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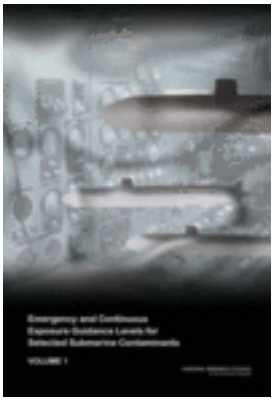

Emergency and Continuous Exposure Guidance Levels for Selected Submarine Contaminants

Subcommittee on Emergency and Continuous Exposure Guidance Levels for Selected Submarine Contaminants, Committee on Toxicology, National Research Council

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U.S. Navy personnel who work on submarines are in an enclosed and isolated environment for days or weeks at a time when at sea. Unlike a typical work environment, they are potentially exposed to air contaminants 24 hours a day. To protect workers from potential adverse health effects due to those conditions, the U.S. Navy has established exposure guidance levels for a number of contaminants. The Navy asked a subcommittee of the National Research Council (NRC) to review, and develop when necessary, exposure guidance levels for 10 contaminants. Overall, the subcommittee found the values proposed by the Navy to be suitable for protecting human health. For a few chemicals, the committee proposed levels that were lower than those proposed by the Navy. In conducting its evaluation, the subcommittee found that there is little exposure data available on the submarine environment and echoed a previous recommendation from an earlier NRC report to conduct monitoring that would provide a complete analysis of submarine air and data on exposure of personnel to contaminants.

Summary

Submariners live in an enclosed and isolated environment when at sea on a submerged submarine. Unlike workers who have respites from occupational exposures at the end of their shifts or workweeks, submariners are potentially exposed to air contaminants 24 hours (h) a day while the submarine is submerged. To protect submariners from potential adverse health effects associated with air contaminants, the U.S. Navy has established 1-h and 24-h emergency exposure guidance levels (EEGLs) and 90-day continuous exposure guidance levels (CEGLs) for a number of those contaminants.

EEGLs are defined as ceiling concentrations (concentrations not to be exceeded) of chemical substances in submarine air that will not cause irreversible harm to crew health or prevent the performance of essential tasks, such as closing a hatch or using a fire extinguisher, during rare emergency situations lasting 1-24 h. Exposures at the EEGLs may induce reversible effects, such as ocular or upper respiratory tract irritation, and are therefore acceptable only in emergencies, when some discomfort must be endured. After 24 h of exposure, the CEGLs would apply. CEGLs are ceiling concentrations designed to prevent immediate or delayed adverse health effects or degradation in crew performance that might result from continuous exposures to chemical substances lasting up to 90 days.

In December 1995, the Navy began reviewing and updating the submarine exposure guidance levels. Because the National Research Council (NRC) Committee on Toxicology (COT) has previously reviewed and provided recommendations for those and other types of exposure guidance levels, the Navy requested that COT review, or develop when necessary, EEGLs and CEGLs for a variety of substances. As a result of the Navy's request, the NRC convened the Subcommittee on Emergency and Continu-

ous Exposure Guidance Levels for Selected Submarine Contaminants in 2002.

STATEMENT OF TASK

Members of the COT subcommittee were selected for their expertise in inhalation toxicology, neurotoxicology, immunotoxicology, reproductive and developmental toxicology, veterinary pathology, pharmacokinetics, epidemiology, and human-health risk assessment. The subcommittee was specifically asked to accomplish the following tasks:

- Evaluate the Navy's current and proposed 1-h and 24-h EEGLs and 90-day CEGLs for the following substances: 2190 oil mist, formaldehyde, acrolein, ozone, monoethanolamine, nitric oxide, nitrogen dioxide, oxygen, carbon dioxide, carbon monoxide, methanol, ammonia, benzene, hydrazine, Freon 12, Freon 114, hydrogen, toluene, and xylene.
- Determine whether the current or proposed guidance levels are consistent with the scientific data and whether any changes to the Navy's exposure levels should be made on the basis of the subcommittee's evaluation.
- For two submarine contaminants for which no guidance levels exist—surface lead and 2,6-di-*t*-butyl-4-nitrophenol—determine whether sufficient data are available to develop EEGLs and CEGLs, and if sufficient data are available, provide recommendations for guidance levels consistent with the data.
- Identify deficiencies in the database relevant to EEGL and CEGL development for the selected chemical substances, and make recommendations for future research, when appropriate.

To accomplish its review, the subcommittee was asked to use the Navy's supporting documentation and other relevant toxicologic and epidemiologic data and publish the results of its evaluations in two separate reports. This is the subcommittee's first report. It contains the EEGL and CEGL recommendations for the following chemicals of concern to the Navy: acrolein, carbon dioxide, carbon monoxide, formaldehyde, hydrazine, methanol, monoethanolamine, nitric oxide, nitrogen dioxide, and oxygen. The remaining chemicals will be addressed in the second report.

APPROACH TO STUDY

In conducting its evaluations, the subcommittee reviewed relevant human and animal data and used data selection criteria described in the NRC report *Standing Operating Procedures for Developing Acute Exposure Guideline Levels for Hazardous Chemicals*.[1] Where possible, primary references were used to derive the exposure guidance levels. Secondary references were used to support the estimates derived and the selection of critical end points. Whenever possible, studies that followed accepted standard scientific methods were selected as key studies (those used to derive the exposure guidance levels). Inhalation exposure studies were used to derive the EEGL and CEGL values. Data on other routes of exposure were considered where appropriate. Human studies were preferred over animal studies. When epidemiologic and human experimental studies were available, a preference typically was given to human experimental studies as these were conducted in a controlled laboratory setting and allowed measurement of personal exposure and end points relevant for derivation of the exposure guidance levels. When appropriate human data were not available, standard laboratory animal studies were used, with preference given to nonhuman primate studies. A weight-of-evidence approach was used to select key studies, thus ensuring that selected data were consistent with the overall scientific database and incorporated what is known about the biologic effects of a chemical on pertinent organ systems.

For derivation of the EEGL and CEGL values, the subcommittee followed basic guidance provided by the NRC report *Criteria and Methods for Preparing Emergency Exposure Guidance Level (EEGL), Short-term Public Emergency Guidance Level (SPEGL), and Continuous Exposure Guidance Level (CEGL) Documents*,[2] but also considered the guidance for

[1]NRC (National Research Council). 2001. Standing Operating Procedures for Developing Acute Exposure Guideline Levels for Hazardous Chemicals. Washington, DC: National Academy Press.

[2]NRC (National Research Council). 1986. Criteria and Methods for Preparing Emergency Exposure Guidance Level (EEGL), Short-term Public Emergency Guidance Level (SPEGL), and Continuous Exposure Guidance Level (CEGL) Documents. Washington, DC: National Academy Press.

developing similar exposure levels provided in more recent NRC reports.[3],[4] The basis for the EEGLs was acute or short-term inhalation and ocular toxicity data, whereas the basis for the CEGLs was repeated inhalation exposure data, and the effects of cumulative exposures were considered. The most sensitive end points were emphasized for derivation of both exposure levels. Also, the subcommittee considered only those health end points relevant to healthy young adult men on the assumption that there are no women serving as permanent crew aboard submarines.

When the key studies, health end points, and exposure levels were identified, the application of uncertainty factors was considered when extrapolating from animals to humans and when extrapolating from lowest-observed-adverse-effect levels to no-observed-adverse-effect levels. When necessary, other factors were applied to account for critical data gaps or for potentially relevant variations in susceptibilities.

CONCLUSIONS AND RECOMMENDATIONS

The subcommittee found substantial differences in the adequacy of the data sets used to derive the EEGLs and CEGLs. For example, formaldehyde has a robust data set that includes both occupational and controlled human studies, whereas monoethanolamine has a paucity of data available for determining effects following inhalation exposure. In fact, there are no human inhalation data for monoethanolamine, and the animal data available are considered incomplete because little information is provided about histologic, hematologic, and enzymatic changes that might occur following repeated or long-term exposure. Few chemicals have substantial data on long-term, low-level exposures. Specific recommendations for research needed to improve the confidence of the derived exposure levels are provided in the individual chemical profiles.

In this report, the subcommittee makes recommendations for 1-h and 24-h EEGLs and 90-day CEGLs for the following chemicals: acrolein, carbon dioxide, carbon monoxide, formaldehyde, hydrazine, methanol,

[3]NRC (National Research Council). 1992. Guidelines for Developing Spacecraft Maximum Allowable Concentrations for Space Station Contaminants. Washington, DC: National Academy Press.

[4]NRC (National Research Council). 2001. Standing Operating Procedures for Developing Acute Exposure Guideline Levels for Hazardous Chemicals. Washington, DC: National Academy Press.

monoethanolamine, nitric oxide, nitrogen dioxide, and oxygen. Those recommendations are listed in Table S-1, and the Navy's current and proposed values have been included in the table for comparative purposes. The bases for the subcommittee's derivations are provided in the individual chemical profiles. Overall, the subcommittee considers the values proposed by the Navy for acrolein, carbon monoxide, formaldehyde, methanol, and nitrogen dioxide to be protective of submariners' health. For carbon dioxide, hydrazine, and monoethanolamine, the subcommittee recommended 1-h EEGL values lower than those proposed by the Navy. The subcommittee considers the other guidance levels for those chemicals to be protective of submariners' health. In the case of oxygen, the subcommittee recommended a higher minimal level for the 90-day CEGL than the one proposed by the Navy; the other minimal levels recommended by the subcommittee are lower than those the Navy has proposed. The subcommittee derived guidance levels for both nitric oxide and nitrogen dioxide, whereas the Navy proposed values for only nitrogen dioxide, assuming that those guidance levels would also be protective in the event of nitric oxide exposure. The subcommittee emphasizes that nitrogen dioxide must be monitored along with nitric oxide, because nitric oxide can combine with oxygen to form nitrogen dioxide, which is more toxic than nitric oxide.

RESEARCH RECOMMENDATIONS

The submarine atmosphere does not appear to be well characterized. In conducting its evaluation, the subcommittee found that few exposure data are available on the Navy's chemicals of concern or other chemicals. This subcommittee agrees with a previous NRC report, *Submarine Air Quality*[5] and recommends again that "the Navy thoroughly survey various classes of submarines for trace contaminants and particulate matter" and that "monitoring on submarines provide complete analysis of submarine air and data on exposure of personnel to contaminants." Furthermore, if the exposure assessments indicate that certain chemicals pose problems (that is, concentrations are higher than 90-day CEGLs), relative source contribu-

[5]NRC (National Research Council). 1988. Submarine Air Quality: Monitoring the Air in Submarines. Washington, DC: National Academy Press.

TABLE S-1 Comparison of Navy's Exposure Guidelines with Those Recommended by the Subcommittee

Chemical	Exposure Level	U.S. Navy Values[a]		NRC Recommended Value[a]
		Current	Proposed	
Acrolein	1-h EEGL	0.05	0.07	0.1
	24-h EEGL	0.01	0.03	0.1
	90-day CEGL	0.01	0.01	0.02
Carbon dioxide	1-h EEGL	40,000	30,000	25,000
	24-h EEGL	40,000	15,000	25,000
	90-day CEGL	5,000	7,000	8,000
Carbon monoxide	1-h EEGL	400	55	180
	24-h EEGL	50	20	45
	90-day CEGL	20	10	9
Formaldehyde	1-h EEGL	3	0.4	2
	24-h EEGL	1	0.1	1
	90-day CEGL	0.5	0.04	0.3
Hydrazine	1-h EEGL	—	4	1
	24-h EEGL	—	0.3	1
	90-day CEGL	—	0.01	0.03
Methanol	1-h EEGL	200	200	600
	24-h EEGL	10	10	50
	90-day CEGL	10	7	10
Monoethanolamine	1-h EEGL	50	6	4
	24-h EEGL	3	3	4
	90-day CEGL	0.5	0.5	0.5
Nitric oxide[b]	1-h EEGL	—	—	130
	24-h EEGL	—	—	50
	90-day CEGL	—	—	3
Nitrogen dioxide	1-h EEGL	1	3	10
	24-h EEGL	1	1	2
	90-day CEGL	0.5	0.5	0.7
Oxygen (min.-max.)	1-h EEGL	130-220 mmHg	—	105 mmHg (min.)
	24-h EEGL	130-160 mmHg	—	127 mmHg (min.)
	90-day CEGL	130-160 mmHg	—	140 mmHg (min.)

[a]All values in parts per million (ppm) unless otherwise noted.
[b]Navy considers the guidance levels for nitrogen dioxide to be also protective of nitric oxide exposure.
Abbreviations: max., maximum; min., minimum; mmHg, millimeters of mercury.

tions should be determined for those chemicals. The subcommittee notes that a few onboard sources, such as cigarette smoking and certain cooking methods, contribute to the formation of multiple compounds considered in this report. Therefore, stricter management or elimination of those sources is likely to solve some exposure problems on board submarines.

The subcommittee did not address exposures to chemical mixtures. When empirical data that characterize mixtures found in submarine air become available, the subcommittee recommends that they be evaluated. The potential for antagonistic, additive, or synergistic interactions between contaminants in the submarine environment is an area of significant uncertainty that remains largely unexamined and needs to be studied.

Several of the chemicals that the subcommittee evaluated for this report are sensory irritants. The derivation of quantitative environmental and occupational exposure limits for sensory irritants is fraught with difficulty because measures of the ocular and respiratory tract irritation experienced by human subjects are often considered subjective. The results of controlled human exposures to many sensory irritants typically use descriptors, such as "mild" or "mild to moderate," and the database for sensory irritation thresholds can be highly variable. Research is needed to quantify the diverse methods and end points used in sensory irritation studies, so that these data can be used in public- and occupational-health risk assessment with greater confidence.

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VOLUME 1

Subcommittee on Emergency and Continuous
Exposure Guidance Levels for
Selected Submarine Contaminants

Committee on Toxicology

Board on Environmental Studies and Toxicology

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Preface

The submarine is an enclosed and isolated environment when submerged. The crew works, eats, and sleeps in this environment and is exposed to air contaminants 24 hours per day, unlike the typical occupational environment where workers have a respite from workplace exposures at the end of the workday or workweek. To protect the health of the submariners, the U.S. Navy has developed 1-hour and 24-hour emergency exposure guidance levels (EEGLs) and 90-day continuous exposure guidance levels (CEGLs) for a number of chemical contaminants.

In 1995, the Navy began reviewing and updating submarine exposure guidance levels and subsequently asked the Committee on Toxicology (COT) of the National Research Council (NRC) to conduct an independent review of several chemicals. As a result of the Navy's request, the NRC formed the Subcommittee on Emergency and Continuous Exposure Guidance Levels for Selected Submarine Contaminants. This report is the first of two reports and provides the subcommittee's rationale and recommendations for the following substances: acrolein, carbon dioxide, carbon monoxide, formaldehyde, hydrazine, methanol, monoethanolamine, nitric oxide, nitrogen dioxide, and oxygen.

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge.

The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the

following people for their review of this report: Janice Chambers, Mississippi State University; Rory Conolly, CIIT Centers for Health Research; Dan Costa, Environmental Protection Agency; Darol Dodd, ManTech Environmental Technology, Inc.; Mark Frampton, University of Rochester School of Medicine; Judith Graham, American Chemistry Council; Alan Hall, Toxicology Consulting and Medical Translating Services; and Barry L. Johnson, Emory University Rollins School of Public Health.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Joseph Borzelleca, Virginia Commonwealth University. Appointed by the Research Council, he was responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of the report rests entirely with the subcommittee and the institution.

The subcommittee thanks Commander Warren Jederberg for his support of this project and his assistance in obtaining necessary background materials. The subcommittee also gratefully acknowledges the following people for making presentations: Mr. Rich Hagar (Naval Sea Systems Command), Captain Victoria Cassano (Bureau of Medicine and Surgery), Mr. James Crawl (Naval Environmental Health Center), Dr. Sal DiNardi (Naval Submarine Medical Research Lab), and Dr. Robert Young (Oak Ridge National Laboratory).

In addition, the subcommittee also had the opportunity to visit a nuclear attack submarine, the USS Hartford, in dock at the U.S. Naval Submarine Base New London in Groton, CT. The crew were extremely helpful in providing information about conditions on the submarine. The subcommittee greatly appreciated the tour and found the information useful in its deliberations.

The subcommittee is grateful for the assistance of the NRC staff in preparing this report: Ellen Mantus, project director; James Reisa, director of the Board on Environmental Studies and Toxicology; Kulbir Bakshi, senior program officer for toxicology; Mary Fox, program officer; Jennifer Saunders and Mirsada Karalic-Loncarevic, research associates; Ruth E. Crossgrove, senior editor; Kelly Clark, assistant editor;

Laura Waters and Robert Policelli, project assistants; and Sam Bardley, library assistant.

Finally, I thank the members of the subcommittee for their dedicated efforts throughout the development of this report.

Ernest McConnell, *Chair*
Subcommittee on Emergency and
Continuous Exposure Guidance Levels
for Selected Submarine Contaminants

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