CMVH
CENTRE FOR MILITARY & VETERANS' HEALTH

Oberon Class Submarine Occupational Hygiene Project

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Final Report

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Chief Investigators:
CMDR Sonya Bennett, CMVH, University of Queensland
Associate Professor Dino Pisaniello, CMVH, University of Adelaide

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Executive Summary

The Centre for Military and Veterans' Health was tasked with creating a hazard exposure profile for Australian Oberon class submariners. These submarines, in service during the period 1967 – 2000, have now been decommissioned and thus this report represents a retrospective exposure assessment.

In developing the exposure profile, reference was made to the available scientific and technical literature. It rapidly became apparent that systematic occupational hygiene and health studies of Oberon class or even diesel electric submarines are rare and with few exceptions, the quality of exposure information is poor. Beyond the literature review, the CMVH team, which included two senior occupational hygienists for the bulk of the work, visited the decommissioned HMAS ONSLOW, conducted focus groups in Sydney and Rockingham, spoke with several experienced submariners and triangulated the evidence to arrive at the hazard exposure profile and inform the conclusions and recommendations.

Tables 4 and 5 detail the exposure profiles and level of evidence of the hazards identified in the project. The legend for the Table 4 and 5 is below:

Legend
* based on proximity to source, task and other factors
Rating: low = low exposure relative to exposure criterion; significant = comparable with or greater than exposure criterion
Quality of evidence: good = published data under actual conditions; medium = professional judgement in conjunction with focus group information and observation; poor = insufficient, unavailable or presumptive

Table 4: Exposure Profile and Quality of Evidence

Hazard	**Most exposed crew***	**Rating**	**Quality of Evidence**	**Comments**
Gases (see below)				
Diesel vapour	Engine room crew	significant	medium	
Other hydrocarbons and volatile organic compounds	Engine room crew, electrical maintenance	low	medium	May be peak exposures when cleaning
Metals (e.g. lead, mercury)	Control room, electrical maintenance	low	medium	May be significant for mercury
Asbestos	Engine room crew	low	medium	
Diesel exhaust particulate	Engine room crew	low	medium	
Other particles	Engine room, cook	significant	medium	
Microbes (including bacteria and fungi)	All	low	medium	
Noise	Engine room	significant	medium	
Vibration	Engine room	low	poor	
Heat	Engine room	significant	poor	
Musculoskeletal	All Panel operators	significant significant	poor poor	 Turning valves
Air pressure	All	significant	good	
Psychological	All	significant	medium	
Poor Illumination	Control room		medium	
Non-ionising radiation	Control room, Electrical maintenance	low	poor	
Electricity	Electrical maintenance	low	poor	

Table 5: Exposure Profile (gases) and Quality of Evidence

Gas	Most exposed crew*	Rating	Quality of Evidence	Comments
Carbon Monoxide (CO)	Engine room, torpedo operators	significant	good	Smoking and cooking also relevant
Hydrogen Cyanide (HCN)	No specific crew	low	poor	Only in the event of fire or possibly torpedo firing
Carbon Dioxide ($C0_2$)	All	significant	good	
Oxygen (0_2)	All	significant	good	
Hydrogen Chloride	Electrical maintenance	low	medium	
Phosgene	No specific crew	low	poor	
Chlorine (Cl_2)	Electrical maintenance	low	medium	
Oxides of Nitrogen (NO_x)	Engine room, torpedo operators	low	poor	Only in the event of fire or torpedo firing
Hydrogen Sulphide (H_2S)	All	low	poor	Peaks possible
Hydrogen (H_2)	Electrical crew	low	good	

There is strong anecdotal evidence that the exposures were tolerated, or volunteered, rather than regulated. Conditions were highly variable, such that peak exposures at the limit of tolerability were often encountered. The impact of intermittent peak exposures on chronic disease risk is uncertain, but the recent occupational health literature suggests that it can be important, that is, it may sensitise the body or result in subclinical health decrements, and be exacerbated in later years.

In conclusion, the occupational hygiene literature for Oberon class submarines appears to be sparse. Whilst engine room crew probably experienced a range of significant exposures by virtue of their proximity to the diesel engines, all of the crew were exposed to a cocktail of substances, by multiple routes. A number of factors blur the distinctions, and direct comparison with exposure criteria is problematic.

However, the exposure profile shown in Tables 4 and 5 illustrate that significant exposures to diesel vapour, other particles, carbon monoxide, carbon dioxide and oxygen (lack of) occurred on the Oberon Class submarine. Additionally, Oberon submariners were significantly exposed to the more traditional types of workplace hazards such as noise, heat, musculoskeletal and psychological hazards. Whilst these types of hazards are not unique to the Oberon submarine the context, of confined spaces and 24 hour exposures, in which the submariners were exposed was unique. In addition, the limited washing facilities and potential for synergistic exposure, e.g. between noise and solvents, need to be acknowledged.

Although it is impossible to re-evaluate most exposures, it may be feasible to undertake biomechanical hazard assessments post hoc, e.g. simulating tasks in the decommissioned submarines to strengthen the level of evidence.

The following recommendations are made in the light of the findings:

- The Department of Veterans' Affairs note the Exposure profile in Tables 4 and 5 for consideration as to how it may assist in the compensation process for submariners.

- Defence make available, where possible, documents that have been identified as highly relevant to this project for review. Should this occur, a supplementary document, expanding on the findings of the current report, could then be provided.

- To expand on the findings of this study, a qualified and experienced biomechanist should categorise manual handling, awkward and repetitive tasks on board the Oberon submarine. The most significant of these should be simulated within one of the decommissioned Oberon boats, and biomechanical risk assessments undertaken to strengthen the level of evidence.

- To expand on the findings of this study, tests of skin absorption and skin permeation of diesel could be undertaken and should be considered to add weight to the evidence of risk of diesel exposure.

- Consideration be given to the conduct of a health study of the submariner population to address ex-Oberon submariner concerns and attempt to identify any adverse health outcomes associated with documented exposures. Specific areas of research could include a cancer incidence and mortality study and neurobehavioural testing, using a suite of sensitive indicators of neurological damage. The Defence Deployment Health Surveillance Program is a potential conduit for such a study.

- The Collins Class submarine was not the focus of this study and has not been specifically considered, however, the literature review did reveal that similar hazards may exist on the Collins Class submarines. Systematic occupational hygiene studies, including biological monitoring of hydrocarbon uptake, could be carried out in Collins Class submarines. A gap analysis of what relevant work has already been undertaken and what could be done to expand current knowledge should be undertaken.

Introduction

The Oberon Class Submarines were first acquired in 1967 and were the first Australian submarines since the decommissioning of the *K9* in 1944.[1] In the interim, The Royal Navy Fourth Submarine Flotilla was based in Australia and utilized only for anti-submarine training, by both the Australian and New Zealand navies and air forces. In the early 1960s, strategic thinking started to change and it was recognized that an ‘operational submarine strike force’ would be a worthwhile acquisition for the Royal Australian Navy (RAN).

The conventional diesel-electric submarines were preferred over the nuclear powered submarines, primarily because of cost. In 1963, Australian government approval was given for the construction of eight Oberon Class submarines in the UK.

The Oberon Class was developed from the Porpoise Class and at the time was considered to be a very efficient and effective submarine in that it could recharge its batteries and exchange air whilst submerged and was very quiet whilst running, thus avoiding detection.

HMAS OXLEY was the first Oberon commissioned in April 1967 and HMAS PLATYPUS, the submarine squadron base, was commissioned on the same day, hence the Fourth Submarine Squadron (RAN) was formed. OXLEY was followed by HMAS OTWAY in 1968, HMAS OVENS and HMAS ONSLOW in 1969, HMAS ORION in 1977 and finally HMAS OTAMA in 1978 to complete the squadron with six submarines instead of the original eight. The relevant characteristics of the Oberon Class are detailed below in Table 1:

Table 1: Characteristics of Oberon Class Submarines

Displacement	2070 tonnes surfaced; 2410 tonnes submerged
Length	89.9 metres
Diameter	8.1 metres
Propulsion	Admiralty Standard Range diesel generators; 2 English Electric main motors
Speed	15 knots maximum submerged
Diving Depth	In excess of 500 feet
Armament	Initially 6 forward and 2 after tubes, discharging Mk 8 and Mk 23 torpedoes forward and designed and built for Mk 20 (antisubmarine) torpedoes aft; Later forward tubes discharging Mk 48 torpedoes and encapsulated Harpoon missiles were added.
Crew	7 Officers and 56 sailors

In 1987, the second submarine base was commissioned in West Australia, HMAS STIRLING. This base was the home of HMAS OXLEY until OXLEY paid off (was

[1] White, MWD 1992, *Australian submarines: a history*, Australian government Publishing Service, Canberra.

decommissioned) in 1992. The five remaining Oberon submarines were phased out over the ensuing period as the new Collins Class submarines started to be commissioned. The last remaining Oberon submarine, HMAS OTAMA was decommissioned in 2000.

In recent years, concerns have been raised regarding the poor working conditions experience by Navy personnel deployed on the Oberon Class submarines, and the potential adverse health effects of this environment. There has been anecdotal evidence from personnel who served on the Oberon submarines of several health conditions they believed to have been caused by their work. In addition, many current and former submariners have had difficulty in having Department of Veterans' Affairs (DVA) claims accepted due to the lack of recognition of the hazards experienced during their submarine service. It is hoped that better authoritative documentation of the known hazards will assist the decision-making process for compensation claims, particularly at the primary level, that is, within the rule base.

The Centre for Military and Veterans' Health (CMVH) was sponsored by the Defence Health Service (DHS) to undertake an investigation of the potential risks and hazards of service on the Oberon submarine. The project is a retrospective occupational hygiene survey of the Oberon Class Submarine. The survey attempts to identify known hazards of the Oberon Class HMA Submarine and, where possible, estimates exposures and risk of harm.

Context

For the benefit of the readers of this report it is considered there is a need to define the term 'occupational hygiene' and to describe an occupational hygiene survey. In some countries, such as the United States of America, occupational hygiene is referred to as industrial hygiene.

The field of occupational hygiene is concerned with evaluating environmental health risks and making provision for their control with the focus being on workers and their interaction with the work environment.

The basic objective of an occupational hygiene survey is to detect and evaluate health hazards and unsafe conditions in the work environment and to recommend methods for their control.

A hazard is defined as an "*inherent property of an agent or situation having the potential to cause adverse effects when an organism, system, or (sub)population is exposed to that agent.*" (WHO, 2004)

A risk is defined as "*the probability of an adverse effect in an organism, system, or (sub)population in a reaction to exposure to an agent.*" (WHO, 2004)

Often the terms hazard and risk are used interchangeably which is incorrect as can be seen from the above definitions as the first is an intrinsic property and the second is a calculated value. Calculation of the probability of an unwanted effect requires both dose and the number affected for a specific effect and therefore without knowing both any calculation of risk is speculative.

An occupational hygiene survey is carried out in a number of steps:

1. Identify the hazards in the work place by discussing with workers and management the issues of concern. This is then followed by a preliminary survey of where and how the exposure to the hazards takes place by identifying the hazards and how workers interact with the hazards. This takes into consideration the what, how, how long, any personal protection used, ventilation, and any other relevant exposure factors. At the end of this stage, conduct of a literature search may be required to identify similar occurrences, exposure levels, health issues, and controls. Medical or compensation records, inventory records, previous incident reports etc may also need to be examined. There may be a need to bring in other specialist professionals, e.g., an occupational health physician, an ergonomist, etc, so that the situation can be assessed in its totality. An occupational health physician is a particularly important member of the investigation team when health issues are the basis for the investigation. The physician may discuss the symptoms with the worker, obtain a health history, examine the toxicology to determine if a relationship exists between the exposure and symptoms, recommend and evaluate any medical/biological tests. It is the physician who is in the best position to comment on short and/or long term health consequences resulting from the exposure.

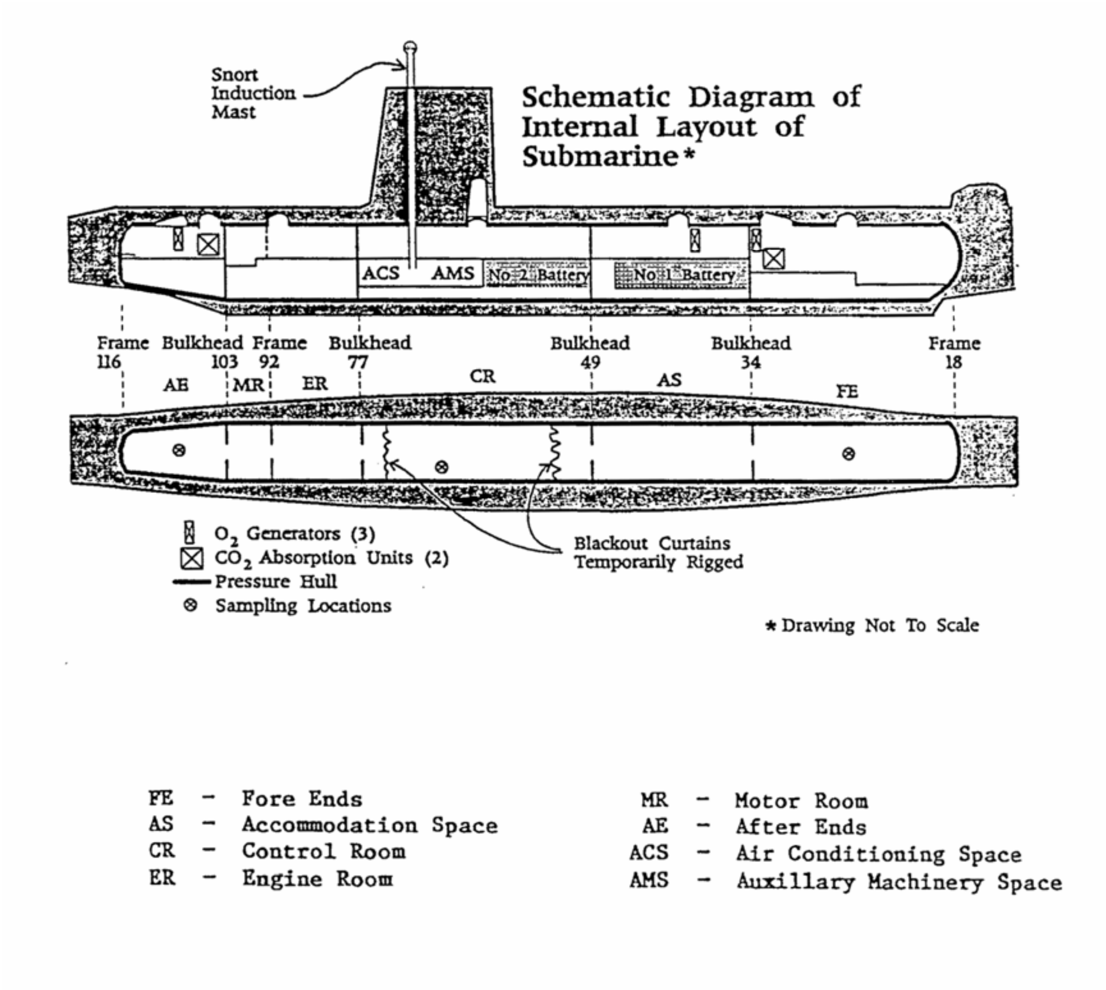
2. Armed with the information from the preliminary survey, a monitoring strategy may be required to quantify the hazard and estimate the risk to health or compliance with Occupational Health and Safety Legislation or Standards/Guidelines. When carrying out the monitoring to assess exposure, the location of the sampling device is on the person (within 30cms of the mouth/nose for chemical substances which are inhaled) or very close to the person's body part which may be affected by the hazard (the ear for noise assessment). Fixed location sampling (static) is generally only done to evaluate equipment performance rather than worker exposure. It is important to use sampling and analysis methods which have been verified as suitable for the particular hazard, otherwise errors may be made when comparisons are made with health guidelines. It should be noted that observation by the occupational hygienist whilst monitoring the worker exposure not only assists in identifying how exposure takes place under working conditions but also may provide a more practical solution in hazard control. The numbers derived have a meaning when they are associated with individuals at work.

3. A report incorporating the initial survey and the analytical results together with any recommendations on how to improve on the control of the hazards is forward to management/workers. The risk to health is generally expressed on the basis of a comparison with an occupational Exposure Standards (Worksafe Australia, (1995)) and their documentation (Worksafe Australia, (1995a), ACGIH, (2001)). The Exposure Standards are generally set to prevent a specific health effect occurring, whereas the agent itself may have a range of effects depending on the level of exposure. The documentation should be consulted not only to determine what compliance protects against but also how good the evidence is for the value set. Therefore the Documentation for the

Exposure Standard must be consulted before applying the values to the work situation. Occupational health limits are dynamic and are in a continuous state of review as new toxicological, or epidemiological, or workplace studies are reported/published and may warrant a change. For agents for which there are no guidelines available, a closer health (medical) watch and reduction of exposure is often advised. No risk calculations are done.

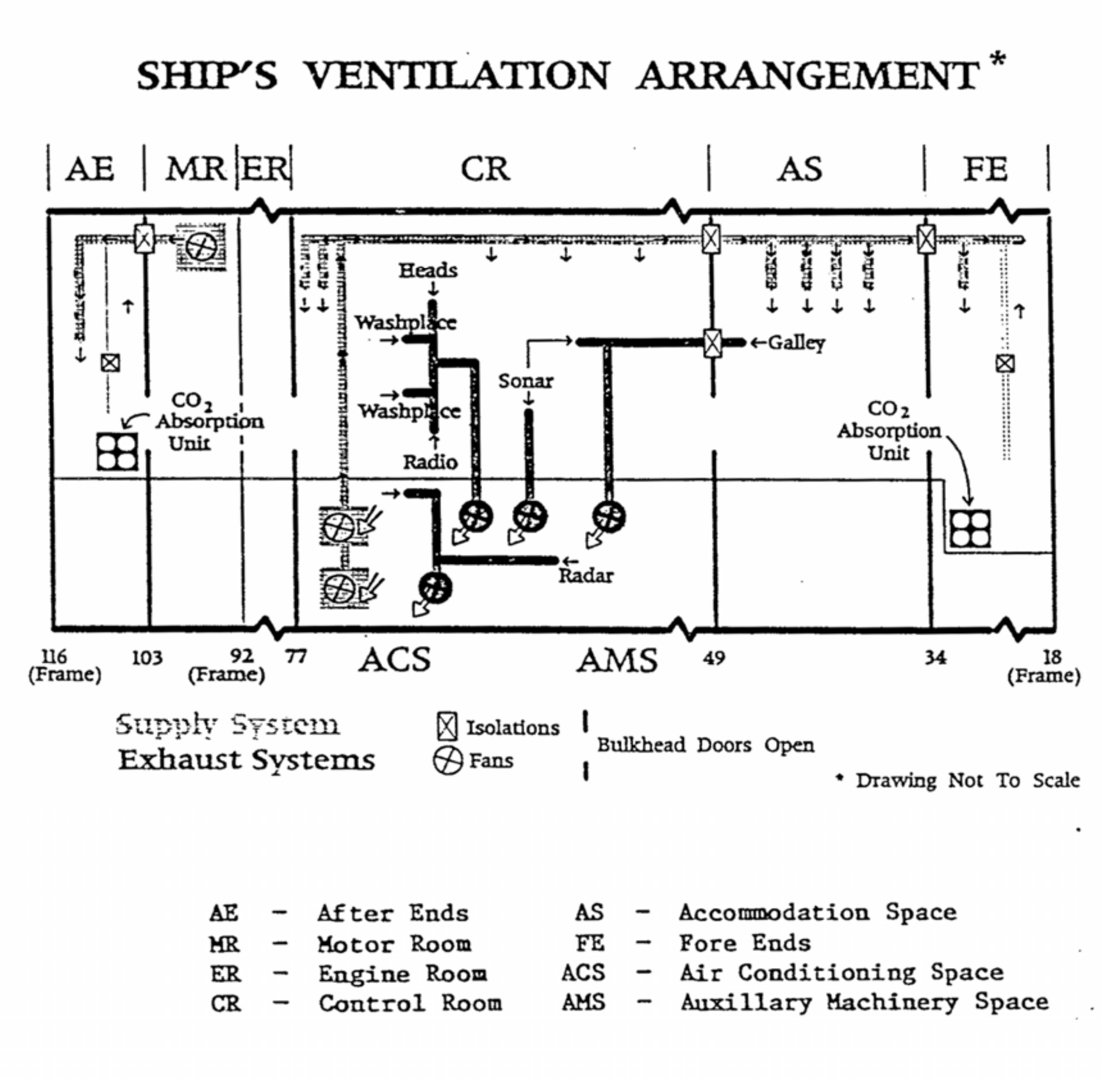
Layout of Submarine

(from Kane and Shergold, 1987)



Ventilation Arrangements

(from Kane and Shergold, 1987)



Aims and Objectives

The aim of the project was to:

a. conduct a retrospective occupational hygiene survey of the Oberon Class Submarine.
b. identify known hazards of the Oberon Class HMA Submarine and estimate exposures and risk of harm based on the available literature and existing Defence Science and Technology (DSTO) reports.

- The broad aims of the project have been further refined below, into activity and the deliverables (text in italics):

- Identify all known occupational hazards aboard the Oberon Class Submarine - *List of known hazards;*

- Attempt to quantify these hazards within retrospective limitations - *List of hazards with quantified measurements, where available;*

- Estimate exposure to these hazards based on proximity and job type - *List estimated exposure to the identified hazards by crew position or branch;*

- Estimate risk of adverse health outcomes based on the hazard and exposure estimate - *Production of an estimated probability of harm score for each hazard;*

- Liaise with Submarine Association of Australia. - *Inspect Oberon Class boat;*

- Conduct 2 focus groups of at least 6 participants each of Oberon Class submariners and related experts - *Focus group protocols (to be approved before use) and report on discussion findings; and,*

- Relate any findings to the existing literature and DSTO habitability data - *Produce a report detailing the identified hazards, estimated exposures and estimated probability of harm from exposure.*

Approach Adopted in this Study

In order to create the exposure profile, the following multifaceted approach was adopted:

- Firstly, a literature review of hazards in Oberon class submarines was undertaken, utilizing the services of a professional librarian, military contacts and other leads. Some of the literature described submariner morbidity and mortality, which together with an understanding of toxicology and epidemiology, may shed some light on likely exposures.

- Secondly, a tour of the decommissioned HMAS ONSLOW was carried out to assess static characteristics of the submarine, and to put exposures into context. Experienced submariners were able to act as tour guides, describing the tasks performed and equipment used.

- Thirdly, focus groups of Oberon class submariners were engaged to identify hazards and to describe their experiences.

- Fourthly, individuals with an expert knowledge of Oberon class submarines and operations were consulted about time activity patterns, and likely sources/pathways of exposure.

- Finally, information from the abovementioned sources was triangulated, with professional judgement, to deduce the exposure profile, according to hazard category.

Hazards, exposure levels (significant/low) and the quality of the evidence (good/medium/poor) are presented in tabular form.
The exposure levels are based on measured values, or, if these are not available, on a metric taking in account proximity to sources, tasks undertaken and other factors. Exposures are compared with exposure criteria where available, and rated as significant or low.
The quality of evidence is classified according to (1) the presence or absence of published exposure data; (2) professional judgement in conjunction with focus group information and observation; (3) lack of availability, inadequacy or purely a presumption of exposure, based on indirect information.

This is a pragmatic approach, attempting to utilize all information, yet acknowledging weaknesses. Note that the outcome is exposure and not risk. Risk is inferred from exposure and health data.

Literature Review

Methodology

The peer reviewed literature and non peer reviewed reports, e.g., US Naval Submarine Medical Research Laboratory reports and DSTO reports, relating to occupational issues on board submarines were identified by electronic (medical [PubMed and Medline] and occupational [NIOSHTIC]) data bases and Google searches.

Assistance was received from Ms M.Bell from University of Adelaide, Barr Smith Library with the construction of the search string [(submarine AND (naval OR navy OR ships OR military)) OR submarines OR submarine medicine Or submariner*) AND English [lang]] and used with the PubMed electronic database. A similar string was used with the NIOSHTIC database. In addition to the above search string a search of Medline and NIOSHTIC was made for ‘submarine’, ‘oberon’ and ‘diesel’. No references could be found relating to ‘oberon’.

Similarly, some departmental and organizational reports were identified via these means. Other departmental documentation was identified by an electronic search of the Defence library database at the Royal Australian Navy Submarine and Underwater Medicine Unit (SUMU). Assistance was received from the OIC SUMU CMDR Sarah Sharkey, the SUMU Scientific Officer, John Pennefather and the SUMU librarian, Mr. Jaakko Tarhala. Dr Wally Mazurek of the Defence Science and Technology Organisation (DSTO) assisted with the provision of relevant documents from DSTO.

The Google search for ‘oberon’ did locate some sites with information about Oberon Class submarines and reference to two DSTO reports. In addition it led to the location of US and UK Navy Research Laboratory home pages and publications. The US publications can only be obtained by purchasing from the National Technical Information Service (NTIS) and likewise for the UK.

Available Literature

The electronic databases (Pubmed, NIOSHTIC) do not identify any literature specific to Oberon Class submarines. There were 560 article references retrieved from Pubmed [National Center for Biotechnology Information (NCBI) at the U.S. National Library of Medicine (NLM)] using the search string [Search ((submarine AND (naval OR navy OR ships OR boats OR military)) OR submarines OR submarine medicine OR submariner*) AND English[lang]], of which 124 were selected for their possible relevance for this project. Using a similar search string with the NIOSTIC in WINSpirs V2.1 database yielded a further 173 references. Both outputs were combined and duplicates eliminated, yielding 294 references. Unfortunately many of the references are to work published in organizational reports or conference proceedings and are not readily available.

Departmental Documents

Defence Science and Technology Organisation Reports

There have been two Department of Defence, Defence Science and Technology Organisation reports published on monitoring which has taken place on Oberon Class submarines.

1. The first report by Upsher *et al* (1994), relates to microbiological monitoring carried out on HMAS OTWAY and HMAS OVENS. No clear reason is given why the microbiological sampling was undertaken other than informal discussion with Officers and crew and Leut A Mellon that identified the high consumption of analgesics for headache relief and skin complaints. An examination of 2 months of medical complaint records confirmed the high prevalence of the two 'complaints'.

The air monitoring and swipe sampling was carried out after 1 hour of HMAS OTWAY and HMAS OVENS berthing following exercises which involved at least 5 days diving. The air monitoring and swipe sampling was carried out in aft and forward accommodation, and swipe sampling in Galleys, painted wall of top loading hatch and sanitary (toilet and shower) areas. Oxygen candles were 'burnt' 11 hours before docking on HMAS OVENS and 6 weeks before on HMAS OTWAY.

Both submarines had low levels of contamination and generally the results were lower for HMAS OVENS than for HMAS OTWAY, except for an air monitoring sample in the forward accommodation when some mouldy bags were moved. The explanation offered for the lower levels of microorganisms on the HMAS OVENS may have been due to the more recent use of oxygen candles and release of chlorine (or chlorine compounds) which act as sterilants. Six recommendations were made to reduce microorganism populations and to measure chlorine concentrations when burning oxygen candles.

Comment. This report identifies some of the bacteria and microfungi found on board HMAS OVENS and HMAS OTWAY. Unfortunately no airborne concentrations were measured during 'normal' operating conditions whilst at sea, only after one hour after docking and an unspecified time while snorting, during which fresh air is drawn in and vented out.

2. The second report was by Loncar *et al* (1996), which evaluated the suitability of auto recording air monitoring equipment to possibly be used on the Collins Class submarine. The trials were conducted on HMAS OVENS 1995. It was stated that routine air monitoring was done on Oberon Class submarines for oxygen, carbon monoxide, hydrogen sulphide, hydrogen and refrigerant (R-12), by using direct reading instruments (Gastech GX91 and Gastech RI-413 (for the refrigerant) located in the Control Room). Readings were made at 3 hourly intervals and logged. Dräger tubes were also used.

In the trials a wider range of air contaminants was monitored: hydrogen, oxygen, carbon monoxide, carbon dioxide, chlorine, hydrogen chloride, refrigerant R-12, volatile organic compounds (VOCs) and aerosols. The air intake for the instruments was inserted into the air ducting so as to monitor the circulating air. The Photo Ionisation Detector (PID) for VOCs was operated independent of the above plumbing. The instruments were connected to a data logger, and located in the extreme rear of the boat. In addition air grab samples into steel bottles were taken for a more detailed analysis on shore.

As the dives were of short duration (less than 4 hours) no oxygen candles were burnt and therefore no chlorine or hydrogen chloride measurements made. During the trials the range of pressure, temperature and relative humidity was: 621-787 mm Hg, 15-32°C, and 35%-76% RH respectively. The gas data was normalized for 20°C and 760 mm Hg and presented in the report in a graphic format, substance/pressure versus time. Short term carbon dioxide was recorded reaching 1.4% whilst carbon monoxide maximum short term reading was 18 ppm. Some gas monitoring instruments malfunctioned during the trials. The use of the data logger allowed the relationship of emission/usage of the various substances to be related to snorting and diving.

Comment. There are no comparisons made with monitoring instrumentation that were current for the Oberon Class submarine. As the data were recorded at one site only, at best it could only be applied to crew in the very immediate vicinity of the sampling point, and would require the data to be extracted for time intervals that the individual submariner spent in that area.

Caution needs to be exercised in interpreting the VOCs data as they were obtained using a non-specific detector (PID), which responds to a broad range of hydrocarbons and the value displayed is based on the substance used in the instrument calibration and the ionization potential selected. Where there is a mixture of substances involved the PID is a useful instrument to follow the *change* in the '*concentrations'* of the mixture rather than determine the concentration of the mixture as the instrument is unlikely to have been calibrated with the mixture. For assessing occupational exposure to diesel emissions there is a specific method, NIOSH Method 5040 (NIOSH (1994), Birch & Ashley, (2002)), which sets out the collection and analysis of elemental and organic carbon, with the former being the surrogate for diesel emissions. Currently no Exposure Standard has been set in Australia or elsewhere in the world for the general workplace environment. Exposure values have been set for the mining industry in the USA (US Department of Labor, (2005)) and Germany (Bundesministerium fűr Arbeit, (2005)). In both countries there are defined methods of sample collection and analysis for elemental carbon. The German value is a technical limit (TRK) which is a performance/control value.

There is no other Australian published material that has been identified in the published literature on air quality or occupational hygiene survey type investigation on the Oberon Class submarines.

Published Literature Relating to Collins Class Submarines

A number of papers have been prepared or presented in conferences on health in the submarine environment based on issues relating to the Collins Class submarine. Although any results of monitoring cannot be directly applied to the Oberon class due to differences in design and technology, both have some common features such as use of diesel-electric propulsion and air supply systems. The papers that have been made available from DSTO seem to focus on diesel and diesel emissions.

1. Mazurek *et al* (date not stated) in their paper "*Airborne Particulates in Diesel-Electric Submarines*" carried out monitoring work on a diesel-electric submarine whose Class is not stated. The investigation arose from submarine crew complaints about 'household dust and black soot emanating from ventilation ports'. Particulate concentrations were collected by the use of direct reading instruments (TSI Dust-Trak, a light scattering laser photometer) and filter based methods for more detailed laboratory analysis. The monitoring filter devices were located at the air intakes/inlets in the engine room. Subsequently the filters were analysed for total carbon by thermal decomposition, for polynuclear aromatic hydrocarbons (PAHs) and nitro-PAHs by HPLC, and soluble salts by ion chromatography. On filters from the engine room fresh air intake, they found not only diesel exhaust particulates (carbon and PAHs) but also about 30% sea salt.

In addition, a physical search and collection from the 'nooks and crannies' and ventilation grills produced fibrous material which under electron microscopic examination was identified as originating from mats and clothing, and was of non-respirable size. The electron microscope examination of make-do filters placed over the air vents showed the presence of fine particulate carbon, whose origin was attributed to diesel emissions.

Monitors were placed in the Forward Compartment at the exit vents of the longest and shortest ducts. The aerosol concentration plots obtained show the time of occurrence of peaks overlapped indicating a common source of emission. The highest readings were closest to the source which supported the crew complaints.

Monitoring was also done in DSS, Control Room, Ward Room, Lower Accommodation Space and Bunk Room. Analysis of the overlay of plots indicates that other sources of emission namely from the Galley also contribute to the overall aerosol pollution.

Comment. Figures 8 and 9 in the paper show the plots of aerosol measurements in the engine room. A value of 0.5 mg/m^3 is used as Maximum Permissible Level (MPL) or Maximum Permissible Concentration (MPC), but nowhere in the paper do the authors identify who set the MPL or MPC or the basis for the number. The paper does refer to the German (0.2 mg/m^3) and the US Mine Safety and Health Agency (0.46 mg/m^3) figures. However in Figure 9 the US value is referred to as US Limit of 0.3 mg/m^3 and is compared with the measured aerosol data. The overseas values (German and US) are for the mining industry in the respective countries and have specific protocols for collection and analysis which are different to those used in this study. Air monitoring data comparisons are only valid when the methodologies used for the collection of the data are the same or correlations have been carried out.

The electron microscope analysis of the make-do filters placed over the air vents identified the presence of carbon which was attributed to diesel emissions. The authors did not consider whether this carbon could have been due at least in part to cigarette smoke. Smoking was allowed on submarines. Black deposits on air vents are not uncommon even in office environments where there are no diesel emissions.

2. Gan & Mazurek (~2003), in their paper "*Diesel Exhaust Particulates: Old Hazard, New Concern*" review the diesel exhaust particles, their properties, three occupational epidemiological studies, and two environmental approaches to risk calculation. Of the two risk approaches the authors consider the California EPA risk model and the risk calculation as suitable for use in quantitative risk assessment. A number of estimates are made using occupational health 'standards' concentrations from Germany and USA and find that the risk ranges from 10 to 60 excess lung cancers per 1000 workers. For submariners, if it is assumed their exposure is at German or US MSHA occupational limits this would result in 60 excess lung cancers per 1000.

Comment. The reader of the above paper should be aware that occupational and environmental approaches to exposure setting differ in philosophy and in monitoring data collection and are therefore not necessarily interchangeable.

3. Mazurek et al (2004), presented a paper "*Internal Submarine Environment*", was presented at the "Humans in Submarines" Conference in Stockholm, Sweden in 2004. This is a review of some of the hazards on board submarines and a little history. It also states that the RAN has established a Habitability and Safety Sub-Group (HSSG) made up of representatives with a working interest in submarines. The range of hazards reviewed include:

- interior design (*multi levels, ladder use, passage dimensions, movement problems*);
- watch keeping (*fatigue, high work loads, circadian rhythm*);
- diet (*calorific intake and exercise*);
- cigarette smoking (*officially restricted but unofficially tolerated*);
- fire (*use of computer modeling and models, paint selection*);
- climate control (*most areas have climate control except for after compartment with the propulsion machinery where temperatures can reach 60 °C*);
- hygiene (*high standards, availability of water for washing, VOCs and toiletries, control on sanitation aids*);
- microbiologic contamination (*conducive to growth, potable water supplies, use of UV versus chlorine for water sterilization*);
- air quality (*maintenance of oxygen concentration, removal of carbon dioxide, air quality standards for submarines but no reference to what standards are used in Australia, real time air monitoring*);
- odour (*typical submarine odour, masking agents pitfalls*);
- snorting (*re-entrainment of diesel exhaust emissions, diesel vapour emissions associated with leaky pipe work*);
- refrigerants (*high concentrations, formation of toxic and corrosive compounds during fires*); and,
- air-independent propulsion.

Data presented in the paper was drawn from previous reports.

4. Gan & Mazurek (~ 2005), "*Exposure to Diesel Fuel*". This paper focuses on diesel fuel/vapour as a pollutant in diesel-electric submarines. The authors have previously reported measuring concentration of VOC's, albeit diesel vapour, using a flame ionization detector (PID) of 50 ppm. Diesel fuel is made up of alkanes, cycloalkanes, and aromatics (C_6 to C_{28}) together with additives. The fuel is classified into 4 categories which relate to use and composition. Marine diesel (DF No.4) contains more higher boiling point materials than other diesel fuels. Therefore care needs to be exercised when comparing properties and health effects with other diesel fuel types. The paper presents chromatograms from air samples taken on board the Oberon Class submarine and illustrates the difference between liquid and airborne samples. These are later used to estimate the concentrations of some substances under discussion. Benzene, toluene, xylene, hexane and naphthalene are reviewed individually for their short term (e.g., CNS and polyneuropathy) and long term (carcinogenicity) health effects. Based on the monitoring data (chromatograms) and PID value, risk calculations of getting specific cancer (for the substance) are made following a lifetime exposure (40 years). The calculations are speculative considering the limitation of the data. Also based on the monitoring data, authors concluded that neurotoxic effects 'are not expected' but did not rule them out completely as there may be a synergistic effect. The paper does provide a list of health effects that may be experienced from exposure to diesel fuel and some of its constituents. Substances such as toluene whose carcinogenicity classification is in 'dispute' probably need careful monitoring when there is a captive population at risk.

Comment. It is obvious from the above papers that there is a lack of published occupational health data on the concentrations of the various pollutants in the Australian submarine environment, specifically for the Oberon Class. The monitoring results cannot be compared with occupational health exposure guidelines as the monitoring does not conform to practices used by occupational hygienists for assessing exposure of persons at work. It may be necessary for RAN to negotiate with overseas navies for access to data that has been obtained on the Oberon class submarines.

RAN Minutes and Documents - Unclassified

Oberon Class

1. Plant & Gibson (1995), Minute "Gas Sampling - HMAS ORION"
Cause of concern was gas emissions after firing of MK 48 Torpedo. Dräger Accuro 2000 used for Hydrogen Chloride (n.d) and Gastech GX-91 for hydrogen sulphide (1 - 4.0 ppm), carbon dioxide (nd - 0.8 ppm), carbon monoxide (157 - 467 ppm), oxygen (16.8 - 20.1 %) and combustible gases (0.1 162 ppm). (nd = less than detection limit). Concern was expressed about the carbon monoxide and oxygen concentrations and recommendation to change the firing procedure during peace time and carry out further monitoring.

Comment. The report does not specify the duration of firing nor the time interval the measurement represents in order to fully appreciate the extent of health threat. The carbon monoxide concentrations appear to be high.

2. Gibson (1995) - “Mercuric Oxide Spill – FWD 609 Type Indicator Buoy”. Regarding clean up of residues from a ruptured MR 44 mercury dry battery. The battery is made up of mercury, mercuric oxide, manganese oxide, and potassium hydroxide. An MSDS and a clean up procedure were attached.

3. Dalton (1996), “Biological Contamination of HMAS ONSLOW Fresh Water Supplies - AMP 8”.
During dry dock maintenance of HMAS ONSLOW the potable water tanks were cleaned out by contractors following the discovery of biological contamination. Calcium hypochlorite was used for the sterilisation. A number of tanks had lead levels which conformed at time of test but may fall outside proposed National Health &Medical Research Council (NHMRC) guidelines.

4. Royal Australian Navy, (1997), “*Royal Australian Navy Oberon Class Submarine Standard Orders - Volume 2: Operating Procedures*”.
‘Standard Orders are issued to standardize drills, terminology and safety procedures in Australian Submarines.’ The Orders manual was examined for already recognized hazards and instructions on how to minimise or reduce the risk. The orders are divided into chapters with each focusing on particular operations of the submarine. In the following text the numbers in brackets refer to the Standard Order number.

Chapter 2 - Safety General: Chapter 2 is 138 pages long and has almost 60 topic headings covering reporting of defects to explosives/pyrotechnic storage to trimming down in harbour. The Orders state that “*a high consciousness of the need of personnel safety is essential”*(2006). The orders give protocols, including the use of specific safety equipment, and command structure to be followed for certain events. Lock out procedures are used, for example, when working near radar or radio antenna due to risk of irradiation. Depending on length of absence returning sailors must undergo retraining. At the time, there was a policy of allowing smoking onboard submarines except under specific conditions, e.g., during fuelling operations or when ‘No Smoking’, is piped. A list of the hazards/hazardous locations/tasks would constitute the basis of the occupational hazards inventory.

Comment. The consequences of exposure to some of these identified hazards may have not only short but long term consequences such as hearing loss from noise, potential brain damage/diminished cognitive skills from exposure to chemical contaminants in sludge tanks.

Chapter 3 – Diving/Surfacing/Snorting: The protocols for these operations are stated, and a number of hazards are also identified. These hazards include less than atmospheric pressure (27 inches or less)(3042) conditions, reduced oxygen content which may not be recognized until too late as crew become unconscious (3043), and, the possibility of hydrogen explosion if the Main Generators stopped on breaking the charge and the battery reached gassing point (3044).

Chapter 4 – Emergency operating Procedures: This chapter states the protocol for Emergency Stations for specified events which include Fire and its possible sources/origins. Fire not only causes physical damage but also releases atmospheric contaminants which may threaten life and habitation. A number of chemical emergencies are also identified requiring special protective equipment and procedures to avoid short and long term effects. Those involved in fighting fires are ordered to protect themselves by wearing thermaguard suits, Kevlar gloves, anti-flash gear plus reducing skin exposure and spark entry points on their own clothing (4019). (*Comment*: Prior to use of Kevlar it is likely that asbestos gloves and blankets were used.) If external organizations became involved in an emergency, simple line drawings of submarine layout were available. Clean up, testing for cleanliness and first aid procedure for spills of torpedo propellant Otto Fuel are documented. The procedure of torpedo 'hot running' is also documented together with testing of fore ends/accommodation space for HCN (5 ppm), NO_2 (0.5 ppm), H_2 (3%), CO (15 ppm), and CO_2 (0.8%) using appropriate Dräger detector tubes and followed by testing for Otto Fuel (0.2 ppm) with its own special tester (4123). The submarine carries a range of pyrotechnics which may be fired from a submerged submarine (4125) and smoke candles (4127). Asbestos blankets were a part of the fire fighting equipment (4126) used in controlling an accidental ignition. Some of the smoke candles (white) are base on calcium phosphide which will release a highly toxic gas, phosphine (4128). The red and green grenades are based on magnesium plus additives to produce the colour. Other substances used in markers, beacons or bubble decoys are fluorescine and lithium hydride. The latter presents risks of fire and corrosive residues when in contact with water. Each submarine carries six Emergency Atmosphere Monitoring kits (EAM) which contain a Dräger pump and packet of tubes for each of the following: carbon monoxide, carbon dioxide, hydrocyanic acid, hydrochloric acid, phosgene, oxygen, chlorine and an EAM chart (4135). The report provides a table which lists the MPC concentrations for Normal, 24 hours, 1 hour, Out/SPEC and the number of pumps.

Comment. The table has two errors. First the MPC Normal for phosgene should be 0-0.05 vpm instead of 0-0.5 vpm, and the second is the unit of measurement for carbon dioxide should be percent (%) and not vpm. The use of 'vpm' instead of 'ppm' may be confusing when referencing other information sources.

Chapter 5 – Miscellaneous Procedures/Incidents. This chapter covers a broad range of topics including transfer of personnel between ships and helicopter (requiring earthing to reduce electrostatic shock) and disposal of rubbish via gash bag ejector or torpedo tubes. In an event of a nuclear attack, a range of radiation detectors are carried and protocols for use are documented.

5. Flynn, (1997), "*Toxic Gas Incident Onboard HMAS ONSLOW - Provision of Medical Information to the RN*".
This report was produced in response to a request for medical information following a toxic gas incident on HMAS ONSLOW which occurred on 1/5/1981. The report provides an attachment with a list of symptoms and the number of crew affected. Forty three out of a crew of 66 were affected. No details about the incident are presented.

6. Maron, (1999), "*Unclassified: - PCB Exposure in HMAS OTAMA*".
This report provides information on the potential health effects of exposure to PCBs following an exposure to smoke/vapour from heating two capacitors though to contain PCBs. Exposure may have been through inhalation and/or skin contact during the clean up stage. The minute writer was unaware whether any one was affected, but advises the crew members who were exposed or think they may have been exposed to

have it recorded. The document also outlines other action to be taken.

Collins Class

7. Maron, (1997), “Review of Swedish Prediction of Medical Consequences in Prolonged Patrol in Air-independent Propulsion Submarines”.
This is a comment on a previous document relating to Swedish Continuous Exposure Limits (CELs). The Swedes proposed to divide the 40 hour week time weighted average Limit Value by 5, except for those with a ceiling limit, e.g., irritants. It appears the Swedes also took into consideration what was achievable by taking air monitoring results from HMS Gotland. The proposed Swedish CELs and RAN values if the concept was adopted are presented in table format (reproduced below): The values were extracted from the discussion.

Substance	**CEL (Swe)***	**CEL (Aus)****	**Substance**	**CEL (Swe)***	**CEL (AUS)****
Ammonia	25	5	Hydrocarbons – Benzene	0.1	1
Carbon Dioxide	-	< 7000	Hydrocarbons – Toluene	10	20
Carbon Monoxide	7	7	Hydrocarbons – Xylene	10	15
Chlorine	0.1	0.1	Nitrogen Dioxide	-	0.6
Hydrogen	-	-	Ozone	0.02	0.02
Hydrogen Chloride	-	1	Sulphur Dioxide	-	0.4
Hydrogen peroxide	0.2	0.2			

Note: all concentrations in ppm (parts per million) and “-“ signifies a value has not been set.
* Proposed Swedish values
** Proposed Australian values by Minute writer

Reasons for the Australian variations are offered. It is also recommended that air monitoring for the above list of contaminants be carried out on the Collins Class submarines and the list revisited. There is also comment on various health issues and health testing. Many of the comments compare nuclear submarine occupant health outcomes with diesel-electric which are not capable of equivalent duration submergence. Irritants appear to present a problem at lower concentrations as their long term health outcomes are not known.

In the Summary the writer advocates the identification and quantification of air contaminants onboard the Collins Class submarines and concludes

“*Based on that information sensible CELs could be set*”.

Comment. The setting of CELs should not be based on the levels found onboard but rather what levels can ensure a ‘healthy and safe’ environment, short and long term. Industry experience dictates that methods of compliance can always be found if needed.

8. Turnbull (1998), “*HMAS COLLINS - Occupational Health & Safety and Noise Survey*”.
Noise measurements were made in a number of locations, including 48 bunk spaces (whilst snorting), the main generator room, and a number of other locations. The L_{eq} measurements were made using 'A' weighting scale, whereas recordings for frequency analysis were unweighted. A number of locations were identified where the noise exceeded 85 dB(A). This was mainly confined to the Main Generator Room with reading 101.7 to 109.2 dB(A). A number of bunk spaces had noise levels, mainly

from the air vents, in excess of 65 dB(A) for cabin accommodation. A number of recommendations were made to reduce noise in bunk spaces and replacement of the headsets in the Control Room. In addition to this a hazards survey was conducted of conditions likely to cause trauma by electric shock, slips, trips, falls, and head injury. This identified 8 situations which fitted into one of the categories.

Comment: Well done as it provides noise levels of submarine diesel engines.

9. Hendrikson. (2003), Minute cover for a report: "*Collins Class Submarines – Aerosols*" by J. Bailey.
This document reviews the progress of the monitoring for aerosols that has been done since 1998 on the Collins Class submarines. The program included the aerosol monitoring in forward and aft areas with the timing to coincide with diesel operations. As an Occupational Health Guidance value in February 2003, the Maximum Permissible Concentration (MPC) for aerosols was 0.5 mg/m^3, applicable for 90 day, 24 hour and one hour time frames, which was apparently higher than overseas military and civilian guidance. The documentation for the MPC and monitoring data were on separate Enclosures (not sighted). Exposure to this was controlled by engine room personnel being advised to wear breathing apparatus when MPC was exceeded and isolation of the engine compartment to limit exposure for other crew. Other strategies for minimising exposure and the need for use of real time monitoring are discussed. The author then proposes that reduced MPC values be adopted: 0.15 mg/m^3 (90 day), 0.3 mg/m^3 (24 hour), 0.5 mg/m^3 (1 hour), and 3 mg/m^3 (5 minutes).

The Bailey report was accompanied with 4 Enclosures:

i. Enclosure 1. 'Draft - DSTO Report on the "Dust" Problem - Collins Class Submarines", dated May 2003.
This looks like a more detailed version of a referenced paper by Mazurek et al, (date not stated) "Airborne Particulates in Diesel-Electric Submarines". Both the quantification and the size dimensions and distribution of the aerosols were monitored using light scattering laser photometer (TSI Dust track x2) and Grimm Model 104 respectively on the Collins Class submarines. The submarines and their monitoring results are identified in the draft. Two photometers were deployed in various locations on the submarine to provide information such as the times and origins of the monitored pollutants. The aerosol concentrations were compared with occupational health values for mining in USA and Germany and with Australian urban environmental standard of 0.01 mg/m^3 for aerosols. The authors advocate the use of Emergency Air Breathing System (EABS) when excursions occur.

ii. Enclosure 2. '*Human Risk Assessment of Diesel Exhaust Exposures in Australian Submarines*'. Author(s) and date of report not stated.
This appears to a more extensive version of the Gan & Mazurek paper 'Diesel Exhaust Particulates: Old Hazard New Concerns'. Beside the reviews of epidemiological studies and risk calculations, it has a wider discussion on the implications the aerosol monitoring results with compliance and compensation. The Enclosure advocates a review of submarine aerosol standards based on data from 1991 Gulf War.

Comment. The authors of this report identify the American Conference of Governmental Industrial Hygienists (ACGIH) as a regulator. This is not entirely correct. In the ACGIH booklet (ACGIH, 2001) listing the TLVs and BEIs, their Policy Statement printed inside the front cover explicitly states that they are to be used as guides for practicing occupational hygienist and not as legal standards. Many governments world wide have adopted these TLVs with some differences and have made them regulatory values, e.g., OSHA PELs in USA, Worksafe (as Exposure Standards) referenced by Commonwealth and State OH&S legislation.

iii. Enclosure 3. '*Hazard Risk Assessment – Aerosol Contamination of Submarine Atmospheres*' by A. Spurling from the Submarine Force Element Group. Dated 17/2/2003.
The Collins Class Air Purification Manual (ABR 6105) sets a limit of 0.5 mg/m^3 for aerosols. If this value is exceeded then breathing apparatus is required. The philosophy is expressed as 'can't discern between harmful and non-harmful aerosols in real time, then treat all as harmful'. All submarines (Collins class) have aerosol monitors fitted in the Main Generator Room. High readings have been obtained on occasions. Explanations for higher emissions were put forward as well as steps to reduce high exposures. There is a directive that monitors must be on at all times when diesel engines are operating. The Hazard Rating Index (personnel) is 10 (acceptable with continuous review).

iv. Enclosure 4. "*MPC Definitions*". No author or date.
The definitions agreed upon are consistent with the UK application of the terms.
a. MPC 90 – if exceeded, reduce below this level within 24 hours.
b. MPC 24 – if exceeded, reduce below this level within one hour, and below MPC90 within 24 hours.
c. MPC 1 hour – a health based emergency level – immediate use of protective equipment (EABS, OCCABA) until contaminant level drops below this level then the MPC 24 and MPC 90 guidelines apply.

Overseas Studies Relating to Oberon Class Submarines

1. Kane & Shergold, (1987), "*An Air Quality Assessment Onboard an "Oberon" Class Submarine - HMCS Okanagan*".
The study objective was to evaluate the atmospheric concentrations of various substances under operational conditions which included snorting with and without air purification, the use of oxygen candles and CO_2 removal, reduced pressures and battery charging emissions. Air monitoring using detector tubes (CO, CO_2, O_2, H_2, arsine, Freon 12, hydrogen chloride, chlorine), three direct reading instruments for O_2, absorption tubes with pumps (stibine, hydrocarbons), syringe grab samples (O_2, CO_2, CO, Freon 12, Methane and hydrocarbons) and 3M passive badges for mercury, were carried out in a fixed location in the aft and fore compartments and Control Room. Both CO and mercury exposure results exceeded the permissible guideline levels.

However the O_2 and CO_2 results demonstrated poor internal air circulation such that oxygen generation or carbon dioxide scrubbing only appeared to affect local areas. The recommended snorting times in BR 3944 do not achieve the desired results - longer times are necessary. A number of other recommendations are made.

2. Severs & Sabiston, (2000), "*An Air Quality Assessment Onboard an Oberon Class Submarine: MMCS Okanagan*".
This is the best paper available in relation to an occupational hygiene survey of the Oberon class submarine. It was an update of earlier work done on the same submarine (see Kane & Shergold, (1987)) and to obtain data for future air quality management. It represented a baseline evaluation of submarine air quality under patrol conditions. CO, CO_2, and O_2 were monitored using calibrated direct reading instruments with 4 sampling points in different locations. Arsine, stibine and diesel organic compounds were collected using absorption tubes and pumps for laboratory analysis. Inhalable airborne particulates were monitored using an aerosol monitor (Data Ram) located for varying periods in the Engine room, Motor room, and Control room. Ammonia, ozone and NO_x were monitored using Dräger detector tubes. Grab samples were used to obtained hydrogen concentrations. Carboxyhaemoglobin (COHb), which reflects on the carbon monoxide (CO) exposure, was measured from exhaled air samples from 20 volunteers. The Relative Humidity (RH) and temperature was measured using a sling Psychrometer.

The reference point for data comparison was BR1326. All contaminants covered in the study fell within the allowable limits. For contaminants not covered by BR1326 or other military standards, Threshold Limit Values were used. On the basis of CO_2 results, the BR1326 prescribed clearance snorting periods are insufficient to effectively clear the CO_2 levels to ambient conditions. From their observations the activation of CO_2 absorption canisters did not drop the existing CO_2 levels but the subsequent rate of accumulation was reduced. Also the Dräger tubes readings were consistently 20% less than the Infra Red Monitor, i.e., they underestimate the prevailing CO_2 concentration. A pressure correction may need to be applied to any readings that are volume dependent. The data also showed the effect of the black curtain on the reduction of air flow and the nullification of the CO_2 absorption system by its location. The report authors proposed a more effective regime for keeping CO_2 in check and discuss its implications.

The oxygen (O_2) levels declined until the O_2 candles were activated. Only the Fore End had consistent restoration of levels, whereas the Control room and the Engine room were inconsistent, demonstrating once again the role of positioning of the candle and the internal ventilation system. The compartments with the generators benefited the most, the Accommodation Space and the Control Room (17.9%) the least.

The CO concentrations varied at the start (2.8 – 5.9 ppm) and rose to (14.9 – 16.2 ppm) depending on location. There was no technology onboard to remove the CO. The biological uptake as demonstrated by the COHb results showed nonsmokers had levels of 0.2 → 2.8%, whereas for smokers the levels were 2.4 → ~5.6%. These were within the Military Standard of 10%. The levels dropped for non smokers as fresh air was introduced by snorting.

No arsine or stibine was found during battery charging process. Although hydrogen was detected it was below the 2% specification limit. Its distribution was even throughout the boat.

Respirable particulates were monitored in the Engine, Control and Motor rooms. As only one instrument was used the locations were monitored consecutively over a total period of 23 hours 48 minutes. During this period the submarine had completed dives and surfaced twice to snort depth. The BR1326 has no limits for respirable particulates, so the occupational TLVs were used. The time weighted average concentrations (TWAs) for each of the locations were:

Engine Room	0.677 mg/m^3
Motor Room	0.033 mg/m^3
Control Room	0.214 mg/m^3

Caution needs to be exercised when applying 8 hour TWAs to submarine environments as composition of the aerosol/particulates should be known. The authors discuss methods for the reduction of aerosols.

The ammonia, ozone and nitrous compounds were below the detection limit of the method used.

The charcoal tube analysis of the diesel organics measured in the Fore-Ends, Accommodation Space, Control Room, and Engine Room is shown below (as reproduced from the report):

Substance	Concentration Range (mg/m^3)
Benzene	0.087 – 0.249
Toluene	0.562 – 1.145
Ethylbenzene*	0.068 – 0.158
m/p-Xylene*	0.282 – 0.881
o-Xylene*	0.122 – 0.359

For the compounds identified with * the highest readings were in the accommodation space, whereas toluene and benzene were highest in the engine room. Benzene can be considered to originate primarily from diesel, whereas the others may also be from paints or cleaning compounds. Thirty three other hydrocarbons (see full list under hydrocarbons in Hazards List -Chemical Hazards) were also identified together with Freon 12. They were a mixture of straight chain hydrocarbons, substituted cyclohexanes, and aromatics including substituted naphthalenes. There was some discussion on the use of carbon filters to remove these substances from the submarine air.

The report concludes with a number of recommendations for improvement of monitoring for contaminants and for improvement of the air quality.

Comment

These are the best papers read in relation to an occupational hygiene survey of the Oberon class submarine.

These studies demonstrate that valuable data can be obtained by using an occupational hygiene approach and equipment for occupational assessment of submarine contaminants exposure. Limitations to current monitoring and environmental control were identified together with options for control. This approach could be adopted on Australian submarines to include personal monitoring, as was done using the 3M badges for mercury, by attaching passive diffusive devices onto the submariners as they go about their duties. The authors have also shown that sampling using battery operated pumps is possible on a submarine. A sampling pump with an appropriate collection device could be used to collect diesel exhaust/vapour emissions for subsequent laboratory analysis for Elemental Carbon and Organic Carbon. These are used in assessing exposure to diesel emissions or volatile/nonvolatile liquid mists. The direct reading aerosol monitors are excellent devices for tracking in real time the release of aerosols and assessing the effectiveness of controls but not for comparisons with health values, without first doing considerably more correlation studies with reference methods.

Other Literature – Not Oberon Class Submarine Types

Although air monitoring results obtained on other type of submarines, such as the Collins Class or other diesel-electric submarines, cannot and should not be extrapolated to the Oberon Class they nevertheless identify issues which may be common: results of carbon dioxide or carbon monoxide exposure, long term hearing loss experienced by submariners who work in the engine or motor rooms, shortcomings of measurement methodologies, etc. The ensuing discussion will be based on grouping of papers on a common theme. Some of the topic areas are based on hazards identified during the walk through visit of the HMAS ONSLOW, docked at the Australian National Maritime Museum in Darling Harbour, and Focus Group Discussion, the analysis of which is presented later in this report.

General

1. Walters (1968) discusses the parameters involved in working in sealed (submarine) environments. He describes the symptoms at various O_2 concentrations starting with 17% (at 1 atm.) and a fall off of night vision to loss of consciousness at 8-10%. The oxygen is generated by the burning of chlorate candles which is accompanied by giving off heat and raising the internal temperature of the environment or by electrolysis of water. Carbon dioxide is a by-product of exhalation, and in a sealed environment, unless removed, the concentrations will increase and can manifest themselves as symptoms in those exposed. Carbon dioxide is removed by drawing air through soda lime or lithium hydroxide packed in cylinders. Other options are discussed for generation of O_2 and removal of CO_2. Walters makes the point that there is very little value to have exposure standards (MPCs) unless there is technology to measure and then comply.

Walters discusses the thermal environment on submarines, with a rough temperature guide of 60-68 °F (16-20 °C) and with a reasonable amount of air movement to achieve an Effective Temperature between 14-17 °C, unless the boats were completely sedentary. Higher Effective Temperatures may be tolerable but as they increase so does the risk of heat stress and heat stroke. The activity may need to be altered to reduce the body heat load.

Sanitation, diet, storage of food and potable water and disposal of wastes is also discussed. With waste storage and disposal comes the need to prevent entry in to the breathable atmosphere the various sewage gases and odours which have suspended in them pathogenic bacteria.
Another issue touched on is the impact of living for long periods in artificial light, the impact on circadian rhythm, and the lack of exercise which would allay boredom and prevent psychological problems as well as improve physical fitness. Other physical hazards such as noise, vibration, electric and magnetic fields, and atmospheric ions are discussed.

2. Tansy *et al*, (1979), analysed 10 years of health data from Polaris nuclear submarine patrols. Data selection was based on illness that occurred at sea, and that requiring one day off from duty. The four most prevalent causes of illness rated in decreasing order were trauma, gastrointestinal problems, respiratory problems and dermal problems. In ninth place was neuropsychiatric problems. Whereas for lost days, the order was trauma, gastrointestinal, respiratory and systemic illness. In the period covered by the study, there was a significant change in CO_2 control in 1967, so a comparison was made before and after this time. The four most prevalent causes of illness before were the same as after but the order was different in that respiratory illness was more common than trauma before 1967 when the significant change in CO_2 control occurred. There was no change in the conditions associated with the days lost. In 5 out of 9 illness categories the submariners had higher rates than the surface ship persons. The authors proposed that higher CO_2 concentrations on submarines may be causally associated with the higher incidence of ureteral calculi. It was thought that the higher incidence of headache and neuropsychiatric disorders in submariners may be due to overall stress imposed by lengthy isolation but that was discounted later in the paper. The authors then examined the factors that could have influenced the rates of illness. One such factor proposed was reduction in CO_2

pollution by 33%. There is a lengthy discussion on the effects of long periods of exposure to concentrations greater than 0.5% CO_2 on lung and kidney. Another factor was the combination of nutrition and the work-rest schedules and the desynchronisation of circadian cycles which may affect the submariners' well being and resistance to disease. There is lengthy discussion on reduction of CO_2, carbon monoxide and lifestyle factors (diet, exercise and work schedules) and their influence on better health outcomes.

Comment. Unfortunately the same group of submariners has not been followed up at a later date to determine how their health has been affected long term. The study does show the benefit of good record keeping, both of the individual and the environment.

3. Davies (1973) produced a list of environmental factors on nuclear submarines that may affect health:

i. Carbon dioxide – 1% level;
ii. Carbon monoxide – 25 ppm;
iii. Limited physical activity;
iv. Relatively unlimited rich diet;
v. No sunlight, artificial UV light;
vi. Close contact with aerosols and charged ions in air;
vii. Demineralised drinking water;
viii. Close physical and microbiological contact in crew;
ix. Continuously variable watchkeeping and lack of external zeitgebers altering biological rhythm;
x. Lack of normal physical, psychological and sensory stimuli;
xi. Climatic factors within the submarine; and
xii. Unknown factors, other than toxic contaminants.

His findings were that the physiological, biochemical and metabolic changes that occurred during patrols had long term health significance for the renal and cardiovascular systems and the blood. At the time of writing the paper the longevity of exposure was too short to detect if there was an increased incidence of adverse health outcomes in the study population.

Comment. This list is equally applicable to diesel-electric submarines with the added contribution of diesel fuel and diesel emissions, combined with much poorer air cleaning and control.

4. Charpentier *et al* , (1993) examined the mortality outcomes, using death certificates, of a cohort of 76,160 enlisted submariners who served between 1969-1982 on US nuclear submarines. There were 811 deaths during that period. The analysis was performed by age, whole cohort, submarine type, and exposure to radiation. The mortality rates were compared with general US male population and internal multiplicative models. The Standard Mortality Ratio (SMR) was highest for: all accidents - motor vehicle accidents (1.06), malignant neoplasms - brain and CNS (1.03), leukemia (0.91), and major cardiovascular – acute myocardial infarction (0.88). Those SMR less than 1 were considered to be consistent with the 'healthy worker effect'. Dose response relationships could not be established other than with

length of service on a submarine. Suicide rates were higher for the discharged group than those in the service, and rapidly approached civilian rates.

Comment. The study period was too short to identify long term effects. If only ‘healthy workers’ are selected for the submarine service, why do their SMRs approach the general populations rates?

5. Inskip *et al*, (1997), examined the mortality pattern, with cancer mortality being of special interest in submariners who underwent their training between 1960 and 1979 and were followed up to 1989. Overall mortality and cancer mortality were less than the civilian rates. However there was a higher rate than for civilians for the digestive system and cirrhosis of the liver. The excess cirrhosis cases were in men who had left the Navy with 67% having being identified as being associated with alcohol use. There was also a higher rate of deaths from accidents (motor accidents) and violence. After discharge the mortality rate rose to be similar to that of civilians. The study limitations are short follow up period (average 18 years) and too short a period of observation for long latency cancers considering the type of exposure experienced. Two ‘expected’ cancers, lung and leukemia, were low.

Comment. The study did not distinguish between diesel-electric and nuclear submariners.

Aerosols

A paper by Riccardi *et al* (2004) describes the air monitoring for a range of air contaminants, including aerosols, whilst an Italian ‘Sauro’ class submarine is on active duty. The ‘Sauro’ class submarines use the Koala air purification system (see Ranieri (2004)) located in 19 locations on the submarine operated for various intervals depending on whether the submarine was snorkeling or submerged. Gases (CO, CO_2, sulphate compounds, volatile organics compounds (VOCs – referenced to propane), and water vapour) were monitored with a Brüel & Kjær photoacoustic spectrometer, with the probe located in the ceiling of the Control room. Oxygen was measured with an Analox oxymeter. Temperature, humidity and pressure were also recorded. Air particulates were collected on cellulose filters using high flow pumps in the Control and Torpedo Rooms. Analysis for particulate composition was carried out later onshore. It would appear the CO_2 concentrations would only drop from 0.74% to 0.62% with air purification even though the submarine had such a large number of Koala units. The CO concentrations changed from nil to 9.4 ppm with the Koala system having very little impact. The VOCs ranged from 46 – 66 ppm. The mass spectroscopic analysis of the particulate matter showed a large number of elements present in very minute quantities.

Comment: The results are not presented in a manner that can be compared with other published work. The measured aerosol (particulate) concentrations are not stated. For instance, the VOC measurements obtained here cannot be compared with the Gan & Mazurek (~ 2005) paper as different instruments were used and, more importantly, different calibrating gases were used: propane and toluene respectively.

Air Quality Standards

1. In his brief paper, Raffaelli (1989) recounts a little of the history of setting exposure limits for submariners in the UK. As in the USA, the values used were based on the ACGIH (American Conference of Governmental Industrial Hygienists) Threshold Limit Values (TLVs) which are based on a time weighted average concentration (TWA) for an 8 hour day, 40 hour week, with time to allow for recovery of the in-taken contaminants between daily exposures. In 1987 the UK Health & Safety Executive introduced the concept of Occupational Exposure Limits (OELs - health based) and Control Limits or Maximum Exposure Limits (MELs - best practice), with the latter being influential for the Royal Navy in its process for setting limits. Owing to the differences in the submerged environment compared with that of a normal workplace, separate limits, Maximum Permissible Concentrations (MPCs) are set by the Institute of Naval Medicine and endorsed by Royal Naval Personnel Research Committee of the Medical Research Council. These were based on current available scientific evidence supplemented by experimental studies if necessary. They are set as ceiling values, and for a small number of substances there are TWAs. Ceiling values in the occupational health field mean the value should not be exceeded.

The definition of a MPC_{90} for an atmospheric contaminant is:

"*that atmospheric concentration which, for continuous exposure for 90 days in a closed environmental system, neither causes nor contributes to ill-health in the short or long term, nor to lasting detectable functional shifts that would lower efficiency of performance to a level hindering fulfillment of prescribed activities of the system or occupants*."

MPC have been set for 24 hours and 60 minutes. UK submarines have MPCs for 23 substances that are monitored in real time, 15 measured retrospectively (taken back to laboratory for analysis), and 19 that have been set as design specifications for machinery.

In the discussion the author also commented that it was coincidental that many of the values set were one-fifth of the occupational values and the lack of recovery time as extremely important in the derivation.

The compounds for which MPC had been set were acetonitrile, benzene, ethylbenzene, hydrazine, methanol, toluene, 1,1,1-trichloroethane, vinyl chloride and xylene. On the intended list because they are present in significant quantities: 2-butoxy ethanol, 1,2-dibromoethane, carbon disulphide, carbon tetrachloride, 2-ethoxy ethanol, 2-ethoxyethylacetate, n-hexane, hex-2-one, styrene and vinylidene chloride.

Comment. Many of the compounds listed above are either solvents or are present as off gassing products from plastic materials on board. Some of these would also have been present on the Oberon Class submarines.

2. In his paper, Dean (1996) identified that the Royal Navy Maximum Permissible Concentration allowable for 90 day patrol (MPC90), allegedly a health

based limit, is derived by dividing the occupational value by 10, with the full details promulgated in BR1326. For example, benzene has an occupational value of 5 ppm which is divided by 10 to arrive at an MPC90 of 0.5 ppm. This methodology is contrary to what has been stated by Raffaelli (1989).

It is of interest to note that the UK Health & SafetyExecutive (HSE) (2005) in its publication on exposure limits for workplaces, in paragraph 94, which deals with submarines and saturation diving, states that '*continuous limits should be derived by dividing the 8-hour TWA exposure limit by a factor of 5'*.

Comment. It is difficult to make a comment on the approach taken without seeing the documentation for MPCs. The latest approach by HSE appears to be rather cavalier as even the occupational values only at best 'protect' against a specific health effect in a normal setting. It has been the practice of ACGIH and the Worksafe Australia (Exposure Standards) to recommend that the documentation be read first before applying the numbers.

3. Östberg & Perrson (2004) collected air quality data on the Gotland Class submarine for the development of future submarine standards but in this exercise compared their results with the Swedish OELs (Occupational Exposure Levels – 8 hour time weighted averages) that are used for assessing normal work environments. The authors did express concern that the CO_2 concentrations exceeded the OEL of 0.5%.

Comment. It would appear that the Swedes have not set any values specifically for submariners as mooted in the Maron (1997) comments paper as they were still collecting data in 2004. It should be noted that the Swedes publish the scientific evidence for setting an occupational exposure limit but do not publish how the value has been arrived after a tripartite review. The user does not necessarily know what health effect the value protects the user from.

4. For the Oberon Class submarine the only air quality listing that could be found was in the Standard Orders (Royal Australian Navy, 1997) the table 'Emergency Atmosphere Monitoring' (p4-117) which lists seven substances: carbon monoxide, hydrochloric acid, phosgene, hydrocyanic acid, chlorine, carbon dioxide, and oxygen. Carbon dioxide has incorrect unit of measurement recorded (should be percent (%) and not vpm), whereas, phosgene has what is probably a misprint for MPC Normal (0-0.05 vpm instead of 0-0.5 vpm). The document also stated the scale and number of pumps needed to get the reading. There is also an action value for Otto Fuel (see previous comment under Otto Fuel). No documentation for the basis of the values could be obtained.

Comment. RAN documentation which supports the values and the associated health effects should exist and would be worthwhile reviewing. The submariners are entitled under the Occupational Health and Safety (Commonwealth Employment) Act 1991 and Occupational Health and Safety (Commonwealth Employment) (National Standards) Regulations 1994 to view this information.

5. Since 1995 the US Navy has used the Committee on Toxicology of the National Research Council, which formed the Subcommittee on Emergency and

Continuous Exposure Guidance levels for Selected Submarine Contaminants, to review and update the submarine guidance levels. Their recommendations for 10 substances (acrolein, carbon dioxide, carbon monoxide, formaldehyde, hydrazine, methanol, monoethanolamine, nitric oxide, nitrogen dioxide, and oxygen) have been published (NRC (2004)). The publication provides a very extensive review of the toxicology and basis for the recommended values. The National Research Council (NRC (2002)) has also published another series on acute exposure guidelines for substances which are sensitizers (e.g., Otto fuel) or irritants (e.g., phosgene) or acutely lethal (e.g., hydrogen cyanide).

Comment. Exposure guidelines (or equivalent) play a critical role in occupational health and hygiene in providing a healthy and safe workplace. They need to be based on good toxicological evidence, if possible, based on human experience. When combined with monitoring data they provide an index to health and safety. The US values are published and available for scrutiny. Similar documentation was not available for other nations, including Australia.

Composition of the Atmosphere

This section will review and comment on several papers which relate to oxygen (O_2) and carbon dioxide (CO_2) and their health effects.

1. Consolazio *et al* (1947) carried out an extensive set of experiments in groups of 4 to 77 volunteers in sealed steel chambers under a variable set of conditions of O_2, CO_2, time, temperature and humidity. A range of tests were conducted to evaluate their biochemical, physiological and psychological state. Conclusions based on their data were that O_2 concentrations greater than 12% and CO_2 concentrations less than 5% did not appear to have any serious impairment to the test group's physical condition or efficiency. There were some minor symptoms such as headache, nasal congestion and dryness of throat, which disappeared when outside air was breathed. Adequate O_2 pressure in lungs, blood and tissue was maintained as a result of hyperventilation and increased pulse rate. Concentrations of CO_2 above 5% were not well tolerated.

Comment. The above study represents a one-off exposure of up to 34-72 hours during which the CO_2 concentration of 5% was reached after about an average of 34 hours (29-37) in the chamber. No sequential repeat exposures simulating a normal submarine environment were done to determine if the observed decrements changed.

2. In a conference paper, Davies (1975) reviewed the problems confronting submariners during possible long habitation periods in nuclear submarines. Over 400 hydrocarbons have been identified with at least 88 found regularly. The difficulty is in defining an acceptable level. Workplace standards cannot be directly applied without complete review of the toxicity of the substance. He cites some experimental work done by Thomas (1968) in the USA where continuous exposure of animals to some selected chemicals at the civilian exposure levels resulted in death of a significant number of the animals before the 90 days were up. Oxygen deficiency may affect night-vision. Above 22% O_2 becomes a fire risk to hydrocarbon laden carbon filters. There are doubts about the long term safety of CO_2 concentrations greater than 1% for continuous exposure. Davies questions some of the MPC90 limits and the level of

protection they will provide. The Royal Navy (RN) had a handbook (Materials Toxicity Guide) which was used as a guide for onboard stores. During and after long patrols biochemical changes in calcium/magnesium/phosphorous that were seen were believed to be caused by CO_2 exposure with possible contribution from lack of sunlight, altered diets and other atmospheric contaminants.

Comment. Is there a RAN equivalent to the RN handbook 'Materials Toxicity Guide'? Such a publication would assist in correctly identifying substance brought on board and used.

3. Margel *et al* (2003) examined the effects on sleep of acute and chronic exposures to high levels (0.30 -1.2%) of carbon dioxide onboard an Israeli submarine. They measured sleep quality using the Respiratory Disturbance Index (RDI) on three occasions: first night onboard but docked, first and last nights of an 11 day cruise. The authors considered the most important finding was the evidence for habituation to the intermittently high readings (88% of the time). The work leaves unanswered what happens in the recovery period following this adaptation.

Atmospheric Monitoring

A number of papers were reviewed which related to monitoring of the air quality on submarines but they dealt with instrument or filter evaluation (Ranieri *et al* (2003); Klos *et al* (2000))

Human Factors – Ergonomics

From the conversations with the submariners during the HMAS ONSLOW visit there was significant reference to manual handling tasks involving torpedoes, loading supplies, opening and closing heavy hatches, manipulating bolts to hatches, operating equipment, and body positioning whilst doing certain maintenance operations, be it painting inside torpedo tubes or crawling over batteries or fixing equipment in very restrictive/confined space or turning small valve knobs close to each other. There were also concerns about vision disturbance due to working in the dark, operating sonar equipment etc.

There are a number of reports relating to ergonomic issues, seating, vision and sonar equipment but these were from the US Naval Submarine Medical Research Laboratory and the reports were not available locally.

Hazardous Substances

1. Asbestos

Standard Orders (Royal Australian Navy, (1997)) and discussion in the focus groups identified a number of situations where asbestos was used or found. Detailed information on how the submariners made contact with asbestos and duration and frequency of the contact was not provided. No literature references were found on the exposure to asbestos in submarines. The only reference found was to removal of asbestos from a carrier ship in the UK (Harries (1971 B)).

Clothing
Standard orders refer to the use of '*thermaguard'* suits during fire fighting. There is no indication of the composition of the '*thermaguard'* suits, but it is considered that in earlier times similar purpose suits were likely to be made of asbestos. Based on industry reports the wearing of asbestos firefighting helmets, depending on whether lined or not, could produce exposures from 0 to 2.3 fibres/ml over the period worn (Lumley, 1971). Wearing of jackets and other items made with asbestos produced exposures of 0.3 – 5.0 fibres/ml (Gibbs (1975)). Samimi *et al* (1981) and Cherrie *et al* (2005) measured exposure to chrysotile asbestos whilst unused and artificially aged mitts were worn. The measured levels were reported to be in the range 0.07 – 2.93 and <0.06 - 0.55 fibres/ml respectively.

Fire Blankets
Asbestos fire blankets were identified in the Standard Orders.
However no (other) published literature has been found which identifies the degree of exposure while using asbestos fire blankets either during training, or actually dealing with a fire. Airborne asbestos concentrations (8.9 and 76.6 fibres/ml) have been reported by Harries (1971b) for the use of similar types of blankets in preheating and then brushing off slag during welding.

Gaskets.
Flanged joints, with gaskets, are used to join pipes to each other or to equipment. Several papers (Cheng & McDermott (1991); McKinnery et al (1992); Fowler (2000);Longo *et al* (2002); Boelter *et al* (2002)) have measured exposures during flange/gasket replacement. The airborne concentrations will depend on a range of factors, e.g., ventilation, state of asbestos, wet or dry method, etc during the removal of the flange/gasket and any surrounding insulation.

Gaskets are also used in diesel engine covers. Liukonen & Weir (2005), in a recently published study of a simulation of a previous practice to completely disassemble and clean a medium duty diesel engine and replace an asbestos gasket, determined that the airborne asbestos fibres for all facets of the job were approximately 10% or less than 0.1 fibres/ml.

Insulation
During the visit to HMAS ONSLOW it was observed that pipework in the engine room was lagged. Whether this lagging contained asbestos or not is not possible to say by merely looking. However RAN records should be able to identify the material specified for the lagging around hot pipes and also other locations where insulation was used.

2. Benzene

1. Dean (1996) calculated the risk of contracting chronic myeloid leukemia (CML) from benzene exposure during patrols over 13 years. He used the benzene concentration data from reports from that period. The maximum and median concentrations were 830 $\mu g/m^3$ (0.26 ppm) and 189 $\mu g/m^3$ (0.06 ppm) respectively. This monitoring data was obtained from nuclear submarines. Measurements on two Oberon Class submarines gave readings of 90-150 $\mu g/m^3$ (0.03-0.05 ppm) and 90-

120 μg/m^3 (0.03-0.04 ppm) respectively. The paper does not state the duration of samples or the locations where the samples were taken. In the paper Dean used 40 ppm-years (0.5 – 6.6 additional leukemia cases per 1000 exposed workers) as the cumulative dose for the risk calculation.

The paper identifies a potential exposure to benzene in relation to venting of outboard diesel tanks inboard to allow for the increasing seawater pressure during diving.

2. A recent study by Glass *et al* (2005) of the Australian petroleum workers found a strong association between benzene and leukemia at exposure doses greater than the cumulative dose of 16 ppm-years.

3. Severs & Sabiston (2000) reported levels of benzene in the range 87 – 249 μg/m^3 (0.027 – 0.078 ppm) onboard HMCS Okanagan which is consistent with the results reported by Dean (1996).

4. As benzene is an ingredient of diesel fuel and diesel exhausts, Boffetta (2004) has reviewed the published epidemiological studies involving diesel exhausts to evaluate whether there is evidence to support that diesel exhaust exposure increases the risk of leukemia, and Acute Myeloid leukemia (AML) in particular. A total of 27 studies and reports were considered. Studies covered a wide range of occupations and industries. The conclusion was that available evidence did not support the hypothesis that there was an association between diesel exhausts and risk of leukemia and AML in particular.

5. In a very recent paper (Kopstein (2006)) advised listing of benzene in Material Safety Data Sheets (MSDSs) be mandatory even if present as a trace contaminant (< 0.1%). Kopstein states that workers using petroleum based solvents, e.g., mineral turps or white spirits, may be exposed to time weighted average concentrations of benzene in excess of the ACGIH TLV of 0.5 ppm, depending on duration of exposure.

Comment. During the visit of HMAS ONSLOW and the focus group discussion the submariners stated that they used white spirit to wash down oily surfaces. Taking Kopstein's work into consideration the exposure to benzene may therefore have been higher than indicated by the air monitoring results presented above if personal measurements were done whilst hydrocarbon solvents were used.

3. Diesel and Diesel Emissions

This particular topic of diesel and diesel emissions has received a considerable amount of attention through DSTO reports and RAN Minutes based on volatile organic compounds (VOCs) and aerosols measurements. It would appear measurements were done in lieu of the recognized method (NIOSH Method 5040) used for measuring diesel emission based on elemental and organic carbon. Several papers originating from Italy and Sweden reviewed in this report have also used general rather than specific methods for measuring hydrocarbons within the engine room of a diesel-electric submarine. They all used either different non-discriminating measurement equipment or a different substance as a reference standard. The results from these studies should not be compared with exposures reported in more recent occupational health exposure studies to diesel emissions as the sampling and analysis methodology was not the same nor was the data compared with other countries regulatory values. Due to the uncertainty of what degree of exposure constitutes an unacceptable level of risk, bodies such as International Agency for Research on Cancer (IARC, 1989b), World Health Organisation (WHO, 1996), Health Effects Institute (HEI, 2002), US National Institute of Occupational Safety and Health (NIOSH 1988), and American Conference of Governmental Industrial Hygienists have not proposed or set an occupational exposure level or a level of risk. These bodies accept that the animal data for carcinogenicity is strong but there are uncertainties in the human studies due to confounders and exposure data deficiencies. The US Mine Safety and Health Administration (MSHA, 2005) and the German Bundesministerium fűr Arbeit (German Ministry of Labour, 2005) have set exposure levels for the mining industries in their respective countries based on elemental carbon sampled and analysed by specific methods. The German value is a technical limit, which means that the best available technology should be used to control the exposure.

Diesel Fuel
The types, composition, and health effects of diesel fuel are well reviewed in a number of publications (IARC, 1989a), (World Health Organisation WHO, 1996). Marine diesels may contain more than 10% polycyclic aromatic hydrocarbons which are associated with possible cancer causation. However in their review of diesel fuel IARC concludes that there is inadequate evidence for carcinogenicity in humans but limited evidence for experimental animals exposed to marine fuel, and rates it as a possible human carcinogen.

Exposure to diesel fuel (liquid) and mists (droplets/aerosols) occurs through fuel handling, cleaning of diesel parts during maintenance, and leakages and/or incomplete combustion in diesel engines/exhausts. A likely source of diesel vapour/mist in air occurs during the period between opening and shutting of the explosion cocks on start up as stated by the submariners during the walk through on HMAS ONSLOW and focus groups.

The hydrocarbon emissions (vapour and mist) are not uniquely due to diesel but also may arise from hydraulic fluids, lubricating oils and mists from draining the air compressor (Rubly (2005)).

From the literature it appears there has been a tendency to measure volatile organic compounds as a whole as it can be done in real time. This technique is fine if the purpose is to identify the source of emission and track its behaviour but it does not give any information about the composition and concentration of the individual components that make up that emission. Only one study (Severs & Sabiston, (2000)) has reported some of the components and their concentrations.

Diesel Exhaust
Diesel exhausts are a complex mixture of gases (carbon monoxide, carbon dioxide, sulphur dioxide, oxides of nitrogen), vapour/mists (a very broad range of organic compounds and their oxidation products), and particulate matter (including carbon, high molecular weight polycyclic aromatic compound, organic heterocyclic compounds, inorganic sulphates and nitrates, and metals (IARC (1989)). It is not

possible with current technology to trap the total emission and consequently over the years various components of the emission have been used as surrogates for making estimates of exposure. Over the past 10-15 years elemental carbon has been the surrogate of choice as it appears to be unique to diesel emissions and absent in cigarette smoke.

No studies have been reported in the literature that measure the concentrations of diesel exhausts in submarines in such a way that the data can be compared with other diesel exhaust studies. The results obtained with aerosol monitors do not represent diesel exhaust/emission concentrations as the instruments used have not been calibrated with diesel exhausts/emission (Willeke & Baron (1990)).

Workplace Induced Body Odour and Photosensitivity
The issue of personal (body) odour, the hydrocarbon smell inside the submarine, and photosensitivity was raised during the walk through visit of HMAS ONSLOW and the focus groups.

An electronic database (NIOSHTIC) search yielded 85 records ([(odor OR odour) OR smell] AND body) of which 2 related to occupational exposure and body odour. First was to sewer workers and hydrogen sulphide (Adelson & Sunshine (1966)), and the second to persistent chlorine smell from skin of workers in a trichlorophenol facility (Dugois *et al* (1957)).

Another report (Knight *et al* (1984)) from a US study of absorption of submarine environment atmospheres concluded:

> '*This indicates that crewmembers absorb atmospheric VOCs during patrol and desorb the contaminants at home'*.

As only the abstract of the report was available it is not known what the 'intensity' of odour was nor whether any work was done to determine how long it took for the body to get rid of it, and whether there were any other effects associated with it.

Once again a search of the NIOSHTIC electronic database using key words [photosensitivity OR photosensitive] AND [PAH OR PAHs] produced 2 relevant articles. The first related to dock workers unloading unheated coal tar pitch and petroleum reported photosensitive reactions to exposed parts of the body. (Gorman & Liss (1985)). The second article reviews the relationship between ultra violet radiation and PAHs and cancer (Lankas *et al* (1980)). Coal tars, coal tar pitch volatiles used or by-products in pencil pitch, aluminium production, and shale distillation plants are known to cause photosensitisation in workers.

Some of the PAHs found in coal tars and coal tar pitch volatiles may also be present in diesel emissions. For example, anthracene was found to cause photosensitisation in guinea pigs and is also found in diesel emissions (Lovell & Sanders (1992)).

Comment. The literature on the health effects associated with diesel emissions has focused on cancer outcomes. There is no available data to identify the magnitude of the exposure that has occurred on the Oberon Class submarines to make any meaningful estimates of risk.

Issues of body absorption of diesel/diesel emissions and photosensitisation have not been studied to the extent of addressing the submariners' concerns. The very limited evidence suggests that it is technically possible to examine absorption/emission of internal submarine atmosphere relationship and there are components of diesel/diesel emissions that may induce photosensitivity. There is the need for further local studies of Oberon submariners and their sensitivity to sunlight, and the Collins Class regarding the extent of absorption and emission of submarine atmospheres by the submariners and the relationship to the submarine atmosphere.

4. Epoxy Resin Paints

Epoxy resins are condensation products of epichlorohydrin and Bisphenol A (2,2 bis(p-hydroxy phenyl) propane) which are then reacted with aliphatic polyamines or in more recent times with amides. The polyamines are responsible for skin irritation and sensitization. To achieve required paint properties the basic ingredients may be modified or other similar types of resin used. It is therefore very important to know what was used in the specific paint. There will also be solvents and fillers/pigments used in the make up of the paint.

It was stated during the walk through visit of HMAS ONSLOW that the inside of the torpedo tubes had to be touched up with epoxy paint. This required the submariner to lie flat on stomach or back and apply the paint with a brush about 6 monthly. The painter often came out or was dragged out a little worse for wear. No information about the brand and name of paint was provided. Inventory lists of materials brought on board Oberon submarines would be extremely useful in these situations.

Two US NIOSH reports were located on touch up painting with epoxy paints during submarine construction and other welding epoxy painted surfaces. The US and HMAS ONSLOW situations are not the same, but the US reports at least give some insight into the type of vapour emissions and health issues that arise out of such situations.

1. Wegman *et al* (1982) investigated complaints of eye irritation, burning throat, nasal and sinus congestion, chest tightness and pain, nausea, extreme fatigue, light-headedness, and severe headaches experienced by welders and fitters doing hot work on an epoxy coated submarine. A number of welders had facial reactions to the fume from hot work on the painted surfaces and the 'smoke' contained phenolic compounds.

2. McManus *et al* (1989) performed a study in response to concerns about possible reproductive effects among the male workers to glycol ether solvents present in epoxy paints used. The glycol ether solvents in question were: Cellosolves – 2-ethoxyethanol (2EE), 2-butoxyethanol (2BE), and 2-methoxyethanol (2ME). The table from the report below shows the full shift breathing zone air samples:

Table (from report)– Personal Sampling Results for Glycol Ether Exposure During Painting with Epoxy Paints.

Solvent	Mean mg/m^3	Range mg/m^3	ACGIH TLV mg/m^3 (skin)
2EE	9.9	n.d. – 84.3	19
2ME	2.6	n.d. - 17.2	16

2BE	120

n.d. = not detected

As the solvents are readily absorbed through the skin, urine samples were collected and analysed for metabolites of 2EE and 2ME. The metabolite of 2EE was found to be in the range of n.d. – 144 mg/g creatinine.

3. Sylvain & Malkin (1998) followed up on worker complaints of headaches, breathing difficulties, skin irritation, rashes, chest pain, shortness of breath, and asthma attributed to brush and roller painting with an epoxy paint inside a Seawolf submarine under construction. Analysis showed that the principle solvent in the paint was n-butyl alcohol (ACGIH TLV 50 ppm). During touch up painting within a tank the personal breathing zone (PBZ) concentrations were 78-130 ppm. In two other tanks, the PBZ concentrations were 2.4 – 25 ppm. Other aromatic hydrocarbon solvents were present in the paint solvents but were not analysed for in the PBZ samples. PBZ exposure to thermal decomposition products was monitored during welding of epoxy painted surface. The analysis was for bisphenol A and the concentrations found were in the range < 0.0002 to 0.0025 ppm. Organic degradation products may contribute to long-term health effects such as cancer, allergic skin reactions, and asthma (Henriks-Eckerman *et al* (1990)).

5. Otto Fuel

Otto fuel is used as a torpedo propellant and is a mixture of 1,2-Propylene Glycol Dinitrate (PGDN) (nitrate ester explosive/propellant), dibutyl sebacate (a desensitizer), and 2-nitrodiphenylamine (a stabilizer). The epidemiology and toxicology of PGDN is reviewed by the National Research Council (NRC, 2002) in its documentation of Acute Exposure Guideline Levels. Exposure can occur by inhalation, skin absorption and ingestion. At low concentrations it is reported to cause cardiovascular and central nervous system effects such as headaches, nasal congestion, eye irritation, and dizziness. Sense of smell cannot be relied on for continuous detection as it induces olfactory fatigue within a few minutes (~ 5 mins.) and chemical instrumentation needs to be used. Tables of effect, time and concentration are published. There were two epidemiological studies of otto fuel exposure of torpedo maintenance workers. The first by Howarth *et al* (1981), did not find any evidence to support chronic neurotoxicity even in workers with the longest exposure. In the second study by Forman *et al* (1987), using hospitalization records, a higher incidence of myocardial infarctions and angina pectoris were found when compared with controls, which had a higher mortality rate. Two control groups were used: non exposed torpedomen and fire control technicians. Unfortunately the number of cases was small and unless hospitalized ,reporting may have been incomplete. Also a longer follow up period would have been more informative.

Another hazard associated with torpedoes is the premature ignition and running of the motor, referred to as a ‘hot run’, whilst still in the torpedo tube. The combustion of Otto Fuel II in the Mk 48 Torpedo engines results in exhaust gases containing a number of hazardous components. The most significant combustion products are carbon monoxide (CO), hydrogen cyanide (HCN), and oxides of nitrogen.

Comment: RAN Standard Orders (see above) use 0.2 ppm PGDN as measured with the Otto Fuel Detector (Mk 15) for stepping up the response in case of spill. The reading time is 10 minutes. The 0.2 ppm is likely to have been based on the ACGIH TLV of 1975, which was given a Ceiling notation, which meant a shortest measuring time of not more than 15 minutes. The current Exposure Standard (from 1985/6; also ACGIH TLV) is 0.05 ppm and should be reviewed. It would appear the Detector needs to be regularly calibrated (Shull (2004)) and checked for electrical safety as an underestimation may result in unnecessary exposure and ill health. It is unknown how often the Detectors were calibrated on the Oberon submarines.

Hyperbaric Environments

Barnard (1975) in his paper on the measurement and control of parameters of hyperbaric environments, namely pressure chambers, examines the physiological factors such as composition of the atmosphere, humidity, oxygen, carbon dioxide, dilution gases and contaminants, and biological factors. Even oxygen may present risk to health when the narrow range of 0.17 to 2.0 bars is transgressed, resulting in hypoxia (lower) or convulsions (upper). For long exposures to CO_2 the permitted concentration was 0.01 bars (= 1% or 10,000 ppm) but in 1970 changed to 0.005 bars. It would appear the downward revision was based on the ability to control and measure parameters.

Microbiological Environment

1. Davies (1973) in his paper in relation to the environment on nuclear submarines stated that as the duration of a patrol progressed the microbiological aspects of the submarine environment simplified with the number of flora decreasing and the changes to skin, nose and throat flora related to faecal contamination.

2. Morris (1975) reviews a little history and his comments pertain to nuclear submarines but are also relevant to diesel-electric as well. Confinement increases risk of infection. The paper refers to an outbreak of *Mycoplasma pneumoniae* infection in a nuclear submarine crew on patrol. Most commonly reported micro-organisms relate to those from the bowel possibly resulting from toilet bowl flushing. Organisms of human origin, and particularly the bowel organisms, can rapidly pollute the vessel and also the potable water storage. *Pseudomonas aeruginosa* is most commonly found and quite often resistant to bactericides used.

3. Barnard (1975) in his paper on the control and measurement of hyperbaric environments identifies that conditions of high temperature, ca. 30 °C, and humidity (RH 60-100) are conducive to microbiological growth, particularly for *Pseudomonas aeruginosa*, which may cause skin infections and infect the external auditory meatus.

4. On a Gotland Class submarine Östberg & Perrson (2004) used chemical marker analysis for bacteria and fungi in dust and found that concentrations resembled those in domestic and work environments. No species or their concentrations were stated.

Noise

No papers detailing the levels of noise on the Oberon Class submarines could be found. The report by Turnbull (1998) has been the only document that has been found with actual noise levels inside a diesel-electric submarine (Collins Class).

Gwin & Lacroix (1985) examined the occupationally induced hearing loss of a group of US submariners and then compared this with the civilian comparison group matched for age. The submariners had a higher than average incidence of hearing loss.

One of the problems in the military is persuading the men to wear the muffs or plugs provided (Coles & Knight (1965)).

Psychological Group or Individual

1. At the Stockholm Conference "Humans in Submarines" Cinqualbre *et al* (2004) presented the results of a study of 72 Dutch submariners who volunteered to participate in a series of neuropsychometric tests. A group of Navy corpsmen were used as a control. Tests and a questionnaire were used to validate findings and evaluate symptoms caused by prolonged exposure to neurotoxic substances, e.g., carbon monoxide and toluene. There was no clear evidence of neuropsychometric deficits. The authors acknowledge there are limitations in their study: tests on volunteers only (response bias) and no exposure profile.

2. Although the study of the effects of diesel exhaust on neurobehavioural and pulmonary functions by Kilburn (2000) did not involve submariners, it does look at the effects of diesel exhausts which are present on diesel-electric submarines. The study involved 6 electricians exposed to diesel emissions at a tunnel construction site, 7 diesel locomotive maintenance personnel and 3 diesel locomotive crewmen and compared them with 159 male subjects with no known exposure to chemicals. Both groups were exposed to a series of neurophysiological and psychological tests. The test group was 'impaired' for all neurobehavioral functions, with the railroad workers, having longer exposure, demonstrating greater effect. They also had worse pulmonary function results. This was the first reported study on the effects of diesel exhaust on neurobehavioural and pulmonary functions and the study author accepts that the results are contestable.

Comment. Diesel exhausts on submarines contain a number of hydrocarbons, such as toluene, xylene, benzene, and other cycloaliphatic compounds and combined with petroleum solvent exposures (e.g., white spirits) are therefore capable of exerting CNS effects if concentrations are high enough. Unfortunately the diesel emission concentrations were not measured during the Kilburn study.

3. Nice (1983) carried out an interesting study in relation to depressive effects in navy wives during separation from their husbands on operational duty using a Mood Questionnaire filled out several times during the husbands absence. The separation group, i.e., those whose husbands were on away duty, had higher depressive affect scores than the controls, i.e., those whose husbands were port bound. Younger wives experienced a higher degree of depressive affect. The effect is greater prior to and during the prolonged separation.

Comment. This study is cited as the submariners stated that they had high divorce rate.

Radiological Hazards

No references could be found in the general published literature on diesel-electric submarines which identified hazards due to non-ionizing radiation.

A paper by Lambert (1968) discusses radiation hazards from ionizing radiation on nuclear submarines.

Thermal Environment

Walters J.D., (1975) discusses the methodology of measurement of hot environments, the application of the results obtained and how to adapt to working in such environments. The measurement is done by using wet and dry bulb temperature, black ball temperature and air movement, using a Kata thermometer. The measurements are substituted into a formula and the value obtained is interpreted on the basis of the WBGT Index to determine the potential for heat stress. Instead of mercury thermometers, thermistors can be used, thus allowing logging of data.

The comfort index (Corrected Effective Temperature, CEV) used the same equipment but the data obtained relies on interpolating the result from a Nomogram.

Walters had reproduced a chart which relates WBGT and CEV and work load. He described results of experimental work carried out by the RN using engine room personnel. It was found that the original formula for calculating the WBGT index had to be modified for hot humid conditions. Despite comprehensive and careful inventory of physical characteristics and personality assessment it was not possible to find a single parameter which could be used as a predicator variable indicating the men that would most likely do well or badly in the heat. In the discussion that followed the paper presentation, it was said that temperatures inside engine rooms and boiler rooms reached 62 °C in the Persian Gulf. The type of vessel was not stated.

Conclusions

The general literature search found only a handful of references which were specific to the Oberon Class submarines: two of Australian and two of Canadian origin. There were also references to two United Kingdom Oberon Class studies but these were not available. The Australian microbiological study did identify locations/situations which could under certain conditions lead to possible health problems occurring but no air monitoring was done under operational conditions to give an indication of exposure. The second study was of limited occupational hygiene value as it focused on instrument performance and was confined to a single monitoring site. There was no personal monitoring. On the other hand the two Canadian studies examined the atmospheric environment on board and factors that affected its quality. The second study identified shortcomings in the existing ‘standard’ practices.

The limited number of RAN Minutes relating to incidents/concerns that had occurred on Oberon Class submarines were more informative about the everyday health and safety issues occurring on the submarines. Many of these Minutes were contained within the open file 88/79858/XX-02 (Unclassified) *Submarines – Occupational and Environmental Health File*, at the RAN Environmental Medicine Unit at HMAS KUTTABUL. This file also contains correspondence relating to the Collins Class submarines. The closed file 88/79858/XX -01 would be expected to contain more information on the Oberon submarine but has been archived with no record of whereabouts and could not be located. An internal search of RAN files might identify more documentation of incidents/hazards which were present on the submarines.

A number of Collins Class studies/reports and Minutes were available. The air monitoring studies that were done had an environmental approach using fixed locations and instrumentation. No personal monitoring was done. Some of these results may provide background readings at best but not personal exposures which can be used in health studies or comparison with occupational health limits. One Minute related to setting exposure limits (MPCs) by following the Swedish example of simply dividing occupational exposure limits by five. The final values appear to have been divided by a specific constant (number) but they should be based on health and not what is currently achievable. The ‘currently achievable’ should only apply to substances for which there is a lack of toxicological and health data.

The literature search has identified that the published papers fall into two categories, either a description of the general atmosphere and life on board a submarine or the evaluation of new instrumentation or air filtering equipment. Research reports appear to concentrate on human performance issues, eg, how to read sonar better or what affects night vision. No papers/reports focus on the mundane chores that the crew perform daily/regularly and yet may expose them to hazards which may have short and/or long term health consequences. The RAN Minutes give a hint that those daily activities are not without exposure to a hazard or hazardous situation. Many occurrences may have gone unreported because of the culture (identified in the focus group report).

To that end, the submariner’s exposure and the environment should be monitored using methodologies consistent with occupational hygiene practice so that the results can be compared with the guidelines. Most of the measurements that have been done on submarines are environmental as the sampling was not done on the submariner but at a location, often well away from where the actual work was taking place, thus making the results less meaningful and more disputable.

Regretfully the literature review has not identified many of the hazards and hazardous tasks that submariners know existed during their lifetimes on Oberon submarines. The reasons for this are many:

- limited record keeping on board;
- accessibility to records (both submarine logs, inventories, and other relevant Navy records);
- culture;
- not covered by OH&S legislation till the mid 1990s;

- secrecy associated with submarine equipment, work practice, and performance, and therefore not publishable;
- space and equipment limitations for specialist outsiders to carryout monitoring;
- limited technologies available for air purification and oxygen generation that were suitable for diesel-electric submarines; and,
- over a thousand US and UK submarine research reports not sighted due to local unavailability and therefore inability to determine their relevance to this project.

An index of the hazards (substances and processes) identified in the literature review is presented in the section titled 'Hazards Identified in the Literature Review'. This list is **incomplete** and should not be used to exclude effects on health that cannot be associated with the hazards on this list.

Hazards Identified in the Literature Review

The following hazards have been identified in the literature. There may be additional hazards that were identified during Focus Group discussions but are not included in this list. Some of the hazards presented here may or may not apply to Oberon Class submarines and can only be confirmed or discounted from material inventories and hazards reports. The (?) indicates uncertainty as the substance or process may have changed during the lifetime of the submarine.

Chemical Hazards

carbon disulphide ·
acetonitrile ·
aerosols ·(non specific)
acid mists from battery charging (sulphuric acid)
air quality ·(general composition)
alkanes ·(another general name for aliphatic hydrocarbons)
ammonia ·
aromatic hydrocarbons
arsine ·
asbestos
- asbestos blankets
- asbestos insulation(?)
- asbestos flange gaskets (?)
- asbestos diesel engine gaskets(?)
- asbestos gloves (?)
- asbestos fire protection clothing (?)

battery reached gassing point (gas emission with acid mists)·
benzene ·
bisphenol A (2,2 bis(p-hydroxy phenyl) propane) ·
2-butoxyethanol (2BE) ·
calcium hypochlorite ·
calcium phosphide - produces phospine·
carbon dioxide - removal efficiency -·CO_2 absorption

carbon dioxide concentrations·
carbon monoxide · CO
carbon tetrachloride ·
cellosolves - brand name for solvents also known as glycol ethers
charged ions ·
chlorine ·
cigarette smoking ·
combustible gases ·
cycloalkanes ·
1,2-dibromoethane ·
dibutyl sebacate (a desensitizer in Otto Fuel) ·
diesel emissions ·
diesel vapour emissions associated with leaky pipe work ·
diesel Exhaust Particulates ·
diesel fuel ·
epichlorohydrin ·
epoxy paints ·
2-ethoxyethanol (2EE) ·
2-ethoxyethylacetate ·
ethylbenzene ·
exposure limits for submariners
fire and corrosive residues from purifiers or oxygen candles·
Fire Blankets ·(if asbestos)
fluorescine ·
formation of toxic and corrosive compounds during fires ·
gaskets · - if asbestos
glycol ether solvents · (Cellosolve)
hex-2-one ·
hexane ·
hydrazine ·
hydraulic fluids
hydrocarbons – identified and quantified in submarine air (Severs & Sabiston (2000))

- benzene
- toluene
- ethylbenzene
- m/p-xylene
- 0-xylene
- cyclohexane
- heptane
- methylcyclohexane
- cis-1,2-dimethylcyclohexane
- cis-1,3-dimethylcyclohexane
- trans-1,2-dimethylcyclohexane
- trans-1,3-dimethylcyclohexane
- trans-1,4-dimethylcyclohexane
- 2-methylheptane
- 3-methylheptane
- 4-methylheptane
- 2-methyl hexane

3-methyl hexane
dimethylcyclohexane
1,3-dimethy;cyclohexane
tetrachloroethane
octane
(1-methylethyl)-cyclohexane
2-methyloctane
ethylcyclohexane
1,1,3-trimethylcyclohexane
propylcyclohexane
(1-methyethyl)-benzene
trans-1,3-dimethylcyclopentane
decane
butylcyclohexane
1-limonene
undecane
trans-1-ethyl-4methylcyclohexane
trimethylcyclohexane
1-ethyl-3-methylbenzene
trans-decahydro-naphthalene

hydrogen cyanide or hydrocyanic acid HCN ·
hydrogen · H_2
hydrogen chloride · HCL
hydrogen sulphide · H_2S
inhalable airborne particulates ·
insulation ·
lithium hydride ·
lubricating oils
manganese oxide ·
marine diesel (DF No. 4) ·
mercuric oxide ·
mercury · Hg
methane ·
methanol ·
2-methoxyethanol (2ME) ·
mineral turps ·
naphthalene ·
n-hexane ·
2-nitrodiphenylamine (a stabilizer in Otto Fuel) ·
nitro-PAHs ·
nitrous compounds NOx ·
nitrogen dioxide NO_2 ·
Otto Fuel ·
oxygen - high concentrations >22%·
oxygen - low concentrations <18%
oxygen candles
oxygen candle residues·
oxygen candle - chlorine material emissions·
ozone ·
polychlorinated biphenyls PCBs ·

phenolic compounds ·
phosgene ·
phosphine · PH_3
polynuclear aromatic hydrocarbons PAHs
potassium hydroxide ·KOH - residue in spent oxygen candles
potassium perchlorate in oxygen candles
1,2-propylene glycol dinitrate (PGDN) propellant in Otto Fuel
phenolic compounds in 'smoke' ·
refrigerant (R-12) ·
refrigerants - other
sewage gases ·
soda lime ·
stibine ·
styrene ·
substituted cyclohexanes ·
toluene ·
torpedo 'hot running'
torpedo tube internal painting ·
1,1,1-trichloroethane ·
venting of outboard diesel tanks inboard
vinyl chloride ·
vinylidene chloride ·
volatile organic compounds (VOCs) ·
white spirits ·
xylene ·

Electricity Hazards

electric and magnetic fields from electric equipment·
electric shock ·
electrostatic shock · - during cable transfer

Environment - Climate

climatic factors within the submarine ·
odour - general submarine·
re-entrainment of diesel exhaust emissions ·
relative humidity ·
snorting
- emissions re-circulated back to submarine air environment
- sufficient time to rejuvenate air to normal

temperature ·

Ergonomic Factors

circadian rhythm ·
continuously variable watchkeeping and lack of external zeitgebers altering biological rhythm ·
desynchronisation of circadian cycles ·
ergonomic
- posture
- lifting/manual handling
- standing long periods

- performance of tasks in cramped conditions
- turning valves close together

falls ·
falls from submarine into sea
head injury from bumping into objects·
interior design (multi levels, ladder use, passage dimensions, movement problems)·
ladders & stairs
slips
trips ·
unknown factors, other than toxic contaminants ·
watch keeping (fatigue, high work loads, circadian rhythm) ·
work-rest schedules ·

General Hygiene

disposal of wastes ·
faecal contamination ·
household dust and black soot emanating from ventilation ports ·
hygiene personal (availability of water for washing, control on sanitation aids) ·
sanitation ·
sludge tanks ·

Medical Factors

analgesics ·- uncontrolled use
body odour – by absorption from submarine atmosphere
carbon dioxide – high concentration exposures – ureteral calculi
demineralised drinking water – balanced mineral intake·
dermal problems
- from chemicals used
- microbiological origins
- insufficient washing water·

diet (calorific intake and exercise -Relatively unlimited rich diet)·
headache ·
hypoxia ·
lack of exercise ·
lack of normal physical, psychological and sensory stimuli ·
no sunlight for long periods·
potable water
- not suitable quality
- lack of minerals

sonar - eye soreness through focus/poor resolution
storage of food ·- freshness or lack of
trauma ·

Microbiological Hazards

bacteria ·
close physical and microbiological contact among crew ·
microfungi ·
micro-organisms from the bowel ·

- mouldy bags and other items ·
- pathogenic bacteria ·
- pseudomonas aeruginosa ·

Noise

- noise
- general for sleeping
- machinery noise
  - identification of high noise areas
    wearing of hearing protection in designated areas
    hearing conservation program·
- sonar signal levels - >85 dB

Psychological Hazards

- boredom ·
- depressive effects in wives during long absences
- lengthy isolation ·
- neuropsychiatric disorders ·
- neurobehavioural effects
- psychological problems ·

Personal Protective Equipment

- clothing
- kevlar gloves ·
- personal protective equipment – problems if:
  - poor fit
  - not maintained
  - correct for job
  - shared but not cleaned between users
  - not used
- thermaguard suits ·

Pressure

- Atmospheric pressure
  - low
  - high ·

Radiation

- artificial light ·
- artificial UV light ·
- irradiation from non-ionising sources, eg, radar, electromagnetic fields·
- microwave radiation
- radar

Safety

- explosives/pyrotechnic ·
- explosion – hydrogen gas build up
- exposure limits for submariners ·
- fire ·
- pyrotechnics ·

smoke candles ·
torpedo 'hot running' - explosion

Ventilation

ventilation ·
black curtain reduces air flow
Snorting – insufficient time to exchange

Vibration

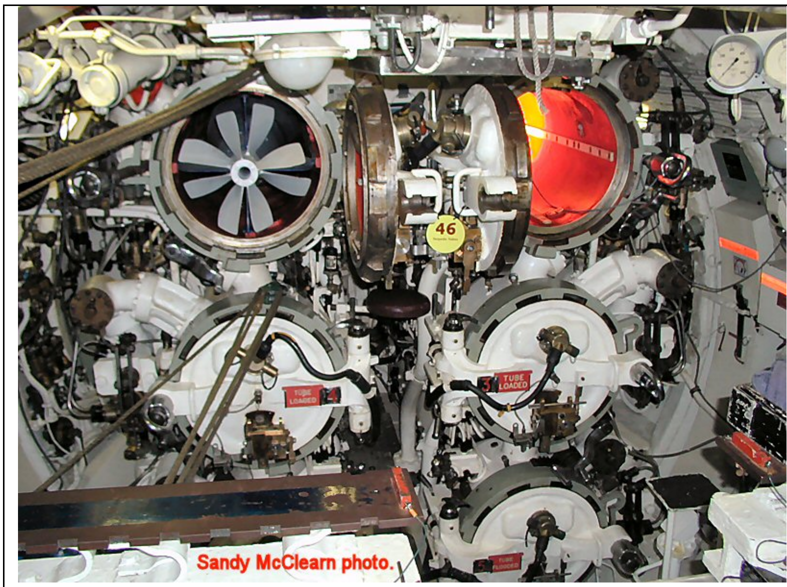
vibration ·

Tour of Oberon Class Submarine

A visit to the decommissioned HMAS ONSLOW (Sydney) was conducted on the 18th November, 2005. The purpose of the tour was to enable the CMVH Review Group to examine the three dimensional features of the submarine, including fixtures, materials of construction and the extent of confinement of each compartment. Ex-submariners from the Sydney-based Focus Group were able to describe the tasks, and equipment used.

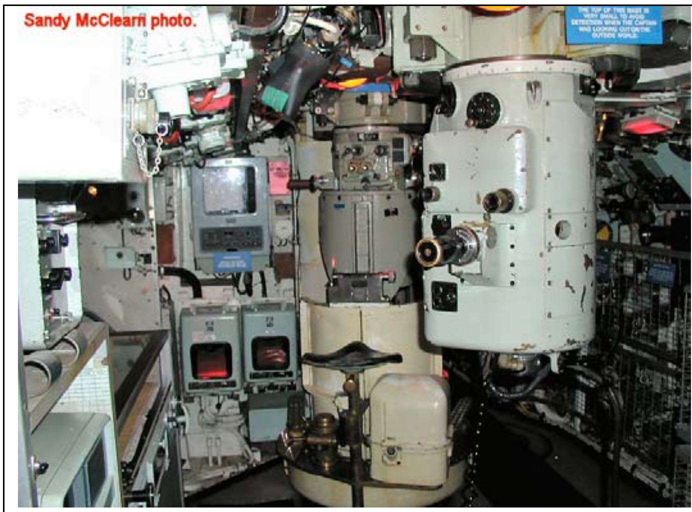
Although it was not possible to gauge the dynamics and smell of the submarine in operation, the tour was useful for discussing experiences, and the information from the tour was invaluable in interpreting the following focus group discussion and placing the literature, in context.

The following pictures and text, courtesy of Sandy McClearn, from
http://www.hazegray.org/navhist/rn/submarine/oberon/
are consistent with what was observed and illustrate sections of selected compartments.



The forward end of the torpedo compartment on the former HMAS ONSLOW. A mock torpedo is loaded in Tube 2, as seen with the propeller. Tube 1 is open, with a light shining down it. The lower two tubes were power loaded; the rest were loaded manually.

	The helm on ONSLOW. This is located on the port side of the control room.
	Looking aft from the control room on ONYX, past the radar and snorkel masts. The hatch through to the engine compartment can be seen in the background.

<table>
<tr><td>
</td><td>The control room on ONYX, looking aft. The attack periscope is in the foreground, with the main periscope in the background. The sonar shack is behind the camera in this view, with the helm out of the shot to the right.</td></tr>
<tr><td>
</td><td>This is taken from the forward end of the engine compartment on ONYX, looking aft. The oil-water separator is seen to the left of the photo; the submarine's diesel fuel was stored in compartments on the exterior of the pressure hull, and the separator was required to prevent seawater contamination from making it to the engines.</td></tr>
<tr><td>
</td><td>Looking aft in the engine room, between the two diesel engines. Diesel - Electric submarines typically run off their batteries, located on a lower deck, and use the diesels to charge the batteries.</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

Focus Groups

In addition to the review of the literature, two focus groups were conducted to expand on the information available. The aim of conducting these focus groups was to assist in identifying potential hazards of the Oberon Class submarine, not defined in the literature, and to add strength to the qualitative estimation of exposures based on job roles.

Methodology

Two focus groups were held in November 2005, one on the West Coast (Perth) where the current submarine Force Element Group (FEG) is located and one on the East Coast (Sydney) where the Oberon Class submarines were located. The venues were the Naval Club in Rockingham and ANZAC House in Sydney.

The focus groups were homogeneous, consisting of male ex-Oberon submariners, who have spent a significant amount of time, at least three years, in active Oberon submarine service. Recruiting was done through the Royal Australian Navy (RAN) and the Submarines Association Australia (SAA). Commander (CMDR) John Hodges, President of SAA nominated SAA representatives in the East (Mr Kevin Hayton) and West (Mr Norm Williams) as recruiting officers. These representatives assisted in the selection, and preliminary briefing of participants for the focus groups. Recruiting in the West was assisted by CMDR Stephen Dalton, Acting Captain of Submarines (CAPTSM). A quota of twelve participants for each group that covered the full range of job categories and included a mix of currently serving members and retired personnel was requested by the investigators. An information and consent sheet was sent to potential volunteers identified by the recruiting officers to further explain the purpose and conduct of the focus group and to obtain official consent prior to participation. A copy of the information and consent sheet is included at Annex A.

An interview guide was developed with questions that flowed from general to specific. Flexibility was built in to allow the group to raise issues. A copy of the interview guide is included at Annex B.

Associate Professor Dino Pisaniello acted as moderator for both focus groups. The focus groups were both approximately 3 hours in length. The sessions were recorded on audio.

A transcript of the audio recording was developed immediately following the focus groups. All information and consent sheets, the audio recording and the transcript with identifiable data were separated and stored in secure systems within a secure building. Transcripts were de-identified by the Principle Investigator and then read carefully by the Investigators. Clarification of any discrepancies was obtained by references to the audio tapes.

Major themes were identified, coded and sorted electronically. Consultation between the researchers confirmed that the themes and codes were appropriate. Where appropriate, direct quotations from transcripts were included in the results in order to illustrate a particular theme or issue. Participants were referred to by a non-identifiable initial in order to assure confidentiality.

Ethical approval for the project was obtained by the Australian Defence Human Research Ethics Committee (ADHREC), the DVA Human Research Ethics

Committee and the University of Queensland Medical Research Ethics Committee prior to the commencement of recruiting.

Results

A total of 25 participants volunteered for the focus groups. A summary of their descriptive characteristics regarding job category, age and length of time in Oberon submarines is given in Table i.

Table i: Summary of descriptive characteristics of participants

Age	Time in Oberon Service	Trades represented
Range: 39-64 years	Range: 2.5-25 years	Electrical; engineering; underwater weapons; stoker; coxswain; commanding officer; sonar, supply, seaman.
Mean: 55.4 years	Mean: 14.3 years	

Whilst it was intended to include a mix of currently serving and retired ex-Oberon submariners, there was only one currently serving participant in the West coast focus group.

It must be emphasized that the experiences and recollections detailed in this focus group report are the memories and perceptions of the veterans. Some may remember events or procedures differently or documentation may present other details.

The thematic analysis of the transcripts produced the eight major themes:

- Oberon submarine environment;
- Working routines;
- Personal Protective Equipment (PPE);
- Commitment to occupational health & safety;
- Record keeping;
- Submarine culture;
- Health hazards; and,
- Health outcomes.

These themes are described in detail below.

Oberon Submarine Environment

During the period that the Oberon Class submarines were in service, working and living conditions were a physical and psychological challenge for the submariners on board. Confined spaces, strenuous work, a lack of personal protective equipment and the very nature of submarine operations all contributed to hazardous working conditions.

There are few other occupations where supplies of oxygen and water may be a health risk factor. On the Oberon submarines, shortages of both were a fact of life. The submariners suffered frequent headaches and breathing difficulties which they ascribed to the effects of oxygen shortages.

Participants described how water shortages created hygiene problems and exacerbated skin irritations.

> "When you finish your watch, wipe your hands on a rag, go and climb into your bunk still in the same overalls. You go from the very high temperature where it's very moist and sweaty into a hopefully very cold mess where you just…All you do is take your boots off and climb into your rack. You could do that for in excess of two weeks without having a shower"

The unnatural lighting on board the submarine was cause for concern.

> "I've gone on patrol and we've been in red lighting from the time that we left, you know, outside the Heads, until we've come back."

The diesel laden environment was one of many concerns submariners had regarding the conditions that they lived in upon the Oberon. During operation diesel fumes and diesel residue were perceived to be throughout the atmosphere.

> "One of the other problems that also is constant, permanent in submarines is that all the surfaces were damp and that was not through moisture damp; that was through diesel dampness. Because little droplets of diesel covered everything…"

> "If you were in your bunk when they fired a torpedo or did a water shot, you'd get a puff of this black stuff (carbon) come out of your ventilation…"

One participant's comment, on visitors' reactions to the submarine display at the maritime museum, demonstrates the pervasive nature of diesel.

> "And they can all smell the diesel fuel. Now this boat doesn't have a battery anymore; there's no diesel fuel on board. So, the inside of OVENS it still retains all the things that we lived with thirty years ago"

Service on other submarines, such as the Collins Class, and exposure to contemporary occupational health and safety (OH&S) programs highlighted for the men the occupational health hazards they had faced on the Oberon. Specific mention was made of the differences between construction of the ventilation system and compartments between the Oberon and Collins Class.

> "It was an open engine room (the Oberon). Not like the Collins Class, they run with the door shut; the engine room is an enclosed area. So what immensely different to the Collins Class and the Oberon is that there is no diesel smell outside the engine room on a Collins Class submarine."

> "Passage ways open, and they had to because that's where the air came into the submarine. To get air into the engine room you had to run with the door open. So at all times, the diesel fumes, the diesel noise, and the oil in the engine room then when the diesel shut down drifted through the submarine. It was part of the ventilation system that actually carried it because as soon as the fumes came out of the engine room… There's your engine room there, the fumes used to come out of the engine room, go down into the AMS—that's where they were saying before where the fans are—and the fans in AMS would distribute the fumes throughout the submarine through the ventilation system."

The participants also discussed the ventilation of unpleasant sewage odour and potentially particulate matter throughout the boat.

> "…So, you would blow a certain amount of sewerage but then you had to vent the air back into the submarine. So, you were getting raw sewerage dissipated throughout the whole submarine."

During the focus group discussions the men expressed strong beliefs in a direct link between conditions on the Oberon and their current health complaints.

> "..a lot of people have really bad problems with their hips because of the constant twisting and turning and trying to get around…one of the other major dramas that a lot of guys have had is with their knees because of kneeling down sitting on their haunches and trying to get around various pipes and so forth."

> "It's incredible. I mean it's uncomfortable. The way of life is ridiculous. I don't wear shorts – I can't. I don't sit around the swimming pool – I can't. I don't go to BBQs – I can't. And when you think about these things, this is Australia – that's our way of life. I've lost all that – I just can't do it. Now if I put a claim to DVA, I'm going to claim my sunburn conditions – they would laugh all the way to the bank."

Conditions on board the Oberon class submarines are perhaps best demonstrated by comparing them to 'outside in the real world'.

> "And they would rub their eyes because the sunlight was that bright, because they hadn't seen the sun for three weeks. And they would be coughing; what is that? It's called fresh air stupid."

Submarine Culture

The participants agreed that during their service they just accepted the conditions, as described above, on board the Oberon. Indeed, living together in the confined space for extended periods of time and sharing the conditions on board created a strong bond between the men. Many of the submariners described how over time the strong feelings of belonging transformed to a sense of "family" with feelings of loyalty remaining today.

> "Everybody looks after everybody else still. I mean, if you have a look around this table now, you've got guys 15 to 20 years have been out of submarine arm per se, in other words no longer serving, but they still – if anybody within the submarine squadron as you know it put their hand up and said I need help – I'll guarantee that 9 out of 10 of these guys would put their hand up and be there to help them."

> "And, it was the loyalty to each other that got us through the job. The shit that happened to us, you know, you wouldn't do it to your dog."

The unique work and living conditions experienced by the Oberon submariners made most of them feel that no one in "civilian life" could understand them. Submariners bonded closely and when on shore leave would quite often immediately go to hotels to drink together. As one participant explained:

> "It's something I keep asking them. When they'd come to me with different things. Why did you go to the pub Friday afternoon after being at sea with all these blokes instead of going home? No one can say because me mate's better than the Mrs, but there was always that underlying thing that D just mentioned. There was that. Family – the boat's your family."

Many references were made to a sense of family, loyalty and camaraderie. Submarine culture and loyalty to their work mates ensured submariners completed many hazardous tasks without complaint. One participant described the culture of non-reporting and of trying to be 'bullet proof'.

> "And I might just say too, I had a claim in through DVA for my knee and, you know I was one of those bullet proof guys, I was very proud to go on patrol, very proud to go to sea, and uh, D was with me in fact when I fell down the ladder and I twisted my knee. I never reported it because you know I didn't want to be one of those sick bay jockeys, you know."

There was general agreement that submariners also had a culture of fear of being seen as someone who wasn't pulling their weight. This manifested in not reporting medical concerns and in a behaviour of 'carrying on regardless'.

> "because we're paid to keep our mouth shut, the medical side of it never gets through. If M would have filled in his bloody log, there's no way his boat would have got a tick in the box. You're not doing your job properly, and why were you malingering chappies. And that's how it works. And none of us were ever going to let the squadron down. And that's fact. And it's still there today in all of us."

> "If you're the weakling, you were the ones looked down on. No one wants to be that weakling, right. And victimised with the group. And that is what's happened over the years."

Whilst a strong 'family' bond on the submarine was described, the family relationships at home were said to be not so stable. There was agreement that submariners had a higher rate of divorce than the general community with some having 3 or 4 marriages. This was attributed to the long periods apart, the stress of neither knowing what the other was doing when the boat was deployed, difficulty in communicating on return and high levels of alcohol use by the submariners.

> "They tell you, you don't communicate at times. Your wife says you don't communicate because you kept a lot of stuff to yourself because you didn't want to tell them."

Working Routines

A major difficulty in describing a working routine upon the Oberon class submarine is that there appeared to be no typical routine for submariners. The submariners concurred that regardless of rank or occupation, working routines largely depended on the operational requirements of the submarine.

> "..if a job came up and it was your part of ship, you did it. There was no consideration to whether I want to do the job or not. Unblocking the toilets, someone's got to do it. So, someone did it."

> "So, I think the whole point is that no matter how many questions you ask about what work happens, the answer is, it is continuous and fluctuates."

Shifts and time off varied in length depending on the demands of the exercise and the particular submarine captain. Examples of shift lengths were given as 6 hours on, 6 hours off during maintenance periods and 3 hours on, 6 hours off during watches. Boats "on patrol" could have two watches of 7 hours on and 7 hours off. Participants were in agreement that rest breaks were often interrupted.

> "So you can never say right I'm 6 hours up, I'm going to have a 6 hour sleep. Something is going to happen halfway through it, and you're back into it."

Common to the submariners were the extended amounts of time spent on the submarines, even when not at sea. Submariners could be away from home for months at a time. One sailor's wife kept a diary for five years noting only her husband's time 'at home' and 'away'.

> "And I will guarantee you that 4/5ths of that was away. And when I was home, I was dutied every 4 nights. So you don't let it go when you come alongside. It's not like Qantas pilots stepping off their plane and saying, I'll see you in two weeks, and going home and doing a bit of training or what have you."

Some group members found it stressful that when they did return home they could leave again at a moment's notice with no idea where they were going or when they would return. Adding to their anxiety was the inability to give their spouses information of their whereabouts.

> "…during 85 and 86 I did 6 work ups. I would get a message Monday morning coming to work normally. I should have been at work in charge of the workshop or in the school. Get your steaming kit, or get your ...... jump kit, get onboard, another worker. I was a mental wreck at the end of that bloody lot, after a year…"

> "All you know that there's icicles forming on the bulkhead – somebody says we're not in the tropical area. Now you could be at sea for 40 days and you still didn't know. All you know is you sail from Sydney, you dive in the South China sea, and you disappear."

One submariner likened the levels of stress experienced as similar to that of active combat and it was widely agreed that submariners were exposed to stressful situations not experienced by other naval personnel. In addition to not knowing where they were, some felt the constant potential danger of their physical environment.

> "What it is is one big stress. Real stress. PTSD – a lot of us probably would have it. You go down there and you go to the Sydney Harbour Heads and there's hundreds of fathoms underneath you. That submarine can only go to a certain depth – after that it's cavitation – that's it."

Commitment to Occupational Health and Safety (OH&S)

Numerous references were made by the group members about their current level of Occupational Health and Safety (OH&S) awareness. The participants used their knowledge of contemporary OH&S procedures to widely critique the lack of OH&S facilities on the Oberon class submarines. They felt that any improvement that occurred in OH&S were reactive rather than proactive and occurred in response to a major incident, in one example given, a fatality.

The submariners unanimously agreed that operational requirements took precedence over OH&S considerations.

> "So, when you got the skipper saying, how long is that bloody diesel going to be off line. The first thing you do – we all lifted them off – and we duck wobbled them out around the corner, and got them out. So again, as W said,

> safety was compromised for speed and expedience. So, that's just the way it was – it was the way you did things."

> "all you could classify the submarine as was a weapons platform. There is no real consideration apart from submarine escape for the inhabitants and therefore there was no occupational health and safety regulations or considerations given."

There was recognition by the participants that a large part of the problem was that many unsatisfactory working conditions could not be remedied.

> "I can't remember any occupational health and safety expert going down onboard a … submarine to have a look around because it would have been a waste of time and money. What the hell could be changed? You know, we couldn't make the hatches any bigger actually, so we didn't have to bend down as much."

> "If you are going to start doing that occupational health and safety sort of thing when the submarine is on the drawing board. Because once it's built, that's what you got."

Personal Protective Equipment (PPE)

With the exception of standard issue overalls and steel capped boots, no personal protective equipment (PPE) was said to be provided to Oberon submariners. There were very strong feelings expressed from the study participants about the lack of PPE.

> "..No! How many times have people got to tell you that there was no such thing as protective clothing."

Even with the availability of overalls, submariners were known to wear Tshirts, shorts and sandals while the submarine was underway, otherwise known as 'steaming rig'.

Of particular concern was the number of chemicals that had direct contact with the skin and the inability to wash properly afterwards because of water shortages. Hands were cleaned ineffectively with rags. Exposure to chemicals was discussed at great length by the participants. Many of the submariners suffer skin conditions that they directly attribute to their unprotected exposure to chemicals.

Head sets were provided for communication purposes in the engine room. It was common practice for submariners to handover their headsets at the end of a shift. The headsets provided little ear (noise) protection and in some instances picked up radio frequencies that made them emit a high pitched squeal. Submariners sometimes removed their headsets to locate unusual noises coming from the engines.

> "I was taught to do it when I first joined submarines. An acceptable practice was you take your headsets off and try and locate where, which cylinder it is, you would then grab a screw driver, put the screw driver onto the cylinder head and poke the other end hard into your head to try to pick the firing noise."

Until the late 1980s, no gloves, masks or breathing apparatus were said to be routinely provided on the Oberon and there were instances where the provision of PPE equipment was counter to operational requirements. For example, high pressure air valves were closed only by hand as mechanical devices could damage the valve seating.

Record Keeping

Lack of record keeping during the time they served on the Oberon submarines was of concern to most of the participants. Submariners all had stories about the lack of accurate medical records.

> "But I think the whole crux of the matter is coming back to this fact that we never carried medical documents and we never documented anything that happened at sea. But I think that's a significant issue, is that nothing has been recorded. The bits that have been recorded in the squadron was what came back from the Coxwains, and with all respect to Coxwains, I suppose it was a bit of a chat and there was never really any documentations. And for those 20/30 years, we have spend and sent people to sea, and we have no record, other than hopefully what you are picking up now."

Some were concerned about the ramifications when a DVA compensation claim is processed.

> "That is the type of medical history that most submariners have. It's ad hoc, and when it comes to DVA, you're never ever correct."

These comments are confirmed by the Coxswain, known as the boats 'doctor', in one of the focus groups.

> "Daily medical attendance records were not kept. If you came to me with a problem onboard the submarine, I would look at your problem, give you an aspirin, stick it to your forehead, and send you away."

> "So over 912 days, only 3 incidents were recorded, and there were 117 incidents that should have or could have been recorded."

All participants spoke of the high level of unmonitored aspirin use. Some reported taking 6-8 per day. This alone is a potential health hazard.

> "There used to be a big tin about that round, about that deep sitting outside the Coxswains…where you could walk past and grab a handful."

> "I kept 5,000 aspirin outside the Coxswain's grot. So anyone walking onto the submarine at any time, day or night, could help themselves to a couple of aspirin."

Some participants talked of inaccurate records with regard to service on the submarines.

> "The point I'm getting at is that records of submarine running are very sparse, and they are not accurate at all. Many, many sailors have been deployed on a submarine and they were never on it because they were loaned at the last minute from the shore base to the submarine, and they were posted from the shore base to submarine – an internal posting – so Canberra never new they went near that submarine. So the records of Canberra will say that this guy didn't go to sea, but, in fact, he could have done weeks and weeks at sea."

Participants generally had the opinion that records of hazard exposure levels were non-existent.

> "I can almost categorically say that in my recollection of… no formal means of noise monitoring was ever done on the Oberon."

Health Hazards

The health hazards identified by the submariners were many and varied. There was no disagreement voiced about the types of hazards encountered. Estimates of exposure to hazardous health conditions varied among the participants but they agreed that the exposure levels were unacceptable. Perceived health hazards are grouped by physical or psychological category below.

The participants had numerous stories of working in unsafe conditions. There was strong agreement about OH&S hazards such as heavy lifting, crouching and kneeling for extended periods, working with chemicals without protection and compromised atmospheric conditions.

> "If I can add there, that the ventilation fans feeding air, or atmospheric air, to all the bunks on board, the suction from those fans was taken at the exact same point as where that air came in to the boat. So the contaminate air was coming in to the boat and being picked up and discharged into peoples bunks, where they were called punkaloovers, the vent right alongside their head"

It was generally agreed that physical hazards were the hardest to escape from and impossible to control, for example, working in confined spaces. Heavy lifting, many hours crouching and poor seating were all identified as potentially preventable health hazards.

A confined environment meant that there was nowhere on board with improved conditions. Air quality was of major concern to the submariners.

> "In particular, too, when you're snorting, you'd always get your own back, which is carbon monoxide…and it was very irritating. And as I was eluding to before, it depended on where you got your diesel from – the sulphur content. Ah, if you got your diesel from the States or Singapore, it was a very, very high sulphur content compared to Australian fuel"

Closely related were concerns about the constantly changing atmospheric pressure.

> "To answer your question, do you know how many times you would be exposed, that situation I spoke about earlier about having to stop the engines quickly and then get the pressure in the boat back to atmospheric pressure. If you were doing a thin castle exercise in one four-hour period tap lines beat me by two. That happened 17 times in four hours, if that's some sort of indication."

Exposure to diesel fumes, diesel residue and other chemicals was identified by most men as one of the most hazardous exposures. Constant exposure and lack of adequate hygiene facilities meant that the men felt they literally absorbed the chemicals.

> "Then let it stand for maybe a minute of something, then lean over the sink and go 'whew' and that would have given a chance for the diesel to settle out and become scum on the top…"

> "You do a long period at sea and then check into a hotel in say somewhere like Singapore OK. And you go to bed, have a shower, have a spa, do whatever you like. Go to sleep on a white sheet and when you wake up in the morning, you can see the yellow outline of your body on the sheet"

> "the engineering manual BR3001 which stressed, when cleaning tanks (as in diesel tanks), it was important that the Coxswain was actually allowed to

> claim more meal allowance for the personnel going into the diesel tanks because we had to eat extra amounts of bread and drink more milk to try and absorb the toxins."

Cigarette smoking caused the most comment by participants. The participants are now aware of the health dangers of smoking (and passive smoking) and agreed that they were heavily exposed.

> "And passive smoking in a contained area – it was literally you could not see through it. So we ourselves agreed that half could smoke now and when they've finished it that half can have a smoke. And that's exactly how we did it, so we could see the movie. And of course halfway through the movie, action stations, action stations – he's at it again – everyone was out of the movie and has gone smash bang, and so life goes on"

The sections below detail hazards identified by participants in the focus groups. They are separated into environmental (incorporating chemical and physical) and psychological hazards. Where uncertainty exists as to the exact name of a substance, it is marked with a (?).

Environmental

- Direct exposure to chemicals including; diesel exhaust, diesel residue, epoxy paints, chromate, Ardrox, tar epoxies, Gamlen, gamosol, autosafe, DDT emulsion, white spirits, Swarfega, raw sewerage, Hydrosulphite, red lead paint, Silvo, Brasso, Trichloroethylene, Isopropyl alcohol (?), perchloroethylene (?), turcosol, asbestos.
- Exposure to air contaminants directly and through recycled air including; cigarette smoke, hydrogen sulphide gases, carbon monoxide, Freon, acid fumes.
- Pressure changes including vacuum conditions
- Depleted oxygen
- Sleep deprivation
- Physical strains from heavy lifting, managing loads through small spaces, turning high air pressure valves by hand, constantly crouching, sleeping in small bunks, being thrown around the boat on diving/surfacing, closing 3 tonne door hatches
- Compromised hygiene; in particular shortages of fresh water for washing or cleaning hands after exposure to chemicals.
- Questionable water quality
- Eyesight strain caused by red lighting, black lighting and long periods of no natural light
- Noise pollution from the engines and in particular the "superchargers"
- Inability to exercise
- Inadequate diet; having to eat whatever was left in food storage even if it was decaying

Psychological

- Stress caused by not knowing where they were or being able to tell their families where they were.
- Stress caused by perceived dangers when submarine submerged
- Stress caused by events, eg, fire, flood, CO poisoning
- Perceived high levels of alcohol dependence
- Perceived high levels of nicotine dependence
- Alarms sounding

Health Outcomes

Participants suffer health complaints that they directly attribute to their time spent on the Oberon submarines. Health complaints identified by the participants include: various skin conditions (photosensitivity, rashes, eczema, dermatitis), headaches, back problems, eyesight problems, respiratory problems, aged appearance, night sweats, tinnitus and other hearing loss.

Many of the submariners also attribute psychological problems such as alcohol dependence, depression, anxiety, sleep disorders and stress to their time on the submarines. It is commonly believed by the Oberon submariners that they have a higher divorce rate than the national average. The submariners believe this is due to high rates of alcohol dependence and long, often secretive, separations from their spouses.

> "You say you don't take it home, but you do take it home. Because if you have a look at submariners, many of them have been married two or three times"

> "Absolutely, the divorce rate in submarines was horrific and I believe there were people close to alcoholism"

Hazard and Health Outcome Matrix

A complete list of all hazards identified in the focus groups is found at Table ii. Where possible, the subgroups that were exposed to the hazard and why they were exposed have been identified, along with the perceived related health effect. This list is from information provided in the focus groups only and informs the hazard exposure profile which is provided in the full report.

Table ii: Focus Group Hazard and Health Outcome Matrix

HAZARD	USED FOR/EXPOSED BY	USED BY/AFFECTED	HEALTH OUTCOME	COMMENT
2 pack paint	Including in confined spaces			
	Tank cleaning			
CO	'getting your own back'	all		
Gamlen; gamosol	degreaser; used for washing		dermatitis	
HP air valves	Panel watch keepers; no spanners allowed on subs		Arthritis - hands	
Smoke bombs and smoke candles- produced phosphine when burning	workups	all	Burning throat/eyes ?long-term	Banned late 80's
cigarettes				
Deep frying fat	Galley cooking	cooks		
diesel	Leaking engines			
Ardrox	Heat exchangers			
White spirits	cleaning	all	dermatitis	
hortosafe				
?solvent	Cleaning generators		Eye and respiratory irritation	short
Sewage tank	Cleaning No ppe 'blowback'	Engineers all	hepatitis	
Noise 160db superchargers on all time on surface	No ppe	Engineers all	Hearing loss tinnitus	
Vacuum atmospheric conditions	snorting	all	Haemorrhoids; painful ears	
Lighting; switching between red and black	Plane; sonars		headache	
Focus on infinity	Periscope operator		Long sighted; headaches	
Focus on confined spaces		all	Short sighted; headaches	
swarfega	Clean skin	all		
DDT	Cure scabies	all		
Epoxy red rubber chlorinate paint	Maintainence Torpedo tubes		Carcinogenic Headaches Cognitive	

			deterioration	
Tar epoxies				
Jason pistols ?beryllium	casing			
Ergonomics,ie, constant crouching, opening heavy hatches, short bunks, seats with no backs or padding, lifting strongbacks (torpedo rails); loading the boat with supplies (30-40kg down ladder); tort checks of battery connectors		all	MS problems Lumbar spondylosis, cervical spondylosis; arthritis	
Poor diet Low fibre, lack of fresh F&V, lack of variety, spoiling	Menu to Canberra deliberately inaccurate often			
O2 candles				
Lack of water	hygiene	all	Rashes, eczema 'doby rash'	
			photosensitivity	
Hydrogen sulphide	?port bottle		Polished metal discolouring	
silvo				
brasso				
trichlorethylene				
Turkisol 'Purple death'				
carbon	LP air hose to clean motors			
freon	refrigerators	AMS	Respiratory irritation	
Garbage waste		all		
Compressed Air cylinders – drawn from compressor in engine room	For emergency breathing	all	headaches	
Battery gassing		Engine room	headaches	
hydrocarbons		all	Skin irritation; ?photosensitivity	
VOCs		all		

asbestos	Exhaust lagging, Gaskets, valves,switchboard, fire blankets and gloves	all		
Lack of exercise			Poor cardiovascular fitness	
Red lighting/black lighting			Nausea, headaches, eye strain	
Battery dipping			Skin burns, holes in overalls	
Stress, isolation			depression	delayed
Stress, isolation			PTSD	delayed
Stress, isolation			anxiety	delayed
Stress, isolation			Alcohol abuse	Short and long term
Exposures various			cancer	
			suicide	
			divorce	

Conclusion

The composition of the focus groups was homogenous, consisting entirely of male Oberon submariners, thus resulting in frank responses to questioning and open discussion. The mean time in Oberon submarine service was 14.3 years and the mean age of participants was 55.4 years, representing a wealth of Oberon experience and perhaps indicating a slight preponderance of submariners who served in the earlier years following commission of the Oberon submarines. The range of job categories was represented with the exception of radio operators and cooks. It is considered that these focus groups are likely to be representative of those who worked on the Oberon submarines. The thematic consistency between focus groups also adds to the weight of the findings.

This qualitative study has demonstrated that multiple health hazards were perceived to have been experienced by Oberon Class submariners in their working environment. The difficult, unpleasant and hazardous working conditions had both physical and psychological health ramifications.

Those hazards emphasized as being linked with adverse physical health outcomes were chemical materials, atmospheric conditions and ergonomic conditions. The lack of water for washing and general hygiene use may have contributed to the adverse health effects of chemicals. The stress of being in an operational submarine and isolation were identified as prominent psychological hazards. In general, all personnel were said to have been exposed to all identified hazards because of the nature of the open ventilation system that circulated air throughout the boat and the fact that a small crew meant that anyone might be required to do any job at any time. There was agreement that engineers were likely to be more exposed to certain types of hazard such as noise, diesel and confined spaces.

Some of the psychological effects increased the use of alcohol and nicotine, leading to potentially further negative impacts on the health and well-being of the submariners. Specifically, the increased use of alcohol may have been associated with higher than average rates of marriage break-up. The secret/confidential nature of the deployments undertaken by the submariners along with the situation of often deploying at very short notice may have further contributed to family disharmony and isolation.

There was a lack of a commitment to occupational health and safety on the Oberon submarine until the late 1980s. Operational requirements often took precedence over OH&S considerations and many hazards inherent in the design of the boat could not be remedied. Personal protective equipment against hazards such as noise, chemical exposure and compromised atmospheric conditions was not available.

A culture of loyalty, family and camaraderie existed that was ascribed to the unique working and living conditions. This culture cemented a need/desire to get the job done, without regard for personal protection and often at significant personal cost. It appears that many of the activities and exposures were based on tolerability more than regard for personal safety. This culture of loyalty to the group and it's association with personal exposure to hazard whilst getting the job done has been demonstrated in aircraft maintenance personnel involved in the reseal/deseal program.[2]

This same culture also manifest as a reluctance to report medical concerns for fear of being seen as 'not pulling their weight'. The lack of reporting was compounded by a lack of record-keeping of medical presentations. This lack of adequate record-keeping on board the submarine meant that many of the adverse conditions and specific incidents, and their subsequent health and medical outcomes, were not documented. The impact of this is possibly even more substantial today than at the time, as it means that there is no evidence to support compensation claims for adverse health conditions.

This qualitative work highlights the range and breadth of issues pertaining to health hazards in the Oberon Class submarine. It should be read in conjunction with the literature review and the full report on the retrospective Occupational Hygiene Survey of the Oberon Class Submarine.

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[2] Commonwealth of Australia, 2003, *Study of Health Outcomes in Aircraft Maintenance Personnel*, Commonwealth of Australia, Canberra.

Derivation of Exposure Profile

Two tables of selected hazards and sources are provided below (Table 1 and 2). Where there was not enough information on a hazard to say anything with confidence, it has not been included. This information is combined with that of table 3 (job location) to arrive at Tables 4 and 5, which together form the Oberon submarine exposure profile.

Table 1: Selected hazards and sources

Hazard	**Source**	**Comment**
Gases (see below)	Various	Usually able to diffuse freely.
Diesel vapour	Engine room, but also present elsewhere	Volatile components adsorbed and desorbed on porous surfaces throughout boat. Higher boiling components more localized.
Other hydrocarbons, polychlorinated biphenyls and volatile organic compounds	Various, including cleaning agents, and electrical fittings	As for diesel vapour
Metals (e.g. lead, mercury)	Solder, batteries, electrical equipment etc.	Usually low level exposure scenarios
Asbestos	various	In gaskets, and fire protection materials (generally before 1980s)
Diesel exhaust particulate	Diesel engines	Fine particles, that may be easily dispersed
Other particles	Various, including cigarette smoke, cooking, fabrics and skin	Fine and coarse particles
Microbes (including bacteria and fungi)	Wet areas or toilets, rotting materials, humans	May be very localized, or spread in food, air or water
Noise	Engines, torpedoes, but also other sources	Often localised
Vibration	Engines, but also other sources	Usually short term, or intermittent
Heat	Engines, cooking but also other sources	Often localised
Musculoskeletal	High pressure valves, push/pull/lift activities; awkward postures, kneeling	Affects crew according to tasks
Air pressure	Snorting etc	Uniform throughout boat

Psychological	Absence, perceived danger, personal relationships	Affects all crew to varying levels
Illumination	Dark environment, no sunlight	
Non-ionising radiation	Stationary and oscillating electric and magnetic fields from equipment	
Electricity	Electrical equipment	

Table 2: Selected Gas Exposure on an Oberon Submarine, at Sea

Gas	Source	Exposure in hours (Typical 24 hour period)
Carbon Monoxide (CO)	Smoking Fires Diesel Exhaust	24 0 (irregular occurrence) 6 - 24 (depends on running)
Hydrogen Cyanide (HCN)	Fire Otto Fuel Residue	(irregular occurrence) (irregular occurrence)
Carbon Dioxide ($C0_2$)	Respiration Smoking	6 - 24 (if not `snorting') 24
Oxygen (0_2)		Low levels if not `snorting'. < 18%
Hydrogen Chloride	Fire	(irregular occurrence)
Phosgene	Fires involving Chlorinated Hydrocarbons	(irregular occurrence)
Chlorine (Cl_2)	Fires Sea Water contact with Main Battery	(irregular occurrence) (irregular occurrence)
Oxides of Nitrogen (NO_x)	Fire Smoking Diesel Exhaust	(irregular occurrence) 24 6 - 24 (depends on running)
Hydrogen Sulphide (H_2S)	Sewage and Bilges	2
Hydrogen (H_2)	Main Batteries	1- 2 depends on `gassing'

(courtesy Rod Baker)

Table 3: Rank and job description by percentage of time spent in submarine compartments, in a typical dived patrol [(1)]

Rank and Name	Rank Description	Job Description	Aft Ends	Motor Room	Engine Room	Control Room	Wardroom (Officers Accommodation)	Accommodation Space	Battery	Torpedo Room
Officers										
	Lieutenant Commander - Commanding Officer	Captain	0	0	0	90	10	0	0	0
	Lieutenant - Executive Officer	2nd In Charge	0	0	0	50	50	0	0	0
	Lieutenant - Electrical Officer	In charge electrical department	0	0	0	50	50	0	0	0
	Lieutenant - Engineering Officer	In charge engineering department	0	0	0	50	50	0	0	0
	Lieutenant - Seaman Officer	Navigation	0	0	0	50	50	0	0	0
	Lieutenant- Seaman Officer	Sonar	0	0	0	50	50	0	0	0
	Lieutenant - Seaman Officer	Torpedos	0	0	0	50	50	0	0	0

Senior Sailors										
	Chief Petty Officer - Coxswain	Discipline, Medical, Caterer, sailor management	0	0	0	10	0	90	0	0
	Chief Petty Officer - Senior Engineering Tradesperson	Engineering maintainer	0	0	50	0	0	50	0	0
	Chief Petty Officer - Engineering Tradesperson	Diesel maintainer	0	0	50	0	0	50	0	0
	Chief Sonar	2nd in charge sonar operators	0	0	0	50	0	50	0	0
	Senior Electrical Tradsperson	Senior electrical maintainer	0	10	0	50	0	40	0	0
	Chief Petty Officer - Senior Engineering Tradesperson	Engineering maintainer	0	0	50	0	0	50	0	0
	Senior Engineering Tradesperson	Engineering maintainer	0	0	50	0	0	50	0	0
	Chief Petty Officer - Senior Engineering Tradesperson	2nd in charge engineering department	0	0	10	0	0	90	0	0
	Senior Electrical Tradesperson	2nd in charge electrical department	0	0	0	20	0	80	0	0
	Senior	Engineering	0	0	50	0	0	50	0	0

	Engineering Tradesperson	maintainer								
	Chief Petty Officer - Senior Executive Sailor	2nd in charge Discipline, Medical, Sailor management	0	0	0	50	0	50	0	0
	Senior Engineering Tradesperson	Engineering maintainer	0	0	50	0	0	50	0	0
	Senior Engineering Tradesperson	Engineering maintainer	0	0	50	0	0	50	0	0
	Petty Officer - Senior Torpedo Operator	2nd in charge torpedo operations	0	0	0	50	0	40	0	10
	Petty Officer - Senior electrical maintainer	Sonar maintainer	0	0	0	60	0	40	0	0
	Senior electrical maintainer	High Power electrical maintainer	0	10	0	50	0	39	2	0
	Petty Officer - Senior electrical maintainer	Radio maintainer	0	0	0	60	0	40	0	0
	Petty Officer - Senior Radio Operator	Radio Operations	0	0	0	60	0	40	0	0
	Petty Officer - Senior Cook	Senior Cook/Caterer, medical	0	0	0	0	0	100	0	0
Junior Sailors										

	Leading Seaman-Radio Operator	Radio Operator	0	0	0	50	0	50	0	0
	Leading Seaman-Stores	Stores manager	50	0	0	0	0	50	0	0
	Leading Seaman-Sonar	Sonar operator	0	0	0	50	0	50	0	0
	Leading Seaman-mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Leading Seaman-mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Leading Seaman-mechanical	Engineering maintainer	50	0	0	50	0	0	0	0
	Leading Seaman-electrical	Electrical maintainer	50	48	0	0	0	0	2	0
	Leading Seaman-mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Leading Seaman-Radar	Radar operator	0	0	0	50	0	50	0	0
	Leading Seaman-Radar	Sonar operator	0	0	0	50	0	50	0	0
	Leading Seaman-mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Leading	Electrical	50	48	0	0	0	0	2	0

	Seaman- electrical	maintainer								
	Leading Seaman- Torpedo	Torpedo operations	0	0	0	0	0	50	0	50
	Leading Seaman- radio electrical	Electrical (Radio) maintainer	0	50	0	10	0	40	0	0
	Leading Seaman- electrical	Electrical maintainer	50	48	0	0	0	0	2	0
	Able Seaman- Sonar	Sonar operator	0	0	0	50	0	50	0	0
	Able Seaman – mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Able Seaman – mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Able Seaman – torpedo	Torpedo operations	0	0	0	0	0	50	0	50
	Able Seaman- Sonar	Sonar operator	0	0	0	50	0	50	0	0
	Able Seaman – mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Able Seaman – mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Able Seaman – Cook	Cook	0	0	0	0	0	100	0	0
	Able Seaman – Radio Operator	Radio Operator	0	0	0	50	0	50	0	0
	Able Seaman – Radar	Radar Operator	0	0	0	50	0	50	0	0
	Able Seaman – torpedo	Torpedo operations	0	0	0	0	0	50	0	50
	Able Seaman-	Sonar operator	0	0	0	50	0	50	0	0

	Sonar								
	Able Seaman-electrical	Electrical (Sonar) maintainer	50	50	0	0	0	0	0	0
	Able Seaman-Sonar	Sonar operator	0	0	0	50	0	50	0	0
	Able Seaman – mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Able Seaman-electrical	Electrical maintainer	50	48	0	0	0	0	2	0
	Able Seaman - Steward	Officers Steward	0	0	0	0	50	50	0	0
	Able Seaman – Radar	Radar Operator	0	0	0	50	0	50	0	0
	Able Seaman – torpedo	Torpedo operations	0	0	0	0	0	50	0	50
	Able Seaman – Radio Operator	Radio Operator	0	0	0	50	0	50	0	0
	Able Seaman – mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Able Seaman – mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Able Seaman – mechanical	Engineering maintainer	50	0	50	0	0	0	0	0
	Able Seaman – torpedo	Torpedo operations	0	0	0	0	0	50	0	50

Notes.

1. Based on the recollection of a senior submariner, after consultation with other submariners
2. Assuming a two watch scenario (6 hours on watch, 6 hours off watch).
3. The Commanding Officer’s cabin is in the Control Room.
4. Officers and Senior sailors may briefly visit most compartments (except the battery) during the patrol, but only briefly.
5. Crew wandered into most compartments (except the battery) during their time off watch, but only briefly.

Table 4: Exposure Profile and Quality of Evidence

Hazard	Most exposed crew*	Rating	Quality of Evidence	Comments
Gases (see below)				
Diesel vapour	Engine room crew	significant	medium	
Other hydrocarbons and volatile organic compounds	Engine room crew, electrical maintenance	low	medium	May be peak exposures when cleaning
Metals (e.g. lead, mercury)	Control room, electrical maintenance	low	medium	May be significant for mercury
Asbestos	Engine room crew	low	medium	
Diesel exhaust particulate	Engine room crew	low	medium	
Other particles	Engine room, cook	significant	medium	
Microbes (including bacteria and fungi)	All	low	medium	
Noise	Engine room	significant	medium	
Vibration	Engine room	low	poor	
Heat	Engine room	significant	poor	
Musculoskeletal	All Panel operators	significant significant	poor poor	Various; Turning valves
Air pressure	All	significant	good	
Psychological	All	significant	medium	
Poor Illumination	Control room		medium	
Non-ionising radiation	Control room, Electrical maintenance	low	poor	
Electricity	Electrical maintenance	low	poor	

* based on proximity to source, task and other factors
Rating: low = low exposure relative to exposure criterion; significant = comparable with or greater than exposure criterion
Quality of evidence: good = published data under actual conditions; medium = professional judgement in conjunction with focus group information and observation; poor = insufficient, unavailable or presumptive

Table 5: Exposure Profile (gases) and Quality of Evidence

Gas	Most exposed crew*	Rating	Quality of Evidence	Comments
Carbon Monoxide (CO)	Engine room, torpedo operators	significant	good	Smoking and cooking also relevant
Hydrogen Cyanide (HCN)	No specific crew	low	poor	Only in the event of fire or possibly torpedo firing
Carbon Dioxide ($C0_2$)	All	significant	good	
Oxygen (0_2)	All	significant	good	
Hydrogen Chloride	Electrical maintenance	low	medium	
Phosgene	No specific crew	low	poor	
Chlorine (Cl_2)	Electrical maintenance	low	medium	
Oxides of Nitrogen (NO_x)	Engine room, torpedo operators	low	poor	Only in the event of fire or torpedo firing
Hydrogen Sulphide (H_2S)	All	low	poor	Peaks possible
Hydrogen (H_2)	Electrical crew	low	good	

* based on proximity to source, task and other factors
Rating: low = low exposure relative to exposure criterion; significant = comparable with or greater than exposure criterion
Quality of evidence: good = published data under actual conditions; medium = professional judgement in conjunction with focus group information and observation; poor = insufficient, unavailable or presumptive

Discussion

This project appears to be the most wide ranging review of exposures experienced on Oberon class submarines, covering hazards as diverse as noise and psychosocial stress.

Concerns have been expressed about exposures that may lead to long term irreversible health effects, such as cancer and neurological damage, but the focus of this study was on hazards experienced at sea, where mission and operability requirements may have been the dominant considerations. In particular, the hazards faced during dived patrols, including snorting, may be regarded as the most significant, and thus the emphasis in this report, and indeed most previous studies, is in respect of that situation. That is not to say that submariners were not also exposed to hazards during shore duties, for example during loading, storage and maintenance tasks such as painting.

One of the strengths of this study was its use of multiple sources of data. In addition to a review of the military and general scientific literature, the CMVH team, which included two senior occupational hygienists for the bulk of the work, visited the decommissioned HMAS ONSLOW, conducted focus groups in Sydney and Rockingham, spoke with several experienced submariners and triangulated the evidence to arrive at the conclusions and recommendations.

The focus groups were able to provide an insight into the day to day experiences and perceptions about hazards and hazard management in the submarine environment. In many ways, the hazards were seen as “part of the job” and exposures tolerated for the sake of others. In respect of the submarine atmosphere, the captain appeared to be the arbiter of what was tolerable. Individual relief could be found in medications, smoking and alcohol consumption. With few exceptions, personal protective equipment did not appear to be used, and personal hygiene was compromised, through a shortage of water. Formal occupational health and safety thinking did not emerge until the 1980s, but it is unclear whether this had a dramatic impact on exposures.

Apart from any physical, chemical and ergonomic hazards that may exist in the submarine, the fact that a relatively large number of sailors are in a confined environment for extended periods potentially creates a raft of health issues, including psychosocial, ergonomic and communicable disease problems.
On the other hand, submariners are a self selected population and there is a strong supportive (“family”) culture. The issue of being a self selected population needs to be considered when examining standardised morbidity and mortality rates, where a healthy worker effect may be evident. Additionally, due to the prevailing submarine culture, illness is likely to be under-reported.

As part of their training, all submariners are expected to know, or be aware of, the jobs of others. This feature, as well as the intrinsic characteristics of a submarine and its operational demands, tend to exacerbate the usual occupational hygiene uncertainties associated with "peak" versus "averaged" exposures; “extended duration” exposures versus traditional shifts, "breathing zone" versus "fixed location" values, multiple exposure routes and variable disease susceptibilities associated with sleep-wake patterns, diet, exercise and socially-driven habits.

In developing the Oberon submarine exposure profile, reference was made to the available scientific and technical literature. It rapidly became apparent that systematic occupational hygiene and health studies of Oberon class or even diesel electric submarines were rare. Based on US research report titles, much of the literature has a focus on performance, and deals with nuclear submarines. However, to the extent that Australian submarines were not significantly modified from the original UK configuration, it is feasible to generalize from the Canadian and UK literature (where available). Some aspects of the nuclear submarine literature, e.g. psychological and musculoskeletal hazards, may also be applicable.

Most of the previous studies of chemical exposure were monitoring equipment evaluations, rather than personal exposure assessments, and those that were of an investigative nature produced very little air monitoring data. The Canadian studies of the *HMCS Okanagan*, which appeared to be the best available, aimed to gather information about the ambient environment, and only approximated a hygiene survey.

The first point that needs to be made is that there is strong anecdotal evidence that the submariners' exposures were tolerated, or volunteered, rather than regulated. Conditions were highly variable, such that peak exposures at the limit of tolerability were often encountered. Canadian studies of airborne chemical hazards demonstrated high peaks, e.g. of aerosols, but the average values were usually within military guidelines. In some situations where intolerable exposures were encountered, personal respiratory protection was required.

The impact of intermittent peak exposures on chronic disease risk is uncertain, but the recent occupational health literature suggests that it can be important for a range of diseases, for example, respiratory disease. In other words, such exposures may not necessarily result in fully reversible effects. In theory, exposures experienced in service may sensitise the body or result in subclinical health decrements, and be exacerbated in later years.

The actual uptake of substances may be influenced by dermal exposure (and ingestion), and the lack of dermal exposure information is a serious gap in knowledge. Apart from exposure to carbon monoxide, biological monitoring has not been done. Thus it is unclear what was actually absorbed into the body. Given that surface contamination and aerosols were present, nearly all risk assessments based on air sampling are likely to underestimate the true situation. There are also some components of mixtures for which no toxicological data are available.

As there are a variety of hazards to consider, these were taken in turn. In so doing, however, it is important to bear in mind that there are very few data related to shore duties, and that, with few exceptions, the quality of exposure information is poor.

In respect of asbestos exposure, the literature for submarines is sparse, but on the basis of comments made in focus group discussions, visual observations and related literature, it appears that asbestos exposure was low. Engine room crew, especially in the earlier years, may have had elevated exposures, but probably less than those found in surface vessel engine rooms. The CMVH team did not have access to design specifications for the submarine. It was understood that chrysotile was the most likely form of any asbestos used in gloves, blankets, lagging and gaskets.

Carbon monoxide is an insidious toxicant, and is generated during diesel engine activity and other combustion processes, e.g. smoking. A major air contaminant was cigarette smoke. It is unfortunate that appropriate measures of cigarette smoke exposure were not available or undertaken. However, measurements in submarines under normal conditions suggested moderate and variable exposures mainly depending on smoking and cooking. Torpedo firing may have been a short term source of elevated carbon monoxide exposure. However, the UK mortality experience and the Canadian measurements of carboxyhaemoglobin imply that smoking-related health problems may not be as great as some might imagine. In a Canadian study, carboxyhaeomoglobin values were within limits, even without smoking restriction. On the other hand, the potentially significant exposures to hydrocarbons warrant further study of morbidity

Owing to the confined nature of submarines, very high and potentially lethal concentrations can occur during a fire or a diesel exhaust vent failure. The long term health consequences of non-fatal peak exposures are not fully understood, and there may be lasting effects. However, it seems unlikely that the lower level exposures represent an appreciable risk.

Engine room and galley crew may have somewhat higher exposures than other personnel. Interestingly, carbon monoxide (and carbon dioxide) measurements provide an opportunity to assess the ventilation characteristics of the submarine. Canadian research confirms poor ventilation (>35 min of snorting required to clear the air), with somewhat poorer ventilation in the rear of the boat.

Carbon dioxide has been identified as a significant exposure problem with exposures often exceeding 1%, and there is some human and animal evidence of medium term health effects directly attributable to such elevated carbon dioxide. Depending on the circumstances, e.g. the use of the blackout curtain, the concentrations may not be uniform throughout the boat. Anecdotally, crew were often panting during dives, suggesting high carbon dioxide and diminished oxygen. As quoted in the Canadian study by Severs and Sabiston, “the maintenance of the submarine atmosphere is a judgement call of the submarine Commander, based on his experience and his personal interpretation of the Standard”. That said, selection into the submarine service implies tolerance to carbon dioxide and thus the respiratory physiological balance may be unusual in this population.

Benzene exposure has been reported in a number of studies. The air concentrations are low (typically less than 0.1 ppm), and on the basis of a “practical” threshold of 16 ppm-years from Australia data in the petroleum industry, it appears that cases of myloid leukemia are unlikely. This conclusion must be tempered by the lack of knowledge of non-inhalational exposure, especially since benzene is a (minor) component of white spirits used to wash down oily surfaces. It is difficult to assess which members of the crew would have had the greatest benzene exposure, although it is tempting to suggest that engine and machine room operators would have had greater exposure, by virtue of diesel exposure, the use of oily rags etc. The available epidemiological evidence, with a relatively short follow-up, for submariners indicates that the SMR for leukaemia is less than 100, but the extent of the healthy worker effect and influence of medical treatment services is unclear.

Chronic exposure to diesel vapour was a feature of the Oberon class submarine. Marine diesel is a complex mixture with greater than 10% polycyclic aromatic hydrocarbons. There are multiple exposure pathways, and whereas inhalational exposure may be experienced by all crew, engine room crew are exposed to localised fuel aerosol, leaks etc. Anecdotally, diesel was a contaminant of water and was an undesirable characteristic of submariners returning home. Air sampling data for diesel components are difficult to interpret, as volatile organic compounds arise from a number of sources, e.g. cleaning agents. In an Australian review by Gan and Mazurek, it was reported that concentrations of greater than 50 ppm were common in Oberon class submarines. Cancer and neurotoxic risks were calculated, although the International Agency for Research on Cancer has concluded that there is inadequate evidence for human carcinogenicity. The lack of biological monitoring data and the complexity of the exposure pathways, make risk assessment problematic. Nevertheless, there is some evidence that solvent exposed workers may experience long term neurological changes (e.g. "painters syndrome", and visual disturbance), and that certain types of PAH exposure may lead to photosensitivity. Some submariners reported that, on returning home, bed sheets would be stained from skin contact. This is a disturbing remark and suggests that skin is a reservoir for the semi-volatile compounds, and that skin permeation studies should be conducted for diesel exposed submariners.

Diesel exhaust particulate exposure has been linked with cancer, and it is clear that submariners were exposed during snorting. There are some technical difficulties in measurement, and the best available metric (i.e. elemental carbon) has not been sufficiently used to be able to evaluate risk. Once again, engine room crew would be the ones most likely exposed.

There is anecdotal evidence of occasionally significant hydrogen sulphide concentrations, as evidenced by high short term detector tube results and visible sulphide deposition. The most obvious source is sewage, e.g. associated with the break-up of the surface crust in the bilge tanks, but the marine diesel may have had an appreciable sulphur content. Like carbon monoxide it is unclear whether there are long term health consequences for these variable exposures. It is uncertain as to whether any particular members of the crew had greater exposures. It was reported that a crew member, if asked, would volunteer to enter a bilge tank.

Generic aerosol exposures have been studied. In a Canadian study, respirable particle concentrations were found to be highest in the engine room. It would be expected that cooking, frying and smoking could also generate significant aerosol. Peaks may arise from re-entrainment of diesel exhaust (“getting your own back”) and a number of other scenarios. It is difficult to interpret the health significance of unspecified aerosol exposure, and future studies should attempt particulate speciation.

Relatively low levels of other air contaminants have been reported. Arsine, stibine ozone, ammonia or nitrous compounds were not detectable in Canadian studies. Mercury was present in small amounts, but values for sonar operators slightly exceeded the guideline of 50 micrograms per cubic metre. Freon-12, associated with refrigeration units, ranged up to 32 ppm, which is well below the guideline of 500 ppm. Hydrogen, chlorine, hydrogen chloride and hydrogen fluoride have been monitored during battery charging. Only a small amount of hydrogen was detected in the battery compartment. These monitoring data would suggest low exposures, but anecdotally, sea water contact with the battery could generate chlorine, and fires could result in phosgene, hydrogen cyanide, chlorine and hydrogen chloride on an irregular basis. Sulphuric acid aerosol was also mentioned as a hazard in the battery compartment.

Finally, a range of cleaning agents, propellants, hydraulic fluids, degreasers, release agents, paints and pesticides were said to be found on the boat or used during maintenance (whilst docked). Epoxy paints, Otto fuel, Brasso, Silvo, White Spirits, turpentine, carbon tetrachloride, Ardrox, Gamlen and Turcosol were mentioned. Without access to an inventory of materials brought on to the submarine, product identification and composition cannot be determined. Day to day cleaning activities using hydrocarbons may result in personal exposure over and above background levels. Of great concern is the reported usage of carbon tetrachloride for cleaning circuits. This substance is known to cause liver damage, and it is tempting to suggest that elevated rates of cirrhosis of the liver among submariners were partly due to the historical use of chlorinated hydrocarbon solvents.

There have been microbiological investigations of submarines, but little in the way of air monitoring. An Australian study involving swipe and air sampling demonstrated low levels of contamination, except when mouldy bags were moved. In other studies, it was found that flora could be related to faecal contamination. *Pseudomonas aeruginosa* was commonly found. A *Mycoplasma pneumoniae* outbreak was reported for a nuclear submarine crew on patrol. Hepatitis and scrotum infections were mentioned in the focus groups. In a recent Swedish study, marker concentrations of fungi and bacteria resembled those found in domestic and work environments. Antibiotics were available on board the submarines, but aspects of their use were not explored further.

Personal hygiene was an issue, due to water rationing. Whilst showering was recommended for certain crew, but this was not always done, perhaps in an attempt to conserve water. Crew went to sleep without changing clothes.
Apart from the confined nature of human occupancy, there seems to be nothing remarkable about the microbiological environment of submarines, and no indication of elevated exposure among any particular subgroup.

The literature search could locate only one report of noise exposure on Oberon class submarines, and this was not representative of normal conditions. Anecdotally, noise was a major issue for those in the engine room, and these crew members were provided with ear muffs and headsets (for some noise reduction and communication purposes). Interference noise was reported for other crew wearing headsets. Data from HMAS COLLINS suggest that noise exposures in the main generator room can approach 110 dB(A) whilst the diesel generators are active. There is evidence that submariners have a higher rate of hearing loss compared with age-matched civilians. Recent guidance on noise management refers to the potential for synergy between noise and chemical exposure, and this may be the case for Oberon class submariners. Carbon monoxide and xylene have been classified as synergistic agents.

No references could be found on radiation hazards pertaining to diesel electric submarines. Nor was it mentioned in the focus groups.

Psychological hazards have not been directly assessed, e.g. via cortisol levels, but it is clear from the focus group information and other data that stress arose during and after deployment. A survey of navy wives, using a mood questionnaire, comparing those whose husbands were away and those port bound, illustrated spouse depression as just one aspect of a complex issue. Compounding the problem is body contamination with diesel. It is likely that psychological "exposures" were not distributed according to rank, but were probably more significant for those married, and with children.

Musculoskeletal hazards arose from assigned tasks, but no exposure data were available locally. Manual handling hazards were described during the submarine visit and during focus group discussions. The hazard of repeatedly rotating high pressure valves in a stooped posture was mentioned on several occasions. It appears that panel operators, and those working in tight spaces have greater exposures. However, a majority of the members of the focus groups reported some back, hip or neck problem.

Atmospheric pressure hazards during dived patrols were commonly reported. Pressure variations led to discomfort, but burst eardrums were not mentioned. All crew would have been affected.

There is little mention of heat stress in the literature, although this would be most apparent in the engine room. In addition, the air conditioning/ventilation system on Oberon class submarines was not suited for tropical climates, and there is anecdotal evidence of heat stress when docked in those ports. The combination of hot and damp skin would have led to heat rashes, and possibly the increased uptake of skin contaminants.

Owing to time constraints and the lack of availability of data, particularly from the UK, an exhaustive literature review could not be conducted. It is possible that musculoskeletal risks, psychological and ergonomic problems have been inadequately addressed. These hazards would be found in all submarines, and not just the Oberon class submarines.

A list of specific data and documents that have been identified as being relevant to this project but were either unavailable or classified (restricted) and therefore unable to be utilised in this report is attached at Annex D. Were these documents to be made available to the CMVH team as unclassified documents, a supplementary report to this report would be able to be provided.

Conclusion

In conclusion, the occupational hygiene literature for Oberon class submarines appears to be sparse. Whilst engine room crew probably experienced a range of significant exposures by virtue of their proximity to the diesel engines, all of the crew were exposed to a cocktail of substances, by multiple routes. A number of factors blur the distinctions, and direct comparison with exposure criteria is problematic.

However, the exposure profile shown in Tables 4 and 5 illustrate that significant exposures to diesel vapour, other particles, carbon monoxide, carbon dioxide and oxygen (lack of) occurred on the Oberon Class submarine. Additionally, Oberon submariners were significantly exposed to the more traditional types of workplace hazards such as noise, heat, musculoskeletal and psychological hazards. Whilst these types of hazards are not unique to the Oberon submarine the context, of confined spaces and 24 hour exposures, in which the submariners were exposed was unique. In addition, the limited washing facilities and potential for synergistic exposure, e.g. between noise and solvents, need to be acknowledged.

Although it is impossible to re-evaluate most exposures, it may be feasible to undertake biomechanical hazard assessments post hoc, e.g. simulating tasks in the decommissioned submarines to strengthen the level of evidence.

The potentially significant exposures to hydrocarbons warrant further study of morbidity.

Recommendations

The following recommendations are made in the light of the findings:

- The Department of Veterans' Affairs note the Exposure profile in Tables 4 and 5 for consideration as to how it may assist in the compensation process for submariners.

- Defence make available, where possible, documents that have been identified as highly relevant to this project for review. Should this occur, a supplementary document, expanding on the findings of the current report, could then be provided.

- To expand on the findings of this study, a qualified and experienced biomechanist should categorise manual handling, awkward and repetitive tasks on board the Oberon submarine. The most significant of these should be simulated within one of the decommissioned Oberon boats, and biomechanical risk assessments undertaken to strengthen the level of evidence.

- To expand on the findings of this study, tests of skin absorption and skin permeation of diesel could be undertaken and should be considered to add weight to the evidence of risk of diesel exposure.

- Consideration be given to the conduct of a health study of the submariner population to address ex-Oberon submariner concerns and attempt to identify any adverse health outcomes associated with documented exposures. Specific areas of research could include a cancer incidence and mortality study and neurobehavioural testing, using a suite of sensitive indicators of neurological damage. The Defence Deployment Health Surveillance Program is a potential conduit for such a study.

- The Collins Class submarine was not the focus of this study and has not been specifically considered, however, the literature review did reveal that similar hazards may exist on the Collins Class submarines. Systematic occupational hygiene studies, including biological monitoring of hydrocarbon uptake, could be carried out in Collins Class submarines. A gap analysis of what relevant work has already been done and what could be done to expand current knowledge should be undertaken.

Annexes

Annex A: The Project Team

Annex B: Information and Consent Sheet-Focus Groups

Annex C: Interview Guide-Focus Groups

Annex D: List of Documents not Available

Annex A to
Oberon Class Submarine
Occupational Hygiene Project
dated 28 FEB 06

The Project Team

Bennett, CMDR Sonya – Project Manager; Focus Group Chief Investigator
Centre for Military and Veterans' Health, University of Queensland

Grygorcewicz, Dr Czeslaw – Research Officer, literature review
Centre for Military and Veterans' Health, University of Queensland

McKenzie, Ms Alison – Research Officer, Focus Groups
Centre for Military and Veterans' Health, University of Queensland

Pisaniello, Associate Professor Dino – Project Chief Investigator
Centre for Military and Veterans' Health, University of Adelaide

Wilson, Dr Eileen – Focus Group Investigator
Department of Veterans' Affairs

Annex B to
Oberon Class Submarine
Occupational Hygiene Project
dated 28 FEB 06

THE UNIVERSITY OF QUEENSLAND

CMVH
CENTRE FOR MILITARY & VETERANS' HEALTH

INFORMATION AND CONSENT SHEET

OBERON CLASS SUBMARINE

OCCUPATIONAL HYGIENE PROJECT

BRIEF DESCRIPTION OF STUDY

The Centre for Military and Veterans' Health (CMVH) is a collaborative centre of the University of Queensland, University of Adelaide and Charles Darwin University. CMVH has been contracted by the Australian Defence Force; Defence Health Services to conduct the Oberon Class Submarine Occupational Hygiene Project.

Concern has recently been expressed regarding the exposures of personnel serving in HMA submarines. Many current and former submariners have had difficulty in having initial DVA claims accepted due to the lack of recognition of the hazards experienced during their submarine service. It is hoped that better authoritative documentation of the known hazards will assist the decision-making process for compensation claims, particularly at the primary level.

The primary study is a retrospective occupational hygiene survey of the Oberon Class Submarine. The survey will identify known hazards of the Oberon Class HMA Submarine and, where possible, estimate exposures and risk of harm. It will deliver this outcome by a review of the available literature and departmental reports, a tour of the Oberon submarine in the Maritime Museum in Sydney (guided by members of the Submarine Association of Australia with extensive Oberon experience) and the conduct of two focus groups of ex-Oberon submariners with relevant experience.

This information and consent sheet is for participation in the focus groups. You have been nominated by either the Submarine Association of Australia or the Submarine Force Element Group RAN as having experience that will be invaluable to the focus group and your assistance is requested by participating.

YOUR PART IN THE STUDY

Your participation in the focus group is entirely voluntary. There is no obligation to take part in the focus group. If you are still serving in the Defence Force or in receipt of a Service-related pension a decision not to participate will not lead to any detriment to your career, entitlements, benefits or future health care. Your participation or non-participation will not be notified to the Department of Defence or the Department of Veterans' Affairs. Currently serving Defence Force members will be considered to be on duty during their participation in the focus group.

You may withdraw from the study at any time. If you are a Serving member or in receipt of a Service-related pension, there will be no detriment to your career, pension or future health care should you choose to withdraw.

If you agree to participate in the study, you will be asked to attend a 2-3 hour session at ANZAC House in Sydney, or at the Naval Club in Rockingham. This session will be chaired by an experienced and impartial moderator and the discussion will be recorded on audio equipment. The moderator will use a pre prepared interview guide but there will be some flexibility to allow for discussion of issues outside the guide.

BENEFITS OF PARTICIPATING

There will be no direct benefit or financial remuneration for your participation in this focus group. However by participating in this focus group you will be contributing valuable knowledge to the Veteran and Defence Force communities about the potential hazards that existed on the Oberon Class submarine. This knowledge may assist you or other Service personnel (current or former) in gaining recognition for Service-related ill-health. It may also assist the ADF in developing the most appropriate supportive and protective measures against future health threats.

RISKS OF PARTICIPATING

Generally, the risks of participating in a study are required to be detailed before any consent can be obtained from you regarding participation. The primary risks involved in participating in this study are related to the confidentiality of the information provided in the focus group. The handling of this information is discussed below in the section entitled "Your Privacy".

YOUR PRIVACY

All information provided by you will be treated confidentially. This Consent form, and possibly the audio recording, will be the only data that contains identifiers of the participants. These will be separated from all other data and stored securely in a locked cabinet to which only the Chief Investigator has access.

All other information and data pertaining to the focus group will be de-identified and stored on password protected computers and/or in secure, locked cabinets at CMVH and accessed only by authorised study personnel. Any reports or published articles resulting from the study will not include any personally identifying information and will preserve your anonymity. Data are accessed only by authorised study personnel and will be stored on password protected computers and in secure storage facilities at the University of Queensland.

CHIEF INVESTIGATOR
CMDR Sonya Bennett
Centre for Military and Veterans' Health
Mayne Medical School Building
Herston Road
HERSTON QLD 4006
Contact telephone: 1800 886 567
07 3346 4861

Should you have any questions, problems or concerns about the conduct of this project, please do not hesitate to contact the Chief Investigator, or you may prefer to contact:

The Australian Defence Human Research Ethics Committee (ADHREC) at the following address:

Executive Secretary
Australian Defence Human Research Ethics Committee
CP2-7-66
Department of Defence
CANBERRA ACT 2600
Telephone: 02 6266 3837
Facsimile: 02 6266 4982
Email: ADHREC@defence.gov.au

This study has been approved by ADHREC as the principle approving Human Research Ethics Committee.

Additionally, this study adheres to the Guidelines of the ethical review process of The University of Queensland. Whilst you are free to discuss your participation in this study with project staff (contactable on the phone numbers above), if you would like to speak to an officer of the University not involved in the study, you may contact the Ethics Officer on 07 3365 3924.

Finally, this study has also been approved by the Department of Veterans' Affairs Ethics Committee (DVAHREC). If you would like to speak to the DVAHREC Co-ordinator they can be contacted on 02 62894709.

OBERON CLASS SUBMARINE OCCUPATIONAL HYGIENE PROJECT

CONSENT

I …………………………………………………………………….give my consent to:

- ❑ Participate in the Focus Group and
- ❑ Audio Recording of the Focus Group session

My consent is provided on the following basis:
I have had explained to me the aims of this research project, how it will be conducted and my role in it.
I understand the risks involved as described above.
I am cooperating in this project on condition that:
The information I provide will be kept confidential
The information will be used only for this project

The de-identified study report will be made available to me at my request and any published reports of this study will preserve my anonymity.

I understand that:
There is no obligation to take part in this study
If I choose not to participate there will be no detriment to my career, benefits, entitlements or future health care
I am free to withdraw at any time with no detriment to my career, benefits, entitlements or future health care
I have been given a copy of the information / consent sheet, signed by me and the Chief Investigator, CMDR Sonya Bennett, for my records

I have also been given a copy of ADHREC's *Guidelines for Volunteers.*

______________________________ ______________________________

Signature of Volunteer Signature of Researcher

______________________________ ______________________________

Name in Full Name in Full

______________________________ ______________________________

Date Date

THIS PAGE WILL BE DETACHED FROM YOUR INFORMATION AND CONSENT FORM

DEMOGRAPHIC DATA

Note: to ensure confidentiality of your information, this page will be removed from the information and consent sheet by the Study team and stored separately.

Please fill in details below

Age	
Years in Oberon submarine Service	
Job category	Primary
	Secondary

Annex C to
Oberon Class Submarine
Occupational Hygiene Project
dated 28 FEB 06

Focus Group Oberon Class Submariners

Interview Guide

Introduction

- Thank participants for coming
- Ensure all have read and signed the Information and Consent sheet. Ask if there are any questions.
- Reiterate purpose of Focus Group
- Introduce Co-Investigators and explain their role
- Explain the process
- Ask permission to audio-record the session. Reconfirm and assure that there will be no personal identifiers.

Questions

Overview – "You have all served in an Oberon Class Submarine, be it HMAS OXLEY, OTWAY, OVENS, ONSLOW, ORION or OTAMA, for at least 3 years and you all held different types of jobs. We will ask a number of questions to help elucidate the particular experiences and health hazards encountered during Service in HMA Oberon Class Submarines. Some of these questions will be general in nature and some will be specific to particular job categories."

1. What were the different types of Boat activity and the overall proportion of each in any one year?

(15 mins)

Prompts: For example,

- How many weeks were spent on deployment each year?
- How many weeks were spent in maintenance each year?
- How many weeks were spent on weekly running each year?
- How many weeks were spent in combat major exercise, designed to test the operability of the system, each year?

2. As we have a variety of job categories here, we would like to go around the group for you to talk us through a typical day for your particular employment category.

(30 mins)

Prompts:

- What was the boats general routine?

- What were the specific tasks conducted during the day for each job category?

3. How did the ‘typical day’ differ for each of the boat activities described in Question 1.?

(15 mins)

Prompts:

- Were the variety of tasks vastly different during maintenance compared with deployment etc

4. How did the ‘typical day’ differ for your progression through the ranks for each of the tasks described in Question 1?

(15 mins)

Prompts:

- Were the variety of tasks vastly different for each rank within a particular job category?

5. What is your opinion of the potential health hazards associated with the routine and tasks described above?

(15 mins)

Prompts:

- Can you identify potential health hazards associated with particular tasks?

6. We would now like to explore further each hazard identified in Question 5.

(30 mins)

Prompts:

- Did exposure to the hazard affect one individual only, several people in the area or the whole crew?
- Was the hazard present during each performance of the task or was it an intermittent phenomenon, perhaps according to venting etc?
- Did exposure to the hazard result in short-term (hours) or long-term health effects (days)?
- Did exposure to the hazard result in the same health effect and severity every time?
- Was the hazard present only in a certain time period?
- Was the hazard and/or exposure to the hazard a result of a specific cause, for example, intrinsic design problem, inadequate SOPs, human error?
- Was the hazard and/or exposure to the hazard recognized as a problem by Senior Officers and how was it dealt with?

Conclusion of Group

- Thank them for their participation

- Explain process from here, when Final Report due.
- Invite participants to have some refreshments

Annex D to
Oberon Class Submarine
Occupational Hygiene Project
dated 28 FEB 06

List of Documents not Available

Documents classified “restricted”:

- Dibben PR, Foulger BE, (1987). " Atmosphere profiles on SSK submarines. Part one: Studies on HMS/M Onslaught, Odin and Otus." Admiralty Research Establishment, Procurement Executive, Ministry of Defence, Holton Heath, Poole, Dorset, UK.

  * Wally Mazuerek (DSTO) custodian for DoD; copy held by CMDR Bennett

- BR1326 (OOS), (1986). "Air purification in O Class submarines", Manual, Ministry of Defence, UK.

  * * Wally Mazuerek (DSTO) custodian for DoD; copy held by CMDR Bennett

- SUBSAFE Hazard Log database: “oberon”, “HMAS OXLEY”, “HMAS OTWAY”, “HMAS OVENS”, “HMAS ONSLOW”, “HMAS ORION” and “HMAS OTAMA”.

  * a response was received from LEUT Ian Harvey, SO SUBSAFE, on 23 February 2006 that a search of this database was underway

- ABR6105 RAN Submarine Safety Manual SUBSAFEMAN-6

- ABR 5806 Air Purification in RAN Oberon Class Submarines (Mar 93)

- Sarah Chapman (Psychologist) - report from time on Collins Class submarine

  * existence of report confirmed at focus groups; title of report unknown

Documents not available at time of writing:

- Occupational exposure limits for hyperbaric conditions: Hazard assessment document. Environmental Hygiene Guidance Note EH75/2
  HSE Books 2000 ISBN 0 7176 1899 4

- Thomas A.A., (1968), US Air Force Aerospace Medical Research Laboratories Report No. AMRL-TR-67-146., Defence Documentation Centre, Virginia, USA. cited by D.M. Davies (1975).

* very important toxicological experimental study of using exposures at workplace standard concentrations as basis of submarine exposures; requested from DoD library; not yet received

- 88/79858/XX-02 (Unclassified) *Submarines – Occupational and Environmental Health File*

* archived from RAN Environmental Medicine Unit with no record available; have approached Gordon Russell Defence Archives; Jenny oldfield Naval Records Queanbeyan; Aus Doc with no success

Data/documents that would be useful if identified:

- Inventory of materials/chemicals on board the Oberon submarines
- Manifests and original design specifications for the Oberon submarines

* so that the extent/type of asbestos can be understood, and the nature of materials on board confirmed

References

Literature Review

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