# Minimizing Exposure to Passive Smoke in the Enclosed Environment of U.S. Submarines

Robert P. Jackman, Perry N. Willette, Debra White, and Susan M. Krizek

**Jackman RP, Willette PN, White D, Krizek SM.** ***Minimizing exposure to passive smoke in the enclosed environment of U.S. submarines.*** **Aviat Space Environ Med 2004; 75:60–4.**

***Objective:*** This study was designed to determine which designated smoking area on a submarine, forward or aft, minimizes nonsmokers' exposure to environmental tobacco smoke. ***Methods:*** A survey was administered and urine tested by an enzyme-linked immunoassay for urinary cotinine before and during a 10 d underway. There were four groups tested; submariners on boats with forward or aft designated smoking areas, with each of these groups further divided into submariners whose watch is primarily forward or aft. ***Results:*** There were no significant differences in urine cotinine levels between submariners whose watches are primarily in the forward section as compared with those who work primarily aft. This was true for predeployment as compared with deployment levels and whether the designated smoking area was located forward or aft. ***Conclusion:*** Using cotinine as a marker, passive smoke exposure appears to be minimum. The location of the designated smoking area aboard U. S. Navy submarines does not appear to have any effect on urinary cotinine levels.

**Keywords:** environmental tobacco smoke, submarine medicine.

PASSIVE SMOKING, the inhalation of particulates from cigarette smoke by nonsmokers, may result in both acute and long-term health problems (2,3,6,9,14–18). In an effort to provide a healthy working environment, in 1994 the Pentagon issued a ban on smoking within all Department of Defense buildings and workplaces (5). During underway operations, submariners are unable to go outside for smoking breaks, so submarines have been excluded from following the smoking ban (1,5). Therefore, nonsmoking members of the submarine community may be exposed to the harmful effects of second-hand smoke.

Cotinine, the major metabolite of nicotine, is found in blood, urine, semen, and saliva (7,8,13,19). Cotinine is considered a more sensitive marker of tobacco exposure than the parent alkaloid since it has a longer plasma half-life (15–30 h) and reaches higher concentrations in saliva, plasma, and urine (7,8,13,19). In addition, since cotinine is produced solely through the metabolism of exogenous nicotine, it is considered a more accurate marker for long-term exposure to tobacco smoke than nicotine levels, which can be ingested in certain foods and found as a contaminant (i.e., lab technicians who smoke).

Davis et al. (4) estimated a range of potential values for urinary cotinine concentrations (0.6–6.2 ng $\cdot$ ml$^{-1}$) based on average and maximal consumption of certain foods including potatoes, tomatoes, cauliflower, black teas, and other plants in the family Solanaceae. These values are an order of magnitude below the level found in passive smokers (70 ng $\cdot$ ml$^{-1}$ or more in urine), suggesting that urinary cotinine levels are not significantly affected by ingestion of these foodstuffs. Urinary cotinine concentrations are a well-established, convenient method to quantify the intake of nicotine by both active and passive smoke exposure (7).

In an effort to maintain a healthy environment on board submarines and decrease the effects of passive smoking, many submarine commanding officers have designated specific smoking areas. No data are available to indicate which smoking areas produce the least exposure of nonsmokers to environmental tobacco smoke. This study is designed to compare passive tobacco smoke exposure among nonsmoking submariners from two Los Angeles Class fast attack submarines with different smoking areas. This information may assist submarine commanding officers in determining which smoking area minimizes the health risks to their sailors. The data may also provide information on passive smoke exposure in other environments isolated from fresh air ventilation.

## METHODS

### *Subjects*

The study group was composed of four groups of nonsmokers and two groups of smokers: 1) nonsmoking aft workers on a submarine with a forward smoking area; 2) nonsmoking forward workers on a submarine with a forward smoking area; 3) nonsmoking aft workers on a submarine with an aft smoking area; 4) nonsmoking forward workers on a submarine with an aft smoking area; 5) smokers on a submarine with a for-

From the Naval Submarine Medical Research Laboratory, Naval Submarine Base New London, Groton, CT.

This manuscript was received for review in May 2003. It was revised in June 2003. It was accepted for publication in July 2003.

Address reprint requests to: Robert Jackman, Cascades East Family Practice Residency, 2801 Daggett Avenue, Klamath Falls, OR 97601; rjackman8@aol.com.

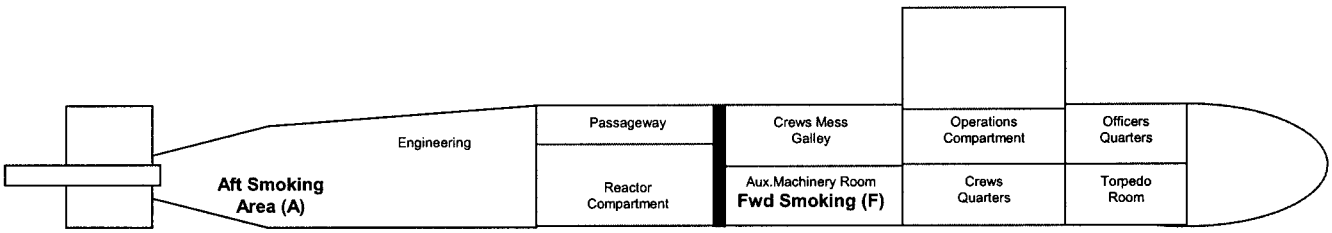


**Fig. 1.** General layout of a Los Angeles Class fast attack submarine.

ward smoking area; and 6) smokers on a submarine with an aft smoking area. The characteristics of the study subjects are as follows: 11.3% were officers, 88.7% enlisted personnel, 7.8% African-Americans, 82% Caucasian, and 9.6% other; 32% of the total study subjects were smokers.

Power analysis using $\alpha$ of 0.05 and $\beta$ of 0.80 indicated a sample size of 17 to detect a difference of 19 ng · ml$^{-1}$ in urinary cotinine levels (urine cotinine levels between 19 ng · ml$^{-1}$ and 70 ng · ml$^{-1}$ are consistent with significant second-hand smoke exposure) (7,8,11,13,19). Therefore, 18 male volunteer submariners from the U. S. Navy were sought for each of the 4 nonsmoking subgroups in order to provide statistical power for the study. Smoking submariners were included in the study to compare the urinary cotinine levels of smokers vs. nonsmokers. The final study population consisted of 115 submariners from two Los Angeles Class fast attack submarines assigned to Submarine Squadron ONE in Pearl Harbor, HI. The only exclusion criteria used was that nonsmoking submariners could not use any form of nicotine product during the study period.

For the submarine with a forward smoking area, there were 18 nonsmoking aft workers, 19 nonsmoking forward workers, and 20 smokers enrolled. The submarine with the aft smoking area had 21 nonsmoking aft workers, 20 nonsmoking forward workers, and 17 smokers who volunteered to participate in the study.

*Procedures*

There were two Los Angeles Class fast attack submarines scheduled for routine deployments, each with a crew complement of approximately 120 submariners, that were used in the study. A minimum continuous underway time of 10 d was required in order for steady-state cotinine levels to be achieved (approximately 8–16 half-lives). A survey of each submarine's crew was administered prior to the underway to obtain demographic information, smoking history, and nicotine exposure.

The first Los Angeles Class fast attack submarine restricted smoking to the main lube oil bay, aft of the reactor compartment (location A in **Fig. 1**). The second Los Angeles Class fast attack submarine only allowed smoking in the auxiliary machinery room on the starboard side forward of the reactor compartment, below crews mess (location F in Fig. 1). In neither submarine did the commanding officer limit the number of smokers in the smoking area at any time.

To estimate the total number of cigarettes smoked aboard the submarine during the underway period, smokers were assigned a study number and asked to anonymously log on a chart the number of cigarettes they smoked. This was confirmed by requiring all smokers to dispose of cigarette butts into a collection container. The total number of cigarette butts was compared with the total number logged to verify the accuracy of the information.

Urine samples were collected from subjects twice: one sample predeployment and one sample underway. Predeployment collections were obtained no more than 2 d prior to deployment. Deployment collections took place aboard the submarine after 10 d underway and prior to docking. Samples were stored at −20°C prior to shipping for analysis at the Neurochemistry Laboratory located at the Dartmouth-Hitchcock Medical Center, Lebanon, NH. Cotinine analysis was performed by enzyme-linked immunoassay. Urine cotinine levels greater than 70 ng · ml$^{-1}$ in nonsmokers (those who do not smoke in any form, chew nicotine gum or tobacco) are considered significant for classifying nonsmokers as passive smokers (7,8,13,19). Levels between 19 ng · ml$^{-1}$ and 70 ng · ml$^{-1}$ are indicative of exposure to significant amounts of passive smoke (7,8,13,19).

*Statistical Analysis*

For parametric data (cotinine data), analysis of variance and *t*-test for independent samples were used to determine intergroup statistical significance; *t*-test for dependent samples was used to determine intragroup statistical significance. For nonparametric data (demographic data), Chi-square or, if appropriate, Fisher's exact test was utilized. Tests are two-tailed, and all $p < 0.05$ are considered significant. An Excel (Microsoft, Redmond, WA) spreadsheet was used for statistical analysis.

All procedures were approved and performed in accordance with the ethical standards set forth by the Internal Review Board committee at the Naval Submarine Medical Research Laboratory and at the Naval Health Research Center. Informed written consent was obtained from each subject prior to enrollment into the study.

## RESULTS

There were no statistically significant differences in urine cotinine levels between nonsmoking submariners assigned to submarines with a forward smoking area vs. an aft smoking area. This was true for predeploy-

TABLE I. EFFECT OF SMOKING AREA AND AREA OF WORK ON URINE COTININE LEVELS AT THE END OF A 10-DAY DEPLOYMENT ON A FAST ATTACK SUBMARINE.

| Group | Pre-deployment Cotinine (SD) | N | Deployment Cotinine (SD) | N | |
|---|---|---|---|---|---|
| Forward smoking area | | | | | |
| Aft non-smoking workers | 3.1 ng · ml$^{-1}$ (4.0) | 18 | 4.5 ng · ml$^{-1}$ (5.9) | 18 | p = 0.15 |
| Forward non-smoking workers | 2.8 ng · ml$^{-1}$ (6.6) | 19 | 4.6 ng · ml$^{-1}$ (4.2) | 19 | p = 0.32 |
| Smokers | 3868.3 ng · ml$^{-1}$ (1877.1) | 20 | 3663.7 ng · ml$^{-1}$ (1913.4) (4627 cigarettes smoked) | 20 | p = 0.46 |
| Aft smoking area | | | | | |
| Aft non-smoking workers | 1.5 ng · ml$^{-1}$ (1.3) | 21 | 2.5 ng · ml$^{-1}$ (4.6) | 21 | p = 0.30 |
| Forward non-smoking workers | 0.9 ng · ml$^{-1}$ (0.10) | 20 | 0.9 ng · ml$^{-1}$ (0.0) | 20 | p = 0.32 |
| Smokers | 2357.9 ng · ml$^{-1}$ (1835.6) | 17 | 1948.3 ng · ml$^{-1}$ (1283.8) (2288 cigarettes smoked) | 17 | p = 0.41 |

Mean and standard deviation with comparison by t-test for dependant samples/ANOVA with repeated measures.

ment as compared with deployment levels (**Table I**) and whether the nonsmokers stood watch primarily forward or aft (**Table II**). All nonsmoking subjects maintained urine cotinine levels well below the values indicative of significant passive smoke exposure (19 ng · ml$^{-1}$) (7,8,13,19).

Smokers had urinary cotinine levels approximately a thousand times greater than nonsmokers (Table I). During the 10-d underway periods, smokers on the submarine with a forward smoking area smoked a total of 4,627 cigarettes and smokers on the submarine with an aft smoking area smoked 2,288 cigarettes. The smokers' urinary cotinine levels reflect these different exposures and are consistent with exposure to significant amounts of tobacco smoke (greater than 70 ng · ml$^{-1}$) (7,8,13,19).

Analysis of the survey data demonstrated significant differences in several categories: a greater percentage of smokers were enlisted personnel [97.3% (n = 36) vs. 2.7% (n = 1) for officers; p = 0.03 by Fishers exact test]; more nonsmokers would prefer a completely smoke-free environment than smokers [68% (n = 53) vs. 0% (n = 0) for smokers; p < 0.001 by Fishers exact test]; a greater number of smokers live with other smokers [37.8% (n = 14) vs. 19.2% (n = 15) for nonsmokers; p < 0.05 by Fishers exact test]; and more smokers chew nicotine than nonsmokers [24.3% (n = 9) vs. 0% (n = 0) for nonsmokers; p < 0.001 by Fishers exact test]. In addition, smokers reported smoking fewer cigarettes per day while at sea than in port [81.1% (n = 30) vs. 13.5% (n = 7)].

## DISCUSSION

This study did not demonstrate any statistically significant differences in urinary cotinine levels at the end of a 10-d underway in nonsmoking submariners working in the forward or aft sections of a submarine, whether the smoking area was located forward or aft of the reactor compartment. These findings reflect a 10-d routine deployment that included multiple ventilation modes for a Los Angeles Class fast attack submarine.

Sailors assigned to these submarines breathe recirculated air the majority of their underway time. For Los Angeles Class submarines, the volume of recirculated air is approximately 103,330 ft$^3$, with 49.1% forward of the reactor compartment and 50.9% aft of the reactor compartment. All living, berthing, training, and dining areas are located forward of the reactor compartment where the majority of off-watch crew activity occurs (Fig. 1). During submerged operations, the submarine's ventilation system is primarily kept in the recirculation mode, completely isolated from the outside environment. Atmospheric particulates are removed by electrostatic precipitators as well as mesh filters and activated charcoal filters (10).

During this study, each submarine performed all of its normal activities, including operations at periscope depth involving emergency ventilation, surface ventilation, and snorkeling. During these alternate ventilation modes (other than recirculation), the ship's atmosphere is no longer completely isolated from the outside environment. **Table III** lists the air exchange rates for each

TABLE II. COMPARISON OF URINE COTININE LEVELS BETWEEN FORWARD AND AFT NON-SMOKERS AT THE END OF A 10-DAY DEPLOYMENT ON A FAST ATTACK SUBMARINE.

| Group | Aft workers | N | Forward workers | N | |
|---|---|---|---|---|---|
| Forward smoking area | | | | | |
| Pre-deployment Cotinine (SD) | 3.1 ng · ml$^{-1}$ (4.0) | 18 | 2.8 ng · ml$^{-1}$ (6.6) | 19 | p = 0.87 |
| Deployment Cotinine (SD) | 4.5 ng · ml$^{-1}$ (5.9) | 18 | 4.6 ng · ml$^{-1}$ (4.2) (4627 cigarettes smoked) | 19 | p = 0.93 |
| Aft smoking area | | | | | |
| Pre-deployment Cotinine (SD) | 1.5 ng · ml$^{-1}$ (1.3) | 21 | 0.9 ng · ml$^{-1}$ (0.10) | 20 | p = 0.06 |
| Deployment Cotinine (SD) | 2.5 ng · ml$^{-1}$ (4.6) | 21 | 0.9 ng · ml$^{-1}$ (0.0) (2288 cigarettes smoked) | 20 | p = 0.13 |

Mean and standard deviation with comparison by t-test for independent samples/ANOVA.

TABLE III. VENTILATION RATES FOR LOS ANGELES CLASS SUBMARINE AND TIMES SPENT AT DIFFERENT VENTILATION MODES.

| Ventilation Mode | Ventilation Rate | Aft Smoking | Forward Smoking |
|---|---|---|---|
| Emergency Ventilate with the Blower | 2200 $ft^3 \cdot min^{-1}$ | 2 h 37 min (1.09%) | 1 h 15 min (0.53%) |
| Snorkeling | 5255 $ft^3 \cdot min^{-1}$ | 4 h 27 min (1.85%) | 4 h 52 min (2.03%) |
| Surface Ventilate | 3385 $ft^3 \cdot min^{-1}$ | 0 h 22 min (0.15%) | 0 h 0 min (0.00%) |
| Ventilate | 2200 $ft^3 \cdot min^{-1}$ | 3 h 47 min (1.58%) | 4 h 54 min (2.04%) |
| Recirculate | (No air exchange) | 228 h 47 min (95.3%) | 228 h 59 min (95.4%) |

of the different ventilation modes and indicates the percentage of time each submarine spent at these alternate ventilation modes. Both submarines spent a minimal amount of time in modes other than recirculation, effectively providing an isolated environment for this study.

The findings of this study suggest that the U. S. Navy's submarine atmosphere-control system is performing its designated task adequately during the time frame of the study. Nonsmokers demonstrated urine cotinine levels well below the values indicative of significant passive smoke exposure. Neither the location of the smoking area nor the nonsmoker's work proximity to the smoking area affected passive smoke exposure.

There has been one other study examining passive smoke exposure in U. S. Navy submariners. Seufert and Kiser (12) studied end-expiratory carbon monoxide levels as an estimate of passive smoke exposure. Their results demonstrated an increased carbon monoxide level in nonsmokers after 62 h of restricted ventilation (recirculation mode only). The limitations of carbon monoxide as a marker are that it is not a direct measure of environmental tobacco smoke and may be generated by cooking, electrical machinery, and diesel generator operations.

The present study has some potential limitations. We examined a short-duration submarine ride. While a 10-d underway is routine for fast attack submarines, deployments of up to 90 d occur, so the duration of this study may have been inadequate to demonstrate significant environmental tobacco exposure. Measuring urinary cotinine levels after 8–16 half-lives allowed sufficient exposure to achieve steady-state levels, therefore, minimizing this possible limitation (7,8,13,19).

Additionally, the amount of fresh air ventilation a submarine uses is variable and is determined by the mission. It is possible that a submarine might submerge for extended periods with no circulation of fresh air from outside the submarine environment. Different results might be found if alternate ventilation modes (other than recirculation) were eliminated.

While performing this study, certain anecdotal facts became evident. Although the environmental control systems were effective in reducing exposure of the crew to second-hand smoke, there was a discernable difference in ambient tobacco odors in the two different submarines. The forward smoking area is located immediately below the crew's mess (Fig. 1). This area is extensively used for dining, training, recreation, and lounging. The aroma of cigarette smoke permeated this space when sailors used the forward smoking area. The aft smoking area is located in a relatively isolated region of the submarine. Only those standing watch routinely occupy this space to perform their duties. A minimal amount of exercise equipment is kept near the aft smoking area and sailors who wish to use this equipment have to accept the aroma of tobacco during workouts. Most of these sailors stated they would prefer a completely smoke-free environment, but, if necessary, would rather tolerate the aroma while exercising rather than during meals, recreation, or training in the crew's mess.

The findings from this study are specific for an enclosed environment with an atmosphere control program using extensive environmental purification systems. It may not be applicable to other restricted environments such as airplanes, trains, or restaurants that do not use the equipment found aboard U. S. Navy nuclear-powered submarines. The data appears to support the conclusion that the use of carbon monoxide/hydrogen burners, carbon dioxide scrubbers, ionized particulate precipitators, mesh filters, and activated charcoal filters can possibly minimize second-hand smoke exposure and provide a clean atmosphere for both smokers and nonsmokers.

ACKNOWLEDGMENTS

This project was conducted under Naval Medical Research Development Command Research Work Unit 63706N-M0096.002-5205, Medical Conditions Affecting Submarine Qualifications. The opinions and assertions expressed in this report are those of the authors and are not to be construed as official or reflecting the views of the Department of the Navy, the Department of Defense, or the United States Government.

The author would like to extend thanks to all those who aided, critiqued, and otherwise helped in the preparation of this paper. In particular, the author thanks the officers and crew of the USS Greeneville (SSN 772) and the USS Los Angeles (SSN 688). Their volunteer spirit was invaluable in the accurate gathering of data for this study.

REFERENCES

1. ALNAV 131/93. Smoking policy for DON controlled spaces. Washington, DC: Department of the Navy; 1993:R212138Z OCT 93.
2. Aronow WS. Effect of passive smoking on angina pectoris. N Engl J Med 1978; 299:21–4.
3. Chesebro M. Passive smoking. Am Fam Physician 1988; 37:212– 8.
4. Davis RA, Stiles MF, DeBethizy JD, Reynolds JH. Dietary nicotine: a source of urinary cotinine. Fd Chem Toxic 1991; 29:821–7.
5. DOD INST 0101.15. Smoke free workplace; Washington, DC: Department of Defense; 1994.
6. Gortmaker SL, Walker DK, Jacobs FH, et al. Parental smoking and the risk of childhood asthma. Am J Public Health 1982; 72: 574–9.

7. Langone JJ, Gjika HB, Van Vanukis H. Nicotine and its metabolites: radioimmunoassays for nicotine and cotinine. Biochemistry 1973; 12:5025–30.
8. Matsukura S, Sakamoto N, Seino Y, et al. Cotinine excretion and daily cigarette smoking in habituated smokers. Clin Pharmacol Ther 1979; 25:555–61.
9. Murray AB, Morrison BJ. Passive smoking and the seasonal difference of severity of asthma in children. Chest 1988; 94:701–8.
10. National Research Council. Submarine air quality. Monitoring the air in submarines and health effects in divers of breathing submarine air under hyperbaric conditions. Washington, DC: National Academy Press; 1988:3–14,59–66.
11. Dawson-Saunders B, Trapp RG. Basic and clinical biostatistics. Norwalk, CT: Appleton & Lange; 1990:118–20.
12. Seufert KT, Kiser WR. End-expiratory carbon monoxide levels as an estimate of passive smoking exposure aboard a nuclear-powered submarine. South Med J 1996; 89:1181–3.
13. Spierto FW, Hannon WH, Kendrick JS, et al. Urinary cotinine levels in women enrolled in a smoking cessation study during and after pregnancy. J Smoking-Related Dis 1994; 5:65–76.
14. Tager IB, Weiss ST, Rosner B, Speizer FE. Effect of parental cigarette smoking on the pulmonary function of children. Am J Epidemiol 1979; 110:15–26.
15. The Surgeon General. Report on reducing the health consequences of smoking: 25 years of progress. Washington, DC: U. S. Department of Health and Human Services; 1989.
16. Trichopoulos D, Kalandidi A, Sparros L, MacMahon B. Lung cancer and passive smoking. Int J Cancer 1981; 27:1–4.
17. Weiss ST, Tager IB, Weiss JW, et al. Persistent wheeze. Its relation to respiratory illness, cigarette smoking, and level of pulmonary function in a population sample of children. Am Rev Respir Dis 1980; 122:697–707.
18. White JR, Froeb HF. Small airways dysfunction in nonsmokers chronically exposed to tobacco smoke. N Engl J Med 1980; 302:720–3.
19. Zeidenberg P, Jaffe JH, Kanzler M, et al. Nicotine. Cotinine levels in blood during cessation of smoking. Compr Psychiatry 1977; 18:93–101.