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SAMPLING OF BREATHABLE AIR IN U. S. NAVY SONAR DOMES

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TECHNICAL REVIEW AND APPROVAL

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The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

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13. ABSTRACT (Maximum 200 words)

The Naval Medical Research Institute (NMRI) was tasked in 1990 to conduct air sampling to obtain baseline air composition in U.S. Navy sonar domes. This data would be used to assess potential long-term effects on personnel who routinely conduct dome entries. To date, samples have been obtained from 6 ships that were subsequently analyzed for volatile hydrocarbons and fixed gases (O_2, CO_2, and CO) by gas chromatography coupled with either thermal conductivity, flame ionization, or mass spectrometry. Only 5 hydrocarbon species (methane, butane, toluene, xylenes, and methyl chloroform) were found at levels >1 part per million (ppm) in the 6 domes following a 24-hour period of non-ventilation. The levels of individual chemicals were well below their threshold limit values for hazardous exposure. These contaminants were reduced by up to 90% following 4 hours of ventilation at the flow rate normally used for dome entries. No hydrocarbons >0.1 ppm, other than methane, were found in any ship's low pressure air supply used for dome ventilation. However, the following safety issues are raised by this investigation: 1) there are no current procedures required to confirm and/or insure the purity of air used for ventilation during dome entries despite the potential for contamination from shipboard and off-ship activities; 2) gas-free procedures for insuring safe access to the point of entry into the dome are questionable and/or poorly defined; and 3) the potential for direct or airborne contact by dome personnel with the relatively toxic tributyl tin oxide that coats the inner dome surface of most ships and the need for protective gear during dome entries is unknown. Recommendations are made in view of these concerns.

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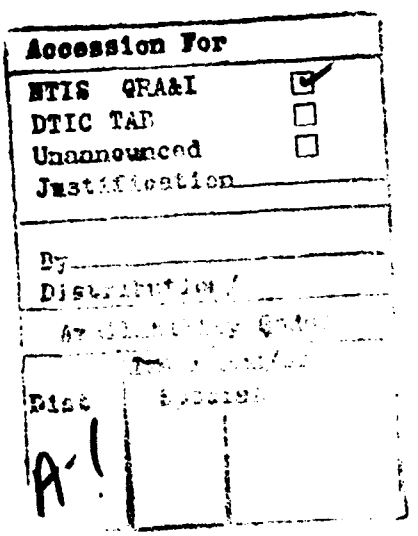

INTRODUCTION

The Naval Medical Research Institute (NMRI) was tasked in 1990 to conduct air sampling to obtain baseline air composition in U.S. Navy sonar domes to assess potential long-term effects on personnel who routinely conduct dome entries (1). NMRI was requested to recommend any procedural changes necessary to satisfy safe breathable air requirements (2). To date, 6 ships have been sampled; analytical results have been reported and discussed previously in official U.S. Navy correspondence (3-6). This report presents a detailed discussion of the investigation and is also being published to facilitate reference and distribution. Conclusions and recommendations made in this report are identical to those made previously to the Naval Sea Systems Command (NAVSEA, references (3-6)). Personnel from the Naval Surface Warfare Center (formerly the Naval Ship Systems Engineering Station (NAVSSES)), Philadelphia, PA coordinated all aspects of ship sampling.

BACKGROUND

Bow-mounted sonar domes are in service on 96 U.S. Navy surface ships including frigates, destroyers, and cruisers. The sonar dome rubber window (SDRW) is a wire-reinforced rubber membrane that forms the pressure-tight boundary between the baseline flat and the banjo forming the complete sonar dome assembly (Fig. 1). This boundary protects the sonar transducer array, reduces acoustic attenuation, and provides hydrodynamic contour to minimize underway water turbulence. The SDRW is normally filled with fresh water and pressurized to 34 pounds per square inch gauge (psig) from the ship's firemain system. A dome entry is performed twice a year to satisfy preventive maintenance requirements and

every 1 to 4 years for an x-ray inspection of the SDRW. In order to enter the dome, a water-to-air interchange is first completed in which the water is pushed out of the dome using air supplied from the ship's low pressure air compressors (LPAC). Then, immediately prior to dome entry, the sonar dome is ventilated for 4 h at 50 scfm (standard cubic foot per minute), which is equivalent to approximately 3.4 times the volume of 3500 ft^3 of the sonar dome. During dome entry, the dome ventilation is continued with the dome pressure maintained at a nominal 14 psig. A minimum of 3 technicians enter the dome via the dome trunk and pressure lock (Fig. 1) for up to 240 min per person maximum during any 12-hour period. Following personnel lock-out, the dome is refilled with fresh water completing the entry procedure.

Since 1971, when the first SDRW was installed on a Navy ship, sonar dome entries have been reportedly performed without any mishap related to air quality. However, at a July 1990 meeting, NAVSEA expressed concern over the safety of breathable air during dome entries and the absence of any requirement to conduct gas-free procedures on the dome atmosphere prior to entry (2). At the meeting, it was decided that the insurance of a safe breathable dome atmosphere, rather than gas-freeing, was the important issue. Unfortunately, almost no information existed regarding the composition of dome atmospheres. The one known air sampling test, conducted in 1985 with 11 ships and cited in reference (7), only provided data on O_2, CO_2, CO, gaseous hydrocarbons, and oil mist particulates in the air supplied to and exhausted from the dome; no breakdown of specific hydrocarbons or analytical details were provided. The limited data from this test was used to define the minimum requirement of 4 h of ventilation immediately prior to dome entry based on a

gaseous total hydrocarbon limit of 25 ppm for Grade D air (8). At the meeting's conclusion, NMRI's help was requested as described above in the Introduction.

A major factor affecting the safety of the atmosphere during dome entries is the quality of the air used for dome ventilation. Reference (9) calls for quarterly testing of any ship's LPAC used to supply breathing air to insure that it meets grade D air standards. The Navy Environmental Health Center had further recommended in 1985 that testing of LPAC air also be done just prior to dome entries (10). However, a potential problem with the LPACs is that intake air is drawn from within ship's spaces as well as from ducts from the upper deck. Consequently, shipboard activities (cleaning, painting, repairing) and spills that can generate volatile chemicals may affect the output air of the LPACs. Similarly, any off-ship influences such as exhaust from neighboring ships or dock-side operations could impact LPAC air quality. Although unessential use of low pressure air is restricted during dome entries, other normal crew activities are permitted. Governing procedures for dome entries simply state that the supervisor should check the input air to the LPAC for freshness before commencing the water-to-air interchange (11,12).

The SDRW contains an organotin compound (tributyl tin oxide (TBTO)) throughout the rubber membrane to impede growth of marine organisms although no TBTO is on the inside surface of SDRWs manufactured since 1989. This inner coating of TBTO can rub-off as powder when dry. Because the inner dome surface is wet during dome entries, airborne TBTO may not be a problem although we are unaware of any measurements of TBTO in dome gas. Reference (13) recommends a threshold limit value-time-weighted average (TLV-TWA) for organotin compounds such as TBTO of 0.1 mg/m^3 measured as tin, to minimize

irritation and prevent effects on the circulatory and central nervous systems. However, except during SDRW repairs, references 11 and 12 gives no requirement for protective gear (e.g., goggles, respirators, gloves, protective clothing) or specific safety precautions related to TBTO for dome entries.

METHODS

Approach

Our initial approach was threefold:

1) Perform ship sampling to determine the nature of any volatile hydrocarbon contaminants that might be a problem during dome entries and to measure O_2, CO_2, and CO.

2) Based on what was found in the dome air, consider the need and possibility of screening the dome air during dome entries.

3) If required, recommend additional procedures to insure chemical safety during dome entries.

Ship Sampling

There are 3 different SDRW pressurization systems currently in use in the U.S. Navy depending on the type of ship: 1) frigates, 2) destroyers and cruisers, and 3) the new Arleigh Burke class of destroyers. Ship selection was designed to provide samples from each of the different pressurization systems and from domes fitted with SDRWs of different ages to see if these factors affected the results. The actual ships sampled were determined by when and where they would be in port and whether their schedules permitted sampling. Despite these

limitations, 6 ships were sampled over a 6-month period from April to September, 1992 although the new Arleigh Burke destroyer was unavailable (see Table 1 for sampling details).

Three different types of samples were drawn from each ship:

1) Dome air after a 24-hour soak at pressure, during which time the dome was not ventilated and no gas added. This pressure soak was begun after the dome had been ventilated for 4 h following the water-to-air interchange.

2) Dome air after 4 h of ventilation from the ship's LPACs. This ventilation had begun immediately after the 24-hour soak samples (item 1) were taken.

3) Ventilating air supplied by the ship's LPACs. These samples were taken approximately 15 to 30 min prior to the 4-hour ventilation samples from the dome (item 2).

All ventilation was done at the standard rate of 50 scfm. The dome pressure was held at 2.1 to 2.8 atmospheres absolute (ATA) during both the 24-hour soak and ventilation phases versus the normal 2.0 ATA to increase the volume of gas collected. Four replicate samples were obtained in each instance using 500-ml stainless-steel cylinders that had been previously heated and evacuated to at least 30 millitorr; these containers have been shown to be suitable for long-term (months) storage of a number of volatile hydrocarbons at ppm levels (14).

All dome air samples were taken from the sonar dome pressurization system piping as close to the domes as possible. On the FF-1052 class ships (i.e., Frigates), samples of dome air were taken via a 1/4-inch pressure isolation valve with a test point connection. The sample point was located in the center of the sonar dome. The 1/4-inch tubing ran approximately 2 ft prior to connecting to a 1/4-inch pipe that penetrated a pressure-tight bulkhead in the center of the dome. On the DD-963, and DDG-993, and CG-47 class ships (i.e., destroyers and

cruisers), samples of dome air were also taken via the pressure isolation valve, but the sample point was located in the upper part of the aft end of the dome. The 1/4-inch tubing on these ships ran approximately 12 ft prior to connecting to a 1/4-inch pipe that penetrated a pressure-tight bulkhead in the top of the dome.

All sample lines were purged 10 to 15 min with dome air at least 5 times the estimated sample line volume. This purge was done to remove the water and deadspace gas from the lines and to equilibrate the sampling lines with the dome gas so that reliable samples could be taken. With air flowing from the sample line, the cylinder was then attached to the sample point and the connection made wrench-tight. The cylinder valve was opened slowly, 1 min was then allowed for pressure equilibration, and the valve closed before disconnecting the cylinder. Replicate cylinders were filled similarly in quick succession. In some cases, additional samples of dome gas were taken at alternative sites farther away from the dome or from different locations within the dome. These extra samples were used to try to determine the potential for the sample lines to affect the sample gas and to evaluate whether the atmosphere within the dome was homogeneous. Samples of ventilating air were taken as close as possible to where the LPAC air entered the domes after sample line purging.

Gas analysis

Hydrocarbon analysis was done by gas chromatography (GC) using Shimadzu GC-9A gas chromatographs (Shimadzu Corp., Columbia, MD). Samples were screened for a broad range of volatile hydrocarbons using GC with flame ionization detection (FID) and 3 different columns. Gas samples (0.5 ml) were introduced into the GC's using gas sample valves. Samples were also analyzed by GC/mass spectrometry (GC\MS; model 5970 Mass Selective

Detector; Hewlett-Packard, Rockville, MD) to identify unknown contaminants, screen for low level species, and confirm identification of all species. Prior to GC/MS, 100 ml of gas was preconcentrated on a solid multi-bed carbon adsorbent (carbotrap 300; Supelco, Inc., Bellefonte, PA). Subsequent thermal desorption (Tekmar Liquid Sample Concentrator LSC-2, Tekmar Co., Cincinnati, OH) introduced the sample into the GC. The following columns were used with the indicated detectors and temperature profiles.

1) Vocol wide-bore capillary column, 30 m x 0.53 mm, 3.0 um film. FID: 50 °C for 3 min, raised at 8 °C/min to 150 °C for 4.5 min. GC/MS: -20 °C for 3.1 min, raised at 20 °C/min to 150 °C for 11.4 min.
2) Supelcowax 10 wide-bore capillary column, 60 m x 0.53 mm, 1.0 um film. FID: 50 °C for 3 min, raised at 8 °C/min to 150 °C for 5 min.
3) 1/8 in x 10 ft stainless-steel packed column with 3% SP-1500 on 80/120 carbopack packing. FID: 40 °C for 1 min, raised at 20 °C/min to 200 °C for 4 min.

GC (Shimadzu GC-14A gas chromatograph) with thermal conductivity detection (TCD) was used to measure O_2 in samples using argon as the carrier gas: 1/8 in x 12 ft stainless-steel packed column with 60/80 mesh molecular sieve 5A packing; 50 °C for 2 min, raised at 20 °C/min to 100 °C for 1.5 min.

GC/FID (Shimadzu GC-9A gas chromatograph) using methanization (Shimadzu methanizer MTN-1) was used to measure CO_2 and CO: 1/8 in x 10 ft stainless-steel packed column with 100/120 mesh carabosieve S-II packing; 50 °C for 4 min, raised at 20 °C/min to 150 °C for 11 min.

Gas samples for fixed gas analysis (0.25 ml for GC/TCD and 5.0 ml for GC/FID with methanization) were also introduced into GC's using gas sample valves. All GC columns used in this study were obtained from Supelco, Inc.

Quantitation of hydrocarbons measured with GC was based on one-point calibration with one of several gravimetric primary gas standards containing mixtures of hydrocarbons certified to ± 2% relative of stated value prepared in hydrocarbon-free gas:

#1) 2 ppm each of Freon 113, methyl chloroform, benzene, toluene, and o-,m-,p-xylenes

#2) 10 ppm each of Freon 113, methyl chloroform, benzene, toluene, and o-,m-,p-xylenes

#3) 10 ppm each of methane, ethane, propane, butane, pentane, and hexane

#4) 10 ppm each of Freons 22, 12, 114, 11, and 113

Precision was better than 5% (i.e., 2 relative standard deviations of the mean response of repeated injections was less than 5%) for GC/FID analysis of the calibration standards and better than 20% for GC/MS. GC/FID responses were linear to within the level of precision over a range from 2 to 10 ppm using standards #1 and #2. Reported hydrocarbon concentrations are based on GC/FID analysis and are estimated to be accurate to ± 10% relative.

Identification of hydrocarbons was based on comparison of retention times of sample and calibration peaks and confirmed by comparison of mass spectra. Unknown compounds that did not match retention times were identified after careful review of library search results using Hewlett-Packard G1034B or G1034C software for the MS ChemStation (DOS series)

with the NIST/EPA/MSDC 54K Mass Spectral Database and in view of the limitations inherent in such searches.

Quantitation of fixed gases measured in samples was based on one-point calibration of GC's with gravimetric primary standards containing levels of O_2 and CO_2 close to what was being measured and 2 to 10 ppm of CO. Mixtures were certified to ± 1% relative or better of stated value for O_2 and CO_2, and ± 2 to ± 5% for CO. Precision was 1% or better for analysis of O_2 and CO_2 standards and 5% or better for CO. Fixed gas quantitation was linear to within the level of precision over the concentration ranges that were measured. Overall accuracy of analysis of O_2 and CO_2 is estimated to be ± 1% relative of reported values.

RESULTS AND DISCUSSION

Air analysis

Only 5 hydrocarbon species (methane, butane, toluene, xylenes, and methyl chloroform) were found at levels >1 ppm in the 6 domes that were sampled following a 24-hour test period of non-ventilation (Table 2). A number of other known and unknown hydrocarbons were also detected at levels <1 ppm; these included ethyl benzene, methyl ethyl benzene, and trichloroethylene. With the exception of methane, which is present in normal air, contaminants were reduced by up to 90% following 4 h of ventilation at the flow rate normally used for dome entries (Table 3). Although only a small number of ships were sampled, contaminant profiles were markedly similar. However, it is unknown whether additional sampling would produce any unexpected findings although sampling of the new Arleigh Burke class of destroyers would be recommended. The few samples taken at alternate

sites (as described above) were similar in composition to that of the primary samples. Thus, there was no observable effect of sampling through a different piping pathway and no observable heterogeneity of the dome atmosphere. No hydrocarbons >0.1 ppm, other than methane, were found in any ship's low-pressure air supply at the time of sampling (Table 4). The somewhat lower O_2 measurements of dome air, compared to 20.9% of standard air, undoubtedly reflect the substantial amounts of water vapor in the air which effectively reduce the relative amounts of the other gases (e.g., O_2 and N_2) in the sample.

Surface equivalent values (SEV) were derived for contaminants in both non-ventilated and ventilated domes by multiplying the values measured in the lab by the dome pressure. These values presumably estimate the effective exposure levels inside the dome. Individual SEV values are well below the TWL-TWAs for an 8-hour workday/40-hour workweek currently specified by the American Conference of Governmental Industrial Hygienists (ACGIH) (13). As normal dome access is limited to 4 h in a 12-hour period, these 8-hour limits should be appropriate in terms of exposure time.

If the air used to ventilate the domes is assumed to be free of hydrocarbons (other than methane) during the course of the sampling exercises, any chemical species in the 24-hour soak samples would have originated from the dome compartment. As toluene, xylenes, and methyl chloroform are common chemicals in paints, glues, adhesives, and many other industrial products, their presence in the samples was not surprising; many sources for these contaminants undoubtedly are in the SDRW compartment. In particular, toluene is used heavily during the manufacture of the SDRW. Approximately 2 ppm methane is normally found in air; the small increase in this gas during the soak probably can be attributed to its

release by living organisms (e.g., algae, bacteria, fungi) in the dome. The only unusual finding was the presence of butane. One hypothesis is that this very volatile chemical is released when TBTO is broken down by organisms left on the dome surface as a normal part of the process of growth inhibition.

The age of the SDRW was thought to be a possible factor affecting offgassing within the dome, especially in the case of toluene. As the SDRW ages, the rubber membrane might be expected to lose toluene and, consequently, less toluene might be found in the dome atmosphere. The situation for butane cannot be predicted as its source is unknown. Figs. 2 and 3 presents SEV values for butane and toluene vs. age of the SDRW at time of sampling; plotted values are from the 24-hour soak samples. Both butane and toluene were poorly correlated with age of the SDRW as evident by observation and respective r^2 values of 0.20 and 0.16 associated with linear regression calculations performed with off-the-shelf personal computer software (Quattro Pro for Windows, Borland International, Inc., Scotts Valley, CA). However, the small number of ships sampled weakens the power of these tests.

Observations

Based on discussions with personnel of the ships that were sampled, no air sampling is performed on the LPACs that supply all the ships' pressurized air including the ventilating air during dome entries. The requirement for quarterly testing to insure that such air meets grade D standards apparently is not being met.

Gas-free procedures described by NAVSEA (15) do not detail what substances should be monitored or which instruments to use for a given situation. On some of the ships sampled, a paint locker was adjacent to the dome trunk where strong solvent odors were

present, insecticides stored, and a CO_2 fire suppression system in place. The presence of these potential hazards raises serious safety questions. During all sampling exercises, certification of the O_2 level was the only gas-free procedure observed.

CONCLUSIONS

1) Low levels of hydrocarbons were found in the sonar dome compartments of 6 U.S. Navy ships after a 24-hour period of non-ventilation. The levels of individual chemicals were well below their threshold limit values for hazardous exposures as defined by the ACGIH. Following 4-hour ventilation of the dome with air from the ships' LPACs, the dome contamination was significantly reduced. At the time of sampling, the LPAC air was found free of volatile hydrocarbons other than methane.

2) It appears that no testing of ships' LPAC air as required by NAVOSH on a quarterly basis is being done. However, because of the potential for contamination of the intake air of the LPACs as discussed above, such periodic testing/certification on a quarterly or other basis will not address the issue of safe dome entries. No procedures currently exist or are required by NAVSEA (11,12) to confirm and/or insure the purity of air used for ventilation during dome entries.

3) Gas-free procedures for insuring safe access to the point of entry into the dome (i.e., access via the dome trunk) are questionable and/or poorly defined.

4) Our sampling and analysis did not deal with the question of non-volatile contaminants such as TBTO, which coats the inner dome surface of most ships. The potential for direct or airborne contact by dome personnel with this relatively toxic chemical and the

need for protective gear during dome entries is unknown.

RECOMMENDATIONS

The following recommendations deal with the two main concerns raised by this study, the potential for contamination of the air used for ventilation during dome entries and the need to insure safe access to the point of dome entry:

1) Shipboard activities having high potential for generating volatile chemicals (e.g., painting, cleaning, equipment repair), which might contaminate the LPAC intake air, should be restricted several hours before and during dome entries.

2) Shipboard spaces and dockside areas should be patrolled immediately before and during dome entries to insure that no smoke, strong odors, or other unusual conditions exist in the atmosphere.

3) Gas-free procedures for the dome trunk should specify monitoring using the appropriate equipment as specified by NAVSEA (15) for the following: oxygen, carbon dioxide, explosive/ flammable conditions, and hydrocarbons.

The most recent NAVSEA instruction (16), includes revised procedures based on the first 2 recommendations that had been previously made to NAVSEA by NMRI (6).

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TABLE 1: SHIP SAMPLING DETAILS

SHIPS SAMPLED	SAMPLE DATE (month/year)	SDRW AGE* (months)
USS Briscoe (DD-977)	4/92	39
USS Kidd (DDG-993)	4/92	154
USS Donald B. Beary (FF-1085)	6/92	41
USS Truett (FF-1095)	6/92	149
USS San Jacinto (CG-56)	6/92	70
USS Hue City (CG-66)	9/92	32

*, age of SDRW at time sampling

TABLE 2. DOME AIR: SEV VALUES POST 24-HOUR NONVENTILATION (PPM)

6 SHIPS SAMPLED APRIL TO SEPTEMBER 1992

	USS Briscoe (DD-977)	USS Kidd (DDG-993)	USS Donald B. Beary (FF-1085)	USS Truett (FF-1095)	USS San Jacinto (CG-56)	USS Hue City (CG-66)
Methane	6.4	6.6	4.2	5.5	7.3	14.3
Butane	9.3	4.8	14.5	10.9	21.0	10.7
Toluene	8.2	3.7	8.2	4.4	33.0	20.3
Xylenes	1.7	4.6	0.4		4.2	3.9
Methyl chloroform						3.4
CO_2	660	1509	563	645	857	1498
O_2	20.8%	20.8%	20.6%	20.7%	20.7%	20.6%

1. Only hydrocarbon species detected >1 ppm in the lab from at least 1 ship are reported here. Blank values indicate <0.1 ppm measured in lab. A number of other known and unknown hydrocarbons were also detected in some samples at levels estimated <1 ppm.

2. Surface equivalent values (SEV) are derived by multiplying the value measured in the lab at 1 ATA by the dome pressure which ranged from 2.1 to 2.8 ATA. O_2 is not corrected for pressure.

3. Values are reported to the nearest 0.1 ppm except for O_2 which is reported to the nearest 0.1% and CO_2 to the nearest 1 ppm. In all samples, CO <5 ppm. Accuracy of analysis is estimated to be ± 1% relative for O_2 and CO_2 and ± 10% relative for hydrocarbons.

TABLE 3 DOME AIR: SEV VALUES POST 4-HOUR VENTILATION (PPM)						
6 SHIPS SAMPLED APRIL TO SEPTEMBER 1992						
	USS Briscoe (DD-977)	USS Kidd (DDG-993)	USS Donald B. Beary (FF-1085)	USS Truett (FF-1095)	USS San Jacinto (CG-56)	USS Hue City (CG-66)
Methane	4.3	4.3	4.0	4.6	4.9	5.3
Butane	0.8	0.4	3.6	1.2	1.3	1.0
Toluene	1.1	0.5	3.2	0.7	4.9	3.4
Xylenes	0.3	0.5			1.3	0.9
CO_2	750	845	695	708	928	859
O_2	20.8%	20.9%	20.7%	20.7%	20.8%	20.6%

1. Only hydrocarbon species detected >1 ppm in the lab from at least 1 ship are reported here. Blank values indicate <0.1 ppm measured in lab. A number of other known and unknown hydrocarbons were also detected in some samples at levels estimated <1 ppm.

2. Surface equivalent values (SEV) are derived by multiplying the value measured in the lab at 1 ATA by the dome pressure which ranged from 2.1 to 2.8 ATA. O_2 is not corrected for pressure.

3. Values are reported to the nearest 0.1 ppm except for O_2 which is reported to the nearest 0.1% and CO_2 to the nearest 1 ppm. In all samples, CO <5 ppm. Accuracy of analysis is estimated to be ± 1% relative for O_2 and CO_2 and ± 10% relative for hydrocarbons.

TABLE 4. DOME VENTILATING AIR (PPM)						
6 SHIPS SAMPLES APRIL TO SEPTEMBER 1992						
	USS Briscoe (DD-977)	USS Kidd (DDG-993)	USS Donald B. Beary (FF-1085)	USS Truett (FF-1095)	USS San Jacinto (CG-56)	USS Hue City (CG-66)
Methane	2.1	2.0	1.8	1.9	1.8	1.8
CO_2	362	373	367	367	364	343
O_2	20.8%	20.9%	20.8%	20.8%	20.8%	20.9%

1. Methane is reported to the nearest 0.1 ppm, O_2 to the nearest 0.1%, and CO_2 to the nearest 1 ppm. Accuracy of analysis is estimated to be ± 1% relative for O_2 and CO_2 and ± 10% relative for methane.

2. No hydrocarbons >0.1 ppm, other than methane, was found in any ship's low pressure air supply at the time of sampling.

FIG. 1. BASIC SDRW SYSTEM

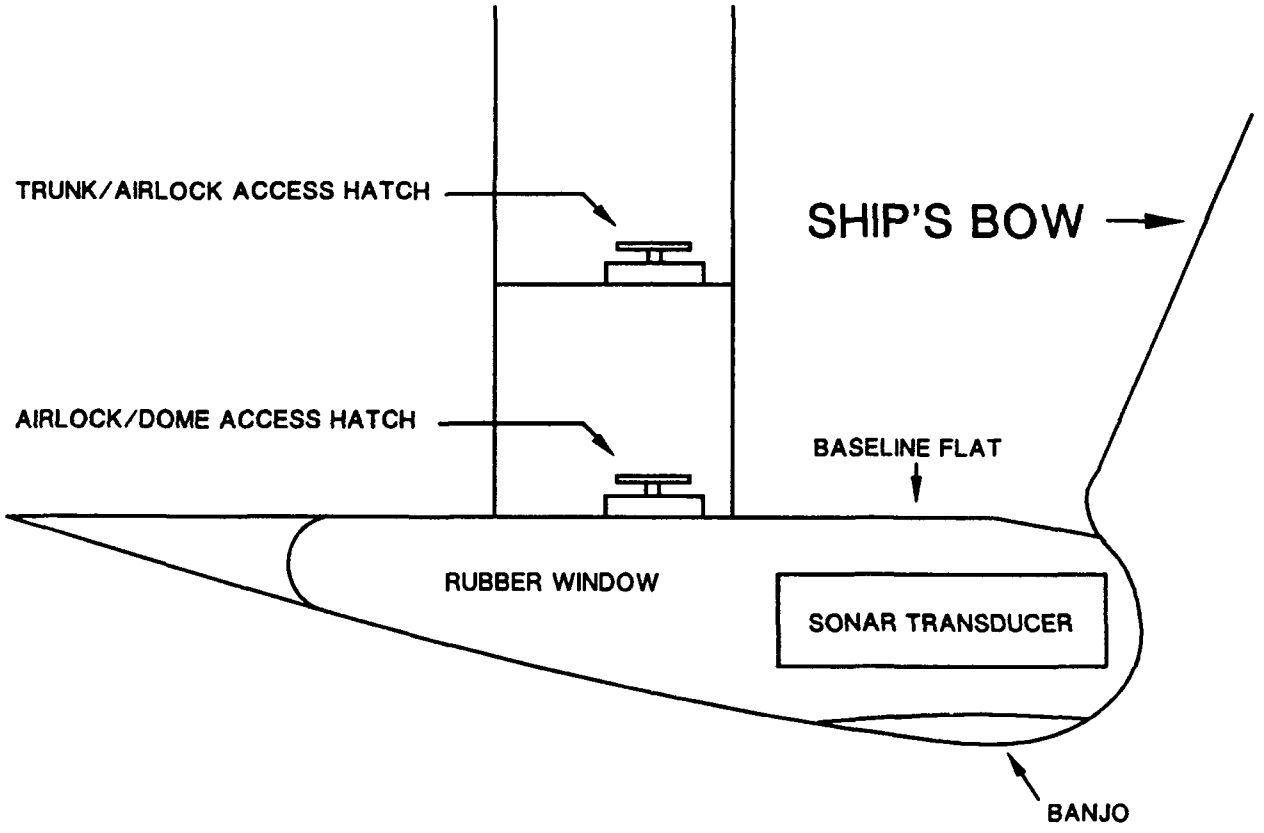

FIG. 2. BUTANE LEVELS VS SDRW AGE

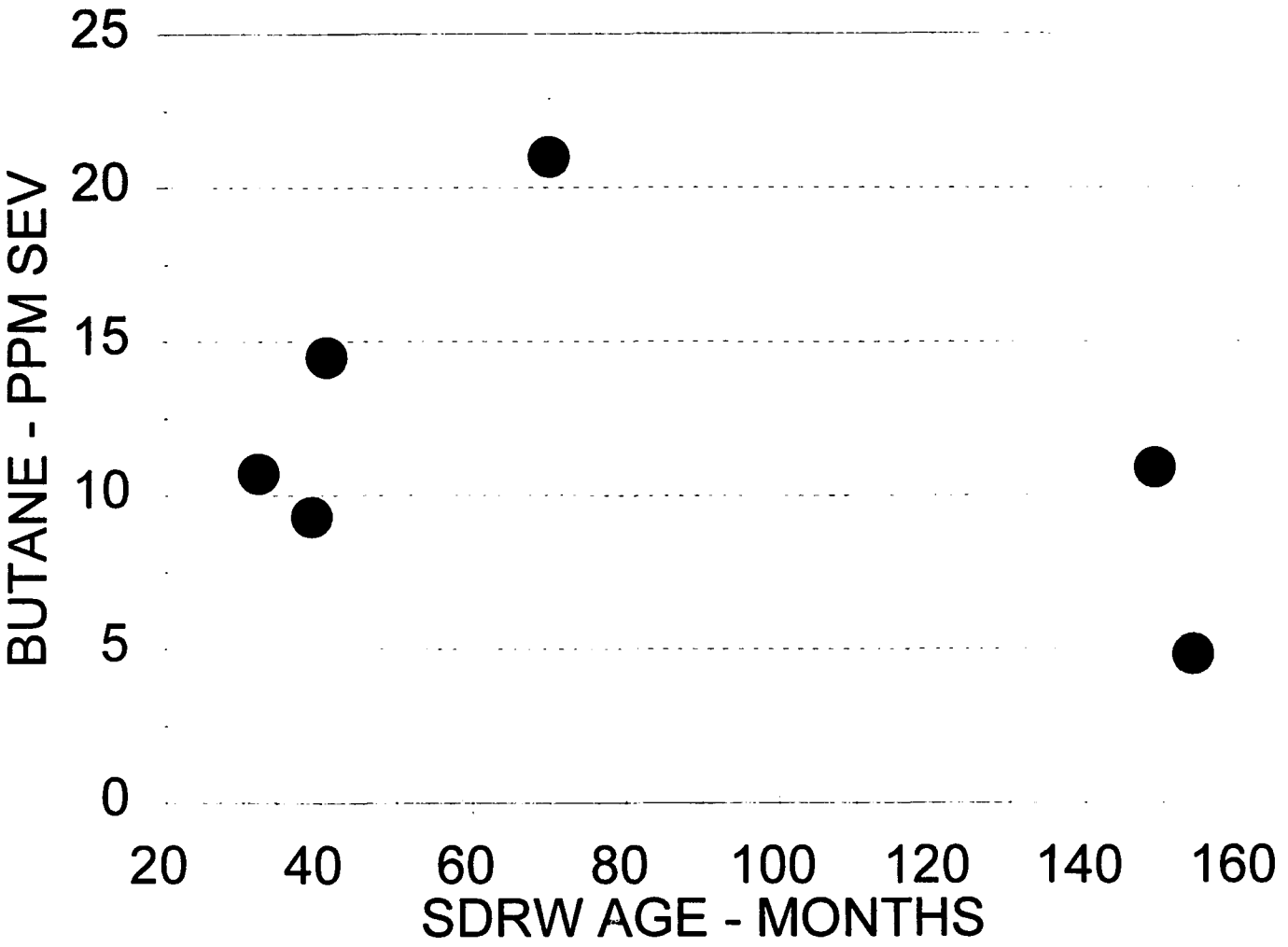

FIG. 3. TOLUENE LEVELS VS SDRW AGE