is the question of whether adhering to a minimum set level of safety is appropriate as it can lead to a culture where Designers, Builders and Owners do not take full ownership for safety but rely on achieving regulation compliance which is a contractual requirement.

Ship Rules are also supported and fed by the ease of access to a ship, by Class Societies, to verify structural and mechanical integrity and in doing so gain further knowledge and experience, and so continually gather information. That frequency of survey and ease of access to record material condition will influence the level of risk within rules that can be tolerated for any ships material or equipment. However, the limited accessibility to submarines, and parts of a submarine, raises the question as to whether ship rule based assumptions supported by ship survey and inspection frequency, and so information gathered, are applicable for a submarine.

Providing the supplier with a clear set of requirements against a product they are going to manufacture is paramount from cost, delivery and especially quality perspectives. Creating a submarine rule set where supplements are required to address security and secrecy ends up with multi part documents. One part bespoke for a specific Owner the other a general set of incomplete prescriptive rules. This two-part rule set approach can lead to ambiguities and misinterpretations in the global supply chain having an impact on cost, delivery and quality. Correct, clear-cut specifications are also a necessity for Class Society verification to ensure that verification is valid.

The naval submarine design build and supply chain dilemma the absence of a shared experience and knowledge foundation to fully support a set of common prescriptive regulations. A goal-based approach can allow design, build and maintenance to a common framework while still protecting sensitive information.

Goal based approaches are not new, but it is significant that IMO have introduced such an approach to provide 'rules for rules'. There are goal based approaches for ships being used to optimise designs, in a way to that prescriptive regulations cannot provide for, to gain commercial advantage. IMO's goal based system isn't directed at specific ship designs but at the classification societies prescriptive design rules to provide a common scope of safety assurance across the industry.

Whilst prescriptive rule requirements do not provide an ideal assurance mechanism for a submarine, the rules do contain processes that can be applied through a goal-based framework to support assurance of submarine design, build and maintenance. Additionally, the ship rule approach by Class Societies has over the years, provided an extensive, qualified and experienced worldwide resource, with supplier, manufacturing and fabrication knowledge. This is a great asset for implementing any assurance approach.

Adopting a goal-based approach may need change within the submarine industry with the biggest change being for the designer who has to take active ownership of the design specifications and detailed safety requirements.

5. Ship standards - Can we use ship standards where applicable?

Marine accident statistics suggest that a majority of ship accidents are down to human error, but there still remains a significant percentage that are due to indirect failings in the quality of supplied equipment, build and maintenance. Putting aside the human error during operations, the submarine industry must be mindful that failures occur on vessels built to ship rules. Ships by their nature can tolerate these failures.

This indicates that compliance with prescriptive standards does not address every safety risk, only those that are known. The statistics would indicate not all hazards are known, especially from the many possible risks from human error during the design, build and maintenance of a submarine. Aspects covered in the safety management system rather than the Rules.

The goal-based system allows you to establish the levels of tolerable risk that will be acceptable in different operational conditions so can target critical systems that require greater levels of resilience. This targeting of requirements can be flowed down to supplied products and new building verification.

A direct translation of ship standards to submarines is not wholly appropriate without transverse whole boat issues being fully considered in the design, build and maintenance. This is true at the component design level and more so at the system design level.

All requirements including "whole boat transverse requirements" originate from the submarine's Concept of Operation Statement and need to be incorporated in the submarine design specification. Using an existing ship rule set to verify the design, even at component level, requires careful analysis as to what extent they consider the transverse requirements and at what point they need to be supplemented by additional specifications.

The use of Ship rules used in conjunction with additional requirements, it should be said, is a tacit acknowledgement that they do not fully address submarine needs.

However, where a design is straight forward, and involves no innovation or optimisation, then prescriptive rules if fully appropriate could be used in isolation. This may provide a cost effective and straightforward solution for designers and builders through incorporating specific Classification Rules. But care must be exercised because where a component for a ship maybe considered straight forward, it may not be the case for a submarine because of transverse issues and the integral nature of systems.

At system design level transverse issues still apply but even further consideration is required due to the degree of integration and multi-functionality of submarine systems. These considerations reduce the applicability of ship standards to submarine systems.

Any rule requirements that are to be used for a component need to be fully mapped to the appropriate verification requirements that take into account the different risk categories that may apply. The risk level assumed is not very clear in prescriptive ship rule sets.

6. The benefits of a Goal Based Approach

6.1 Drivers for Goal Based Compliance.

The first question we need to ask is what do we mean by goal-based assurance? Goal based assurance is a method which establishes safety activities through the selection of applicable Standards or tailored solutions. A justification process is used to show that these applicable solutions meet the goals of the assurance regime and are valid for the Concept of Operations.

There are several developments set to have a dramatic influence on goal-based submarine assurance:

- The recent development of the Naval Submarine Code (NSubC) by the International Naval Safety Association (INSA).
- The ability of goal-based assurance to respond to the unique challenges of submarine design, and the difficult and complex issues of prescriptive requirements, for multi-functional elements.
- Reduction in global and national portfolios of standards for submarines, and confidence in the often out-dated content.
- Reduction in technical capability of the Owner in submarine design, build, maintenance and decommissioning coupled with a great reliance on the submarine builder and commercial maintenance facilities.
- Increased demand for submarines, in particularly MOTS.
- Increased commercial offerings of small but complex submarines to the global market.
- Increasing technology and sophistication of submarines and naval warfare.

Picking up on the NSubC, which was developed by INSA as goal-based submarine standard. It was originally created in 2012 and developed by a specialist NATO team before being passed on to INSA. The NSubC follows the same structure as the Naval Ship Code NSC [1]. The NSubC has a tiered structure as shown in figure 2.

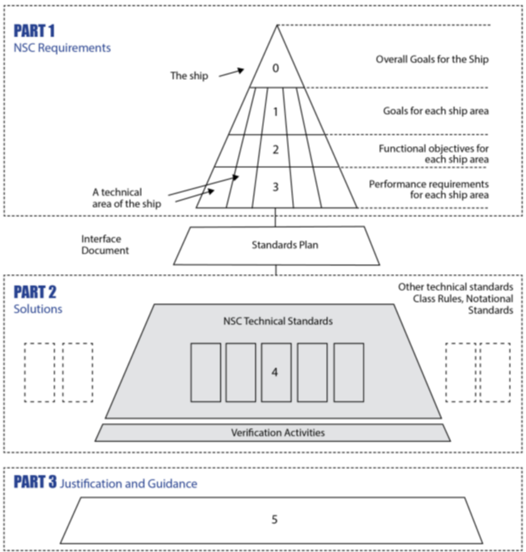

Fig 2. Naval Ship Code Parts and Tiers

The NSubC overall Aim is the safety of the submarine. Chapters, covering different areas of the submarine, have goal that supports the overall aim. Achieving the goal is through the addressing the Functional Objectives supported by Performance Requirements within those chapters. That makes up the first 'tier' and covers design intent. The next tier is about the solutions that support requirements, objectives and goals. Population of these are restricted as they contain highly classified information. A goal-based assurance approach does not give away sensitive information as the solutions selected for the project, will be protected by a NDA or a Governmental agreement. But the process to arrive at those solutions has confirmed compliance with the overall safety aim.

The purpose of the NSubC is to ask the right questions of the designer and or operator to ensure the correct standard or solution is chosen. This process can incorporate various assurance elements such as risk, national or international standards as applicable. In a goal-based approach one of the key elements is how risk is recognised in the assurance process. Including risk in the approach allows the Owner to alter the level of verification require for a component based on its safety category and safety function.

6.2 What do we need to include in a Goal Based Standard for Submarines?

Submarine builders are seeing the benefits of the NSubC as an overarching safety standard in new build projects. By aligning a goal-based code/standard to the NSubC, which is easily achieved by follow its structure, allows the User to see which parts are directly comparable.

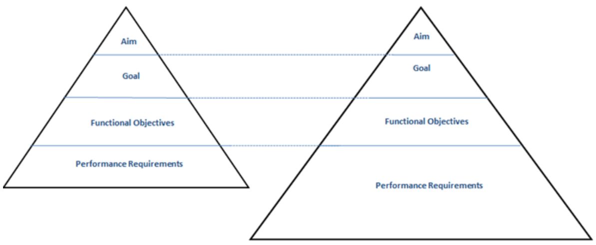

Fig 3. Alignment of goal based standards

Figure 3 is an example of how this can be achieved. Both Codes have similar higher level tiers, Aim, Goal and Functional Objectives. Then the lower tier can contain more detailed requirements based on what the Code is trying to achive, but there is a common structure which the User can follow.

Alignment is key for the inter-operability of a goal based approach. The goal based assurance process must have the right questions to work with a wide range of standards and requirements. Standards and requirements that may not be known to the process due to them being secret in nature. This address design sharing differences between ships and submarines as we discussed previously in this paper.

Any assurance process would need to ensure the project specifications, Rules, Codes and standards proposed for submarine design and construction are justified against an established and recognised set of Goals, Functional Requirements and Performance Requirements for submarine safety equivalent.

A goal based assurance process can be applied over the full submarine lifecycle, establishing the required safety assurance activities to be carried out during design and build and thereafter in-service or alternatively may be restricted to particular lifecycle phases as desired.

One of the key benefits of a goal based assruance process is that is can be tailored to an entire subamrine, systems or individual componement. Take a component as an example. A goal based assurance process could ask the following questions:

- What is the function of the componment?
- What is environment that the component has to operate in?
- What system is part of?
- What elements does the component comprise of?
- What are the transverse issues that need to be considered, shock, noise etc?
- What are the normal, abnormal and emergency operating conditions?
- What risks does the component present?
- What are the consquences of failure?

These questions can be applied to submarine systems or build. It requires the designer to indentify an applicable solutions and provide the justification to demonstrate why their solutions are appropiate. This will also indentify key product verifcation activities to be applied during manufacture and build to ensure design intent and build quality requirements are achieved.The process is shown in fig 4.

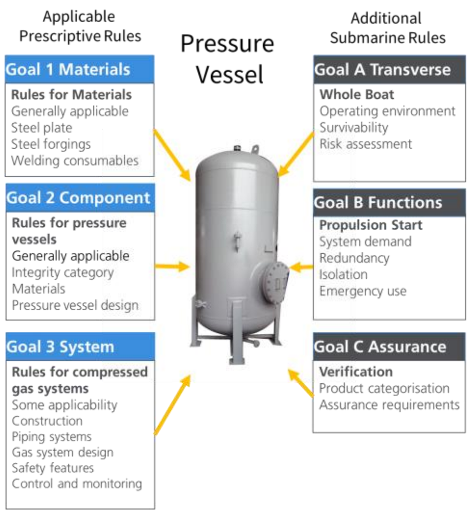

Fig 4. Application of Prescriptive Requirements

Goal based structures can allow prescriptive rule where appropriate. Within a goal-based approach suitably justified "commercial" lower tier regulations and standards can support cost efficiencies, ease of implementation and simple compliance verification. Actual equipment and component product verification can still use the ship rule methodology but with additional requirements derived from the goal-based approach. The goal-based system can also accommodate safety assurance of innovative, complex, high risk, high cost products setting safety level appropriately for each application.

In the pressure vessel example shown, subject to evaluation of the submarine transverse requirements, the material rules can be used for procurement and for an air start pressure vessel, the normal 3rd party inspection requirements can be applied. However, the transverse requirement for shock, may impose material toughness limits which would need to be added to the equipment specification. At the system level it can be seen that the prescriptive rule cease to apply because of the additional system safety and functional requirements.

The same philosophy can also be applied for submarine build verification, using a modified assurance methodology. The scope and criteria would differ from the normal ship requirements, modified by the goal-based approach.

Similarly, for in-service, the principles of inspection, acceptance criteria and survey are pertinent, but the scope would need to reflect the output from the goal-based approach.

Modification would be required for availability and access issues. In the event that any spares, replacement material or equipment were needed during in-service maintenance these would have to satisfy the original goal-based system outcomes in respect of specification, safety levels and quality requirements to maintain design intent.

The goal based assurance process gives the fleixibliy to use different solutions whether they be rules, codes, stardards or tailored solutions by asking intelligent questions through goal based framework, that are then suitably justified. The process can form part of the safety argument for the life of the submarine.

6.3 In-service considerations

New submarines are being designed for longer service lives and current submarines have service lives extended beyond the original design working life. With these increased time spans Owner's face, the risk of original builders or equipment manufacturer not being current or available to support a submarine refit. Hence losing the ability to ensure compliance with the original design intent. The advantage of a goal-based assurance process is that it asks the questions at the start of the design and build and captures the relevant information that can be used later down the line by the Owner to establish the required design intent.

The Owner is ultimately responsible therefore safety and cannot avoid that responsibility. They must have a safety case that allows an analysis with the current state of the submarine to ensure that defects do not combine to reduce safety, in the longer term they will need to include the results of survey to ensure that the safety case remains valid through life.

Submarines in service will rarely meet all the requirements assumed in the designers' safety case. Pump performance deteriorates, valves leak, and cracks can grow. The owner needs to institute a survey and maintenance regime that provides the information needed to update the safety case to give confidence that the required level of safety is maintained.

Submarines need routine maintenance to remain operational, and a detailed schedule, derived from the safety case and operational requirements, will be required to ensure that all required maintenance is carried out. Missed or late maintenance and outstanding defects will influence safety, and this must be evaluated against the safety case. Without a plan, detailed records and a quality assurance regime the Owner will not be able to assure themselves that the submarine remains safe.

Components obtained to replace defective or life expended items and refurbished equipment must either match exactly those replaced or the safety case will need to be updated to take account of any change in function or performance. The supply chain will need to be quality assured to ensure that the components supplied meet the standards specified and that the provenance of anything fitted to the submarine does not invalidate the safety case. The Owner must ensure that the operator and maintainer does not inadvertently invalidate the safety case by using non-conforming material or take on board prohibited material into the closed environment.

Periodic survey will be needed to ensure that static systems such as the hull remain within the design parameters. Detailed records of the condition of all structural elements must be obtained from the builder, and the safety case should define the survey periodicity needed to ensure that the case remains valid. Again, detailed records must be maintained, as, if for instance you find a crack, you will not know if it is growing, how fast it is growing, and therefore if you need to do something about it unless you have detailed records. The Owner will also need to evaluate the effects on the safety case to make any repair decision.

Defects can arise at any time and most are benign by themselves. However, a combination can become dangerous, and a method is required to evaluate the overall effect. Traditional safety cases are good at defining a level of safety as designed and built, but any fall off in performance or potential in systems and equipment (the hull is a system) will need assessment against the safety criteria established by the Owner. To carry out this assessment against an imperative operational requirement to go to sea, requires some forethought and development of a flexible safety system, before it is needed at short notice.

The Owner's responsibility for safety is absolute and cannot be delegated. Any system developed to provide 'Safe to Operate (dive) certification can use other organisations to provide advice, maintain records, carry out maintenance, both in service and refit, carry out modifications, carry out surveys and evaluate the results, and update the safety case. However, the Owner is responsible for selecting competent organisations to carry out the work and must have the expertise in house to provide competent oversite and authorisation.

The maintenance of an adequately safe submarine depends on accurate and comprehensive record keeping. Record keeping is a through life activity and must start with the design definition, giving the limits of operation, the achieved performance, build records, and initial safety case and continue with all survey information, changes, defects and other work done until disposal for scrap. The details of these requirements must be defined in the design and build contracts, maintenance contracts and contracts for change as much of the data is ephemeral and must be captured as it is produced. Many owners exist far from the original Design Authority and builder, and companies cannot be expected to maintain teams and databases unless specifically contracted to do so. Even in-house build, maintenance and change facilities will need to be reminded of the need to keep defined records and the safety organisation will need oversight of the record keeping ensuring that vital information is not lost.

The Safety Case is vital to the ability of the Owner to know that an adequate level of safety is being maintained through life. This requirement must be built in to the original definition of the safety requirement on the designer and builder, as it is very difficult to manipulate a traditional safety case once changes or defects occur through life. The Concept of Operations may well change during its lifetime, or the submarine may be sold to another operator. A goal based assurance process provides the mechanism to correlate all required information and to ensure that it is captured and recorded through asking the right questions, records these assumptions and objective evidence which forms a basis for a necessary engineering judgement to allow continuing safe operation.The development of the design assurance and the safety argument can provide the equivalent of 'class rules' to base the surveys etc on.

The goal-based assurance process gives the flexibility to maintain safety assurance despite the pressures of operation and the complexity of the interaction of submarine systems. Used properly it ensures that all necessary information is captured and enables the Owner to maintain confidence in the acceptability of the level of risk incurred by operating the submarine.

7. Conclusions

This paper has highlighted the issues facing builders and Owners undertaking new submarine build or keeping existing submarines in operation. Submarines are complex naval assets and a goal based approach allows for flexibility and innovation within design, build and maintenance solutions. It keeps sensitive information protected and also provides a mechanism to help maintain standards portfolios.

Goal based assurance can be used to:

Owners need help to perform their safety responsibilities. The system proposed in this paper will allow organisations such as class societies to provide their traditional, design assessment, product verification survey. In a goal-based assurance system to Designer's, Builder's and Owner's without having to share closely guarded operational secrets.

The pace of technical change is outstripping the ability to create prescriptive Rules and Standards. If Builders and Owners want to successfully exploit new and novel technology, then a goal based assurance process provides the ideal platform.

References

[1] ANEP Naval Ship Code Edition G, Version 3

Author/Speaker Biographies

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After retiring from the MoD he has acted as a consultant to many submarine and surface ship projects on propulsion and auxiliary systems, and the management of the design process.

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