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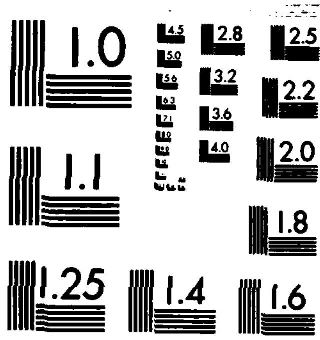
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Report No. CG-D-11-85

A CREW EXPOSURE STUDY - PHASE II
VOLUME II - AT SEA
PART A

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H. L. Kaplan
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Final Report
April 1985

Prepared for:

U.S. Department of Transportation
United States Coast Guard

Office of Research and Development
Washington, D.C. 20593

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A CREW EXPOSURE STUDY – PHASE II
VOLUME II – AT SEA
PART A

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16. Abstract

The objective of this effort was to implement the Phase I test plan for characterizing occupational exposures of crew members on bulk liquid tankers to chemical substances, primarily cargo vapors. Additional chemical substances included nuisance dust, asbestos fibers, oil mist and silica dust. This report documents the measurement and monitoring data that were collected on six at-sea voyages that involved tankers carrying Subchapter O, Subchapter D and unregulated liquid products. The interpretation of these occupational exposures was based on a conservative method that makes use of the medical monitoring response level concept and current values of the ACGIH TLVs. This method was developed because the work routine that forms the basis for TLVs is not generally applicable to marine operations. Noise dosimetry was performed on two voyages in order to characterize the environment in an Engine Room and in the Deck Department of a state-of-the art product tanker.

This study concluded that the potential for unacceptable inhalation exposures is greatest during open tank gauging and entry into product tanks. Volume II, Part A represents the body of the Final Report. The detailed voyage reports are contained in ~~Volume II~~, Part B.

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We wish to thank Prof. James Hammond of the University of Texas School of Public Health In Houston for his valued assistance to the project team. Finally, this report could not have been produced without the skill and patience of Mrs. Dorothy Endicott who typed the report manuscript and revisions.

EXECUTIVE SUMMARY

"A Crew Exposure Study - Phase I" was the title of a research project that developed a test plan and methodology for assessing occupational exposures of workers to potentially hazardous chemical substances in the work environment for both the marine chemical transport industry and the offshore drilling and production industry.

The Phase I At Sea test plan, which was implemented in Phase II, emphasized characterizing occupational exposures to chemical substances during all phases of tanker operations. Chemical substances were defined to include cargo vapors and gases, rust and paint chipping debris, asbestos, oil mist, silica from sandblasting and spray paint solvents. A limited amount of noise dosimetry was also included to characterize the noise environment in an Engine Room and in the Deck Department of a state-of-the art product tanker.

Because the offshore and merchant marine industries differ with respect to their basic operations, chemical substances, exposure potentials and work schedules, the results of Phase II are being published in two volumes.

- Volume I - Offshore
- Volume II - At Sea

This volume addresses the At Sea portion of the study.

The at-sea test plan included five Deck Department voyages and one Engine Room/Pump Room voyage. These voyages involved a wide range of products from highly toxic Subchapter O chemicals that are carried in relatively small parcels to high volume Subchapter D commodities such as crude oil and gasolines that are transported on dedicated tankers. In addition, a wide range of ship configurations as well as cargo transfer, venting, gauging and tank cleaning equipment were represented on vessels whose ages differed by as much as 30 years. A corresponding variety of work practices was observed.

Maritime work schedules depart significantly from the traditional land-based schedule of 8-hour days and 40-hour work weeks. Accordingly, they are variously termed novel or unusual work schedules. An extended work routine results if a crew member works continuously through one or more regularly scheduled rest periods. OSHA and ACGIH occupational exposure limits are based on the conventional work schedule (8-hour days and 40-hour weeks). Consequently, neither of these exposure limits are strictly applicable to the maritime work schedule. Mathematical schemes that modify 8-hour exposure limits to reflect maritime schedules and environments have not matured to the point where they can be applied with confidence. In view of these limitations, the following conservative interpretation scheme was applied to the exposure data.

- For a given chemical substance, a medical monitoring response level was defined to be equal to one-half of the most current value of the ACGIH TLV-TWA regardless of exposure duration.

- Exposures less than the medical monitoring response level are not considered to be toxicologically significant.

- Exposures greater than or equal to the medical monitoring response level are considered to be toxicologically significant and are designated occupational exposures for medical monitoring purposes. The precedent for this criterion is contained in Chapter 12 of the USCG Medical Manual (COMDTINST M6000.1) dated 8 August 1984.

- If an exposure concentration exceeds the TLV-TWA, then a potential hazard is presumed to exist in addition to the exposure being subject to a medical monitoring requirement.

- Duration of exposure is not considered until the presumed hazard is investigated as described in the next item.

- After the mechanics of the above screening have been completed, then those exposures that are greater than the TWA are reviewed toxicologically on an individual basis. This review utilizes known effects of exposure to a given vapor, and the results of the review determine if any change in the classification is justified, i.e. did the presumed hazard exist.

The 1984-85 version of the ACGIH TLVs has been used in this report. When a TLV did not exist for a substance, corporate exposure limits or Material Safety Data Sheet information was used.

The results of this project formed the basis for several conclusions. The primary conclusions are as follows.

- The tank gauging exposure data clearly reinforce the advantages of restricted gauging with sounding tubes over open gauging through ullage ports. This statement applies equally to periodic (pre-topoff) as well as topoff gauging. Exposures received during restricted gauging with sounding tubes were all less than the medical monitoring response level, while only about 50 percent of the open gauging exposures were less than their respective medical monitoring response levels.

- To date, only one crew member has been observed using an air purifying respirator for protection during open gauging. This work activity is incorrectly perceived as not presenting an inhalation hazard that justifies respiratory protection. This conclusion acknowledges that not all cargos possess the volatility and exposure limit needed to generate an inhalation hazard.

- The data from this project confirm earlier findings that worker-entry into cargo tanks is an area of concern with respect to vapor inhalation exposures. Thirty-eight percent of the entry exposures exceeded the medical monitoring response level with 22 percent of all entry exposures being above the STEL. Collectively, the following factors contributed to exposures above the medical monitoring response level:

  - no pre-entry testing of the atmosphere for oxygen, combustible gas or toxic concentrations,
  - entry into an unknown atmosphere without respiratory protection to test the atmosphere to determine if it is acceptable for crew members to enter and work,
  - no ventilation during in-tank work,
  - crew members with and without respiratory protection in the same unacceptable tank atmosphere,
  - crew members entering tanks of their own volition and without direction and
  - entry decisions being based on odor.

- Based on all tank entry observations, the potential for dermal exposure exists if open, short-sleeved shirts, shorts, street shoes, cloth work gloves or no gloves are used during in-tank work such as residue mucking.

- While inert gas systems on crude carriers have mitigated a fire and explosion hazard, the occupational exposure situation has not been correspondingly remedied. Tanks are opened at the end of loading and before discharge commences so that product ullage and water content can be manually gauged. During these operations, hydrogen sulfide exposures from the sour crude on one voyage exceeded the medical monitoring response level of 5 ppm. These integrated values were obtained with relatively slow responding passive dosimeters. Direct reading instrument measurements of H_2S concentration in the breathing zone indicated the presence of transient H_2S levels that approached or exceeded 1895 ppm. On the basis of the hexane, benzene and toluene components in crude oil, the mixture medical monitoring response level was exceeded on two occasions both of which were associated with the surveying operation at the end of loading. Breathing zone measurements of total crude oil vapor indicated that the work environment contained fluctuating vapor concentrations that ranged to 4000 ppm or more as hexane.

- o Merchant mariners generally consider chemicals regulated by Subchapter D to be of little or no respiratory hazard and Subchapter O chemicals to represent a great hazard. The results of this study show that significant overexposures are occurring to both Subchapter O and D (e.g. gasoline) cargos. The data indicate that a knowledge of the characteristics of individual chemicals in both Subchapter O and D is necessary to ensure the safety of the mariner.

The following major recommendations are based on the above conclusions.

Environmental monitoring indicates that 38% of the entries into tanks which contained Subchapter D or O products resulted in vapor exposures in excess of the medical monitoring response level. A significant number of entries occurred with little or no pre-entry testing of the atmosphere or ventilation during in-tank work. To decrease the possibility of harmful exposure, at least the following elements of a tank entry procedure should be addressed in both Subchapters D and O.

- o The atmosphere to be entered without respiratory protection should be tested to ensure that it contains at least 19.5 percent oxygen by volume and that the concentrations of toxic vapors are less than the current exposure limits as recommended by the American Conference of Governmental Industrial Hygienists (or the best available information if a TLV does not exist). This is consistent with ANSI/NFPA 306 - "Control of Gas Hazards on Vessels". Continued atmosphere testing should be conducted throughout the entry period to ensure that safe levels are maintained.

- o Personnel responsible for atmosphere testing should be able to demonstrate that they are knowledgeable in the proper use of the equipment and that the instruments (oxygen, combustible gas and toxicity) are correctly calibrated and that they are in working order.

- o Forced ventilation should be provided continuously while crew members are in confined spaces such as cargo tanks.

- o Any existing requirement for use of an SCBA (self contained breathing apparatus) or any other respiratory protection equipment should be supplemented by a respiratory protection program similar to the programs in ANSI Z-88 (current version) and 29CFR 1910.134.

- o A deck safety watch should be in attendance at all times when crew members are in ship's tanks. The safety watch should be able to communicate with the personnel in the tanks, and emergency response equipment should be readily accessible.

- Prior to entry into a confined space an entry permit should be completed by the person entering the tank and a deck officer. The entry permit should be a formal record that proper confined space entry procedures (as stated above) have been followed.

Some elements of the recommended entry procedure are already included in Subchapter O. Subchapter D does not include any confined space entry procedures for a vessel at sea.

All Subchapter D products can be open gauged. This is normally accomplished through an ullage port. The vapor concentrations at the open port can approach or equal the saturated concentration corresponding to the cargo temperature at the end of loading. The open gauging data that were collected on this project indicate that 46 percent of the gauging exposures prior to tank topoff exceeded the medical monitoring response level and that the percentage above the medical monitoring response level increased to 52 at topoff. Conversely, none of the Subchapter O products resulted in exposures above the medical monitoring response level when restricted gauging with sounding tubes was used. To reduce vapor exposures during gauging, the cargos that permit open gauging should be reviewed. Currently some Subchapter O and all Subchapter D products can be open gauged. For those cargos that represent a vapor inhalation hazard (based on saturated vapor pressure, temperature and the medical monitoring response level) an engineering control such as restricted gauging should be required. If this is not practical and open gauging is to continue as it is currently practiced, then it is recommended that Subchapter D be amended to include the following considerations.

- When it can be shown that a certain product constitutes a respiratory hazard during open gauging as described above, then appropriate respiratory protection equipment should be used.

- When respiratory protection is necessary, its use should be supported by a respiratory protection program comparable to ANSI Z-88 (current addition) or 29CFR 1910.134.

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GLOSSARY OF TERMINOLOGY

A/B	- Able-bodied Seaman
PM	- Pumpman
O/S	- Ordinary Seaman
CM	- Chief Mate
2M	- Second Mate
3M	- Third Mate
ACGIH	- American Conference of Governmental Industrial Hygienists
CHRIS	- Chemical Hazards Response Information System
NIOSH	- National Institute for Occupational Safety and Health
OSHA	- Occupational Safety and Health Administration
O_2/CGI	- Oxygen/Combustible Gas Indicator
H_2S	- Hydrogen Sulfide
OVA	- Organic Vapor Analyzer
SwRI	- Southwest Research Institute
TLV-C	- Threshold Limit Value-Ceiling
TLV-STEL	- Threshold Limit Value-Short-Term Exposure Limit
TLV-TWA	- Threshold Limit Value-Time Weighted Average
USCG	- U. S. Coast Guard
PEL	- Permissible Exposure Limit
MOU	- Memorandum of Understanding

GLOSSARY OF CHRIS CODE ABBREVIATIONS FOR VOYAGE CHEMICALS

Common Name	Abbreviation
Benzene	BNZ
Gasoline	GAT
Isobutanol	IAL
Methyl Ethyl Ketone	MEK
Methyl Isobutyl Ketone	MIK
Butanol	BAN
Xylene (per isomer)	XLO,M,P
Ethanol	EAL
Methanol	MAL
1,1,1-Trichloroethane	TCE
Ethylene Dichloride	EDC
Trichloroethylene	TCL
Ethylene Glycol	EGL
Caustic Soda	CSS
Acetone	ACT
Perchloroethylene	TTE
Propylene Glycol	PPG
Styrene	STY
Glycerine	GCR
Methylene Chloride	DCM
Naphtha	NCT
Crude Oil	OIL
n-Hexane	HXA
Toluene	TOL
Cellosolve Acetate	EGE
Ethyl Acetate	ETA
n-Propyl Acetate	PAT
n-Propanol	PAL
Isopropyl Alcohol	IPA
Butyl Cellosolve	EGM
Vinyl Acetate	VAM

I. INTRODUCTION

"A Crew Exposure Study" is a two-phase research project that was conducted by Southwest Research Institute for the U. S. Coast Guard, Office of Research and Development, Marine Technology Division. The purpose of both phases of this study was to characterize the occupational exposures of crew members to chemical substances in the work environment on bulk liquid tankers and barges at sea and on offshore drilling and production facilities. While inland barges were not specifically investigated in this study the results should be equally applicable to this industry, since the equipment and tasks performed are similar. These chemical substances include the liquids, vapors, dusts, mists, and gases that are associated with various operations. Occupational exposures include the inhalation, dermal, and ingestion routes of entry into the body. Occupational exposures to noise were also considered where appropriate. Because the nature of the potential exposures and the work routines on product tankers and barges differ greatly from those on offshore facilities, the results of the Crew Exposure Study have been published in two separate volumes. In Phase I, the offshore drilling and production results are presented in Volume I (Reference 1) while the results for tanker operations at sea are contained in Volume II (Reference 2). Phase II documentation has been similarly divided into two volumes. Volume 1 (Reference 3) presents the offshore drilling and production portion of the study. This document, Volume II of Phase II, reports the results for bulk liquid tanker operations at sea.

I.1. Background

The U. S. Coast Guard has responsibility for the health and safety of employees that are involved in the transportation of bulk liquids by water. This long-standing responsibility is derived, in part, through the Ports and Waterways Safety Act and Vessel Inspection Laws of the United States. Responsibility, authority and jurisdiction were further clarified in a 1983 Memorandum of Understanding (MOU) with OSHA (Reference 4). This MOU acknowledges that the OSH Act is not enforceable with respect to working conditions aboard inspected vessels and that the USCG is the primary safety and health agency in this work area.

The Coast Guard's concern for the health and safety aspects of bulk liquid tanker operations predates the MOU with OSHA. In 1977, the USCG initiated a series of research projects to recognize and evaluate the potential for occupational exposures during tanker operations and to identify the work activities that have the highest exposure potential. Initial efforts concentrated on exposures during cargo transfer operations in marine terminals (References 5 and 6). The second generation of projects - A Crew Exposure Study: Phases I and II - extended these efforts to include the work activities and corresponding exposures that may occur while the tanker is underway in either a loaded or ballast condition.

Thus, Phase II of the Crew Exposure Study represents the fourth in a series of projects that were designed to develop (1) an understanding of the work environment aboard bulk liquid tankers and (2) an occupational exposure data base that can be used to guide the selection of engineering, administrative and/or protective equipment controls.

I.2. Objectives

The main objectives of Phase I of "A Crew Exposure Study" were to (1) verify that occupational exposure monitoring was feasible during all major tanker operations, (2) develop a test plan that would generate exposure data that is representative of a wide range of products, vessel configurations and cargo handling equipment, and (3) conduct a trial implementation of the test plan. Having accomplished these objectives, the thrust of Phase II consisted of implementing the Phase I test plan and interpreting the data. A secondary objective of Phase II was to (1) continually assess the applicability of the analytical models in References 5 and 6 to new exposure scenarios and (2) identify any new work/exposure scenarios that may be amenable to analytical modeling.

In executing the Phase I test plan, emphasis was placed on occupational exposures to cargo vapors. Occupational exposures to non-cargo related chemical substances were also included. Noise was the only physical agent that was represented in Phase II.

The next section of this report discusses the details of the scope and philosophy of the test plan.

II. EXPERIMENTAL PLAN

Six at-sea voyages were conducted in Phase II of this project. Five of these voyages were concerned with occupational exposures in the Deck Department, and one voyage concentrated on Engine Room/Pump Room operations. The emphasis on Deck Department operations reflects the higher potential for exposure to cargo vapors relative to the Engineering Department and Pump Room.

The central theme that was followed in selecting vessels for these voyages was that the composite results should be representative of the industry. That is, the results should reflect the spectrum of operational procedures, vessel equipment and vessel configurations that are present in the marine chemical transport industry. An adjunct to this central theme was that a wide range of bulk liquid products should be represented in the project.

Based on the Phase I recommendations, six voyages were selected for the Phase II at-sea experimentation. Over the course of this project, the chemical/product tanker industry was significantly affected by both domestic and international economic factors. In response to these factors, certain selected vessels were temporarily or permanently removed from service or the class of service was altered to the extent that vessel operations were no longer consistent with project objectives. Substitute vessels were identified that maintained and enhanced the central project theme that was described above.

The six voyages that were ultimately executed on Phase II together with their characteristics are summarized in Table I. In the aggregate, the cargos that were transported ranged from high to low toxicity and were regulated under Subchapters O* and D**. Product classifications correspond to USCG regulations.

Table I indicates that a wide range of product classes were represented by these six voyages. The age of the vessels ranged from less than one year to roughly 30 years old. Four of the six vessels are classed as product/parcel chemical tankers. The remaining two vessels were a crude oil carrier and an integrated tug/barge (ITB).

* 46-CFR, Part 153, "Safety Rules for Self-Propelled Vessels Carrying Certain Bulk Dangerous Cargos.

**46CFR, Part 30, "Tank Vessels - General Provisions."

TABLE I. VOYAGE IDENTIFICATION AND VESSEL CHARACTERISTICS

Voyage No.	Vessel Characteristics	Primary Cargos
1	1a,2a,3a,4b,5a,6a	Motor/Aviation Fuels
2	5b,6b	Motor/Aviation Fuels
3	1b,2ab,3b,4ac,5a,6b	Chlorinated Solvents
4	1b,2a,3c,4a,5b,6a	Sour Crude Oil
5	1b,2ab,3a,4abc,5a,6b	Acetates, Alcohols, Aromatics, Ketones
6	1b,2ab,3bc,4a,5a,6a	Motor Fuel, Ketones, Blended Solvents, Process Oils, Blending Stocks

Code of Vessel Characteristics

1. Crew Size
   a. Minimum Crew
   b. Maximum Crew
2. Tank/Hull Type
   a. Tank Walls Integral with Hull
   b. Double-Bottom Tanks
3. Gauging Systems
   a. Open
   b. Restricted
   c. Closed
4. Vent Systems (Loading)
   a. b/3 or 4m (or high velocity)
   b. Reasonable Height
   c. Vapor Return
5. Cargo Discharge System
   a. Deep well
   b. Pumproom
6. Propulsion System
   a. Diesel
   b. Steam

The vessel in Voyage 6 represents a state-of-the art tanker. This ship included the following Deck Department equipment that was installed to minimize occupational exposures to product vapors.

- o Closed loading of all tanks with vapor venting through elevated high velocity vent relief valves.
- o Two closed gauging systems on all tanks with ullage readout both at the tank and remotely in the Cargo Control Room.
- o A backup portable restricted gauging system.
- o Permanently installed washing machines and stripper pumps.
- o A dehumidified air system to expedite gas freeing of tanks to acceptable atmospheric concentrations.

This vessel represents the newest generation of product tanker in the U. S. Flag fleet and was included in this project to enhance the vessel coverage and to assess the merits of the latest control technology.

A typical voyage consists of four elements:

- o product loading,
- o a laden voyage from a loading terminal to a discharge terminal,
- o product discharge and
- o sailing in a ballast condition from the discharge terminal to the primary loading terminal.

Not all of these elements were included in every voyage. The logistics were tailored to the voyage objectives. For example, on a Deck Department voyage, the laden leg was occasionally omitted because previous results had indicated that a low potential for cargo and non-cargo related exposure exists during this phase of the operation. Similarly, Deck Department voyages always included the ballast leg because it is during this phase of the voyage that product tanks are washed and entered. These activities have a high potential for product vapor exposure. Two SwRI staff members participated in each voyage which lasted from two to three weeks.

In Phase I, the design sampling (occupational exposure monitoring) strategy was structured around identifying two crew members in a given department and monitoring their exposures during work and non-work periods throughout the duration of the voyage. The objective was to generate total exposure profiles on given individuals. This approach involved continuous monitoring that included full-watch and short-term exposures. It became apparent that this strategy was too restrictive in the sense that the selected individuals may not be assigned to specific activities of interest or those activities may occur but during their rest periods. This approach was not conducive to maximizing the quantity of exposure data on a given voyage.

The strategy that evolved was oriented towards a job activity and was relatively independent of the number of crew members involved in the activity. For example, tank washing and tank entry are activities of interest. If several tanks were to be washed, ventilated and entered over several consecutive watches, then crew members on each watch would be monitored for vapor exposure until the activity had been completed. Because this strategy is job activity oriented, sample durations reflected the duration of the activity which included short-term, partial-watch, full-watch, etc.

Work activities of the crew were documented simultaneously with the exposure monitoring. For a given crew member, this documentation included (1) a description of the work being performed, (2) proximity of the worker to contaminant sources, (3) duration of the work activity, and (4) the use of any engineering, administrative or personal protection equipment controls. This type of documentation facilitates interpretation of the exposure data, and it minimizes the occurrence of invalid exposure samples.

This project has emphasized occupational exposures to chemical product vapors. The potential also exists for exposure to non-cargo related vapors and other contaminant forms. Non-cargo related vapors can be generated during activities such as spray painting. Potential airborne particulates include sandblasting debris, rust and paint chipping debris and asbestos fibers.

Vapor sampling was accomplished primarily using charcoal tubes; passive dosimeters were occasionally employed in parallel with the tubes or as the primary sampling device when the crew member indicated a preference. The appropriate NIOSH sampling and analysis procedures (Reference 7), or their equivalent, were utilized on the charcoal tubes. Manufacturer's procedures were followed for the passive dosimeters. Insofar as possible, particulate sampling also followed NIOSH recommended procedures. Based on experience, sample collection procedures that use impingers are not practical in the marine environment. For this reason, passive colorimetric dosimeters were used for monitoring hydrogen sulfide exposures.

Motor and jet fuel were transported on several voyages. Motor fuels included regular, unleaded and super unleaded gasoline. In evaluating the exposures to these products, benzene was considered to be the second component in a benzene/"gasoline" vapor mixture. The rationale for this decision is as follows. The ACGIH TWA and STEL account for the presence of benzene at a presumed average concentration in the liquid. As the TLV for "gasoline" is very sensitive to the benzene content and the products involved all grades of gasoline and a jet fuel all with unknown benzene levels that contributed to the vapor environment, it was felt that the additive approach to evaluating "gasoline"/benzene vapor mixture exposures would present the most conservative results.

Noise monitoring was included on two voyages. Noise exposures were monitored during Engine Room operations on Voyage 2 and during Deck Department operations on Voyage 6. It was included in Voyage 2 because noise is a major element in the work environment in engineering spaces.

Noise was included in Voyage 6 to characterize the levels arising from

- vapor venting through clustered high velocity vents during loading,
- the use of portable stripper pumps for intank sump cleaning, and

- simultaneous operation of multiple deck-mounted, cargo discharge pumps that were in close proximity to one another and were located in relatively sheltered areas.

At the conclusion of each voyage, a voyage report was written. These reports, which documented the observations and the sampling results, are contained in Volume II - Part B of this final report.

III. MARITIME WORK SCHEDULES AND THE ROLE OF EXPOSURE LIMITS

The American Conference of Governmental Industrial Hygienists (ACGIH) annually publishes recommended exposure limits for a wide range of chemical substances (Reference 8). These exposure limits fall into three categories.

- o Threshold Limit Value - Time Weighted Average (TLV-TWA),
- o Threshold Limit Value, Short Term Exposure Limit (TLV-STEL),
- o Threshold Limit Value-Ceiling (TLV-C).

For purposes of this section, the ACGIH definition of TLV-TWA is quoted below.

> "The Threshold Limit Value-Time Weighted Average (TLV-TWA) - the time weighted average concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect."

Based on this definition and supporting human or experimental data, TWAs are assigned to chemical substances. These TWAs are assigned specifically to apply to land-based industries in which the work routines consist predominantly of

1. conventional 8-hour workdays,
2. 40-hour workweeks,
3. 16-hour biological purge periods between adjacent intra-week work days,
4. a two-day purge period between adjacent work weeks and
5. a relatively constant exposure environment from day to day.

These five points, however, do not have their counterparts in the maritime work routine and exposure environment. This observation will be expanded and discussed below.

The traditional maritime work schedule consists, at a minimum, of alternating 4-hour watches separated by 8-hour rest periods. This schedule applies seven days per week for the duration of service aboard the vessel. The duration of service (or annual schedule) may consist of 30, 60 or 90-day periods aboard the ship separated by vacation periods of comparable length. Other work schedules also exist, and the durations of work and vacation may not be comparable. While the workday may contain only eight working hours, they are not continuous hours. Therefore, in the aggregate, Items 1-4 do not occur amongst maritime workers. These maritime work schedules have been variously termed novel or unusual workshifts to distinguish them from conventional schedules.

In general, land-based employees work in an environment where ambient contaminant concentrations are relatively constant from day to day. In contrast, work place concentrations of cargo vapors are highly variable on bulk liquid tankers. A typical domestic, round trip voyage between the Gulf and East Coasts may last for two weeks. The voyage and its exposure potential may vary as indicated below.

- o Loading
  - two days,
  - exposure potential is maximum for open vented, open gauged cargos,
  - except for single product carriers, the probability is minimal that successive watches will involve essentially constant concentrations of chemicals,
  - the chemical mix should be expected to be highly variable from watch to watch and with- a given watch.
- o Laden Voyage
  - five days,
  - cargo vapor exposure potential is minimal as tanks are sealed and maintenance work is not performed on loaded tanks.
- o Discharge
  - two days,
  - exposure potential is minimal as cargo vapors are not discharged into the work place under normal operations.
- o Ballast Voyage
  - five days,
  - potential for exposure to cargo vapors is maximum during tank cleaning and tank entry,
  - activities would not normally involve exposure to single product for a full watch, a full day or two successive watches or days,
  - cargos and exposure levels should be expected to vary widely.

Thus, periods of maximum exposure potential are separated by several days, and within a period of maximum exposure potential, the mix of chemical vapors is highly variable. It is concluded that Item 5 in the TLV-TWA definition does not occur in the marine chemical transport industry.

While the 4-on, 8-off work schedule forms the basis for the maritime work routine, there are a number of situations that can result in considerably more than eight hours of work in a single day, and continuous work through one or more regularly-scheduled rest periods is usually involved. The net result may be termed an extended work routine.

The existence of extended work routines has been documented primarily in the Deck Department, which is consistent with the emphasis on this project. Extended work periods arise principally from (1) defined responsibility, (2) overtime work or (3) shift swapping. Extended work schedules of 12 to 30 consecutive hours on a one-time or temporary basis and an average of 16 hours per day over a 30-day period have been documented.

The novel and extended work routines have been historically associated with the maritime industry. Until very recently, however, analogous routines have not existed in land-based industry. Consequently, exposure limit guidelines have been defined around the conventional 8-hour workday. However, various land-based industries have recently instituted novel work schedules for their employees. This change in operating procedure has raised questions concerning exposure interpretation because actual work schedules don't coincide with the schedule that is assumed in the TLVs.

The concept of TLV adjustment has been suggested as a means of addressing this issue. Basically, the concept involves modifying the numerical value of the existing chemical-specific TLV so that the body burden in the novel work schedule does not exceed the body burden that would be experienced in a TLV level of exposure. There are five mathematical or numerical models that have been proposed to meet the adjustment criteria.

- Hickey-Reist (Reference 9)
- Roach (Reference 10)
- Mason-Dershin (Reference (11)
- Brief-Scala (Reference 12)
- OSHA Field Manual (Reference 13)

All of these models have been published within the past 10 years. They are discussed qualitatively below. Analytical details of each model are presented in Reference 14.

Hickey-Reist Model

The Hickey-Reist model for adjustment of vapor inhalation TLVs assumes that the body is a well mixed, one-compartment reactor. Conservation of mass equations are used to describe the accumulation of contaminant burden within the body during periods of exposure as well as the reduction of body burden during non-exposure periods. Exposure levels are assumed to be at the same constant level for all work periods. Contaminant uptake and excretion by respiration are assumed to be first order, constant rate processes. The governing equations are applied in a piecewise fashion to formulate peak body burden expressions for the conventional work schedule and a completely general novel work schedule. Equating of peak body burden, which implies equal protection of the worker in the novel schedule, results in a general expression for the TLV adjustment factor, F_p. For a given substance and work schedule, the calculated value of the adjustment factor is multiplied by the existing TLV or PEL to arrive at an exposure limit for the novel schedule. When the work cycle and the distribution of work shifts within the cycle are repetitive, then a closed form solution for F_p can be derived.

From an operations standpoint, the difficulty in applying the Hickey-Reist model to maritime work schedules is that the exposure environment is not constant from shift to shift throughout the work cycle. Previous discussions have indicated the exposure level is highly variable throughout a voyage, and there may be extended periods of minimal or no exposure.

The Hickey-Reist model is based on the assumption of equal body burden protection. The predictions of this model or any other model are not meant to take precedence over established exposure guidelines because the models require validation.

Roach Model

As in the Hickey-Reist model, the Roach model also incorporates first order uptake and respiratory elimination, constant exposure level and the concept of equality of peak body burden. The model accepts constant workshift lengths but rest (no exposure) periods of arbitrary duration. The model for TLV adjustment is based on an expression that represents the ratio, R, of peak body burden in the conventional schedule to the body burden at the end of any given shift in the novel work schedule.

If the novel work schedule involves regular, repetitive work/rest periods as in the traditional maritime work schedule, then the peak body burden occurs at the end of the last 4-hour watch before the vacation period begins. Under these conditions, it can be shown that the adjustment factors for the Roach and Hickey-Reist models are identical.

It has been shown that the Hickey-Reist and Roach models are equivalent for the example maritime work schedule. As such, both models predict that the TLV may be increased for substances with short half-lives without violating the peak body burden criterion. However, short half lives are usually associated with substances that have ceiling TLVs or whose TLVs are based on irritation. For those cases, the documentation that forms the basis for the TLV should take precedence over model predictions.

Mason-Dershin Model

The Mason-Dershin model is based on a set of assumptions that are the same as those used in the two previous models. The unsteady differential equation (conservation of mass) for body burden accumulation is integrated for arbitrary work-recovery schedules. This general solution contains a finite series of exponential terms that reflect the overall clearance rate constant. An adjusted TLV-TWA is calculated by equating peak body burden at the end of the last shift in the novel work schedule to the corresponding burden at the end of work on the fifth day of the conventional schedule. Rather than close the finite exponential series in the general solution, Mason and Dershin have tabulated the saturation fraction for various work schedules and durations of exposure. Example tables are presented for methanol and benzene. Using both of these chemicals and two land-based novel work schedules (four 10-hour days and three 12-hour days), TLV adjustment factors were calculated for both the Mason-Dershin and Hickey-Reist models. The calculated adjustment factors were the same in all cases. The conclusion is that the models are identical. For regular, repetitive novel work schedules, the Hickey-Reist model is more convenient because all exponential series are expressed in closed form. Neither the Hickey-Reist nor the Mason-Dershin models can conveniently account for peak body burdens that occur within a work schedule that consists of a highly variable assembly of work-recovery periods.

The authors of this model state that it is applicable to polar solvents but not solvents that have nonlinear accumulation kinetics (accumulation alters accumulation mechanisms) or to substances that are irritants or sensitizers. The authors do not recommend adjustment of TLV-TWA excursions or TLV-STELs.

Brief-Scala Model

The Brief-Scala model is the first published attempt to cope with exposure limits for non-standard work schedules. The model consists of a TLV-TWA reduction factor and an adjusted excursion factor for exposure above the TLV-TWA. The latter adjustment was derived for use with ACGIH excursion factors that preceded publication of TLV-STELs. Both adjustments account for increased potential for exposure time during the unusual work schedule and the reduced number of hours for biological recovery during off work time. The TLV-TWA adjustment can be modified for 7-day work weeks by referencing work-recovery periods to a weekly basis.

The authors indicate that the reduction technique can be used if the TLV-TWA is based on acute or chronic systemic effects and if the ceiling designation is based on chronic toxicity but not irritation. The reduction factor technique is applicable to work periods of reasonable duration. It would not be appropriate for the extended maritime work periods that were described earlier because the model tends toward a zero TLV-TWA as the number of consecutive work hours approaches 24.

OSHA Field Manual

Chapter XIII of the 1979 OSHA Industrial Hygiene Field Operations Manual is entitled "Modification of PELs for Prolonged Exposure Periods". The prolonged periods that are considered essentially represent land-based novel work schedules, e.g. four 10-hour days/week, six 7-hour days/week. As such, the maritime novel work schedule would be excluded. However, there are certain features of the assessment procedure that may have application to the marine work environment.

The adjustment procedure begins with the compound under consideration. Each substance in 29 CFR Part 1910.1000 is assigned to one of six work schedule categories. This categorical assignment governs the extent of allowable PEL adjustment. The six categories and the adjustment criteria are summarized in Table II, which was extracted from Page XIII-5 of the Field Manual. Examples of products that are shipped by water and which would have no allowable OSHA PEL adjustment are shown below.

Work Category Schedule	Chemicals with no Allowable OSHA PEL Adjustment
1A	Chlorine, Chloroform, TDI, o-Dichlorobenzene
IB	MEK, Ethyl acetate, Allyl alcohol
1C	Vinyl chloride, Dibutyl phthalate, Benzene

An update of the Field Manual based on the 1984-85 ACGIH TLV list would result in marine chemicals such as butanol and gluteraldehyde being included in Category 1A. Categories 2 through 4 permit a PEL adjustment. These adjustments are based on reciprocity, i.e., equivalency of dose between the conventional and novel work schedule. This approach neglects any reduction in the biological recovery period that results from a novel work schedule.

Table II. Summary of Work Schedule Categories

Work Schedule Category	Principle Group Characteristic	Conditions Resulting in Adjustment	Adjustment Formula
1A	Ceiling limit standards	None	None
1B	Irritants	None	None
1C	Technologic limitations	None	None
2	Acute toxicity only	Exposed >8 hours/day	Adj. PEL= PEL x 8 hours/ hours exposed/day
3	Cumulative toxicity only	Exposed 40 hours/ week	Adj. PEL = PEL x 40 hours/ hours exposed week
4	Both acute cumulative toxicity	Exposed >8 hours/day and/or exposed greater than 40 hours/week	The equation for Category 2 or 3, whichever results in the greatest protection

The "no adjustment" criterion for Categories 1A and 1B is clear. Category IC can be clarified. Substances in this category reflect industries or processes for which there is a physical limit on the state-of-the-art for engineering controls. According to the OSHA categorization, there are few marine chemicals in Category 1C.

The Field Operations Manual was updated in August 1983, but the section dealing with PEL adjustment remained intact. The reference PELs from the 1968 ACGIH TLV list were not updated.

The concept of "no adjustment" of exposure limits for Categories 1A, 1B and IC may be conveniently applied to the marine environment because the determinations are independent of work schedules. However, if this criterion were to be used, then the reference exposure limits should reflect the most current and conservative values.

On the basis of biological purge period considerations, it is not clear that the adjustments for Categories 2, 3 and 4 are applicable to the marine environment. The adjustments based on reciprocity or equivalency of dose may be applicable for certain substances that are cleared rapidly from the body, e g , substances with half-lives less than eight hours. However, for substances with half-lives greater than eight hours, the purge period may be insufficient to eliminate residual body burden regardless of the number of work hours preceding the break or the allowable adjusted exposure limit. Adjustments in Categories 2, 3 and 4 should reflect the actual work schedule and the most current exposure limits. Current adjustments do not reflect the decreased purge period.

On the basis of exposure duration, the adjustments in Categories 2, 3 and 4 are not applicable to parcel chemical tankers because the operations that are conducted and the variety of chemicals handled do not result in continuous exposure situations that exceed 8 hours/day or 40 hours/week. Further research would be needed to determine the applicability of Category 2 through 4 adjustments for single product tankers where extended work schedules during tank gauging and cleaning may result in exposure to a single substance for greater than eight hours.

The assumptions of equality of peak body burden, constant exposure level during a shift and periodic, equal duration work shifts permit a closed form solution for some of the TLV adjustment factor models. While these assumptions may be valid in certain cases, the closed form approach does not reflect the variable exposure profiles and extended work periods that are characteristic of marine operations. It is plausible that at some point in time these factors could result in a body burden that would temporarily exceed the corresponding accumulation from a TLV-TWA exposure.

To demonstrate this point, the first order differential equation for body burden accumulation as presented by Mason and Dershin was integrated for an arbitrary exposure duration and initial body burden. The equation reflects the partitioning of the vapor between the air and body spaces. A similar expression was developed for clearance during non-exposure periods. By applying these equations in a piecewise fashion, it was possible to calculate the time-dependent body burden for variable exposure levels and durations within a shift. Extended work shifts and reduced rest periods are easily represented. It was assumed that the exposure concentration was constant over the sampling interval, which was less than the duration of a 4-hour watch. As a boundary condition, the body burden at the beginning of the next time interval of interest was required to be equal to the burden at the end of the preceding interval.

The measured occupational exposure data in Figure 1 were input to the formulation. This figure indicates that exposure commenced with the beginning of a 4-hour watch. The body burden for this exposure profile is shown in Figure 2 together with the accumulation that would be predicted for a constant exposure at the current TLV-TWA. An initial body burden of zero was assumed. The actual chemical substance that is reflected in the body burden profiles is unimportant. The relevant point is that the actual body burden temporarily exceeded that which would be predicted for a TLV-TWA exposure. The amount and duration of such temporary deviations may be important to the toxicologist in assessing the impact of the exposure environment.

Several methods of TLV adjustment have been presented and discussed including methods based on body burden accumulation models. The concept of TLV adjustment for unusual work schedules is relatively new. Consequently, there is no single model that is totally acceptable for the maritime work/exposure scenario. The American Industrial Hygiene Association has a standing committee to give guidance on TLV adjustment. The efforts of this committee have just begun, with a long-term goal of developing formal TLV adjustment guidelines.

In the marine environment, novel or unusual work schedules with prolonged work shifts may not permit an adequate reduction of body burden of chemicals and thereby invalidate TLV-TWA and PEL values. In addition, exposure excursions may frequently exceed acceptable limits because control and monitoring of concentrations, durations and frequency of exposure are not readily accomplished during marine operations. This same limitation on control and monitoring may result in marine worker exposures that exceed other standards such as the TLV-STEL, TLV-C and OSHA ceiling values. Furthermore, these standards, as well as the 8-hour time-weighted averages, may not be applicable to many of the exposures of marine workers to mixtures of chemicals which have interactive effects.

Adjustment of existing standards to the exposure conditions of marine operations appears to be a promising approach to ensure a safe environment for the marine worker. However, present adjustment models have limitations, which have been discussed, and need further development and validation before they should be used for many of the types of exposures encountered during marine operations. For the present, the most prudent approach is the conservative application and interpretation of existing guidelines.

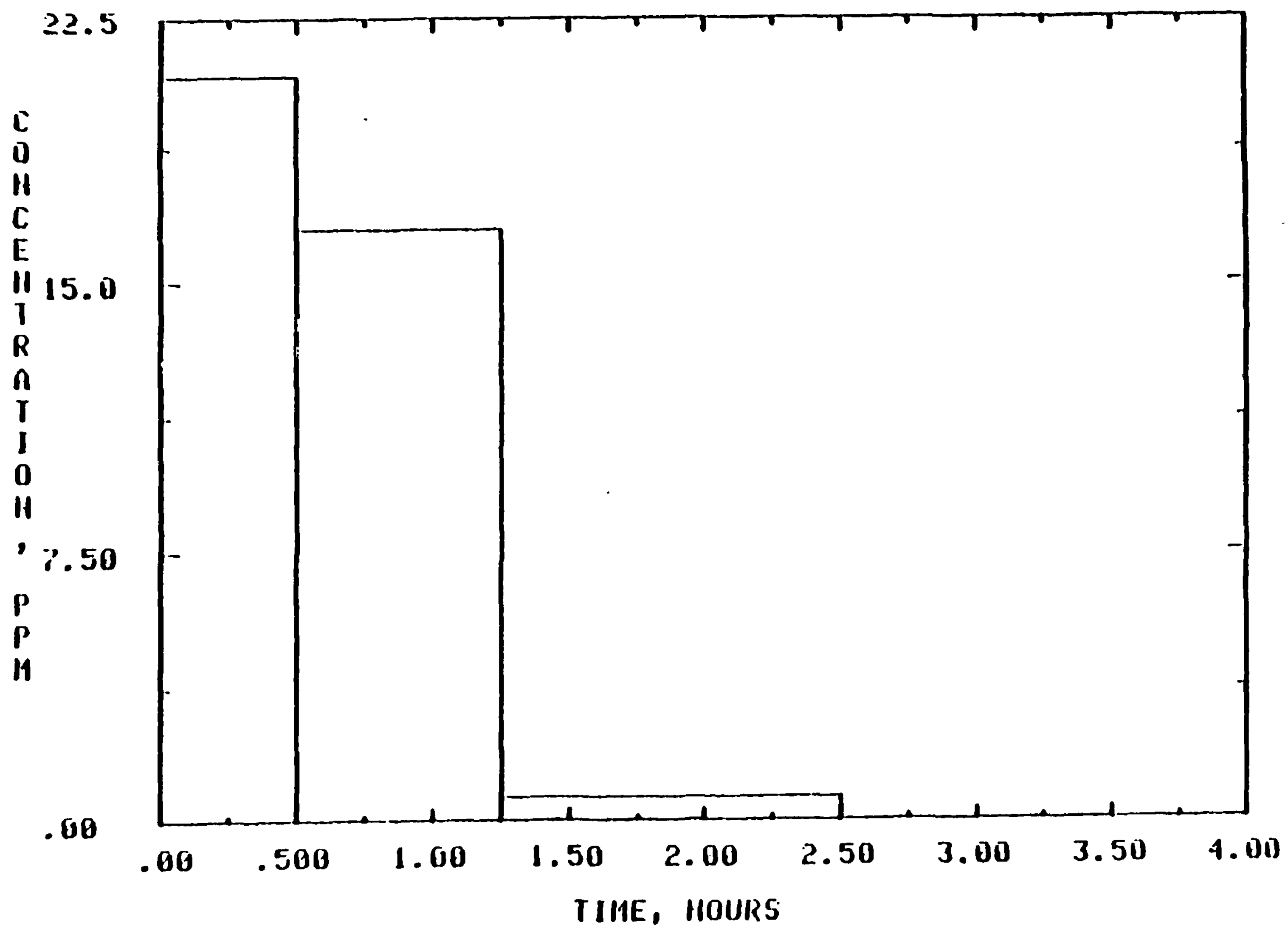

FIGURE 1. EXAMPLE EXPOSURE PROFILE DURING A FOUR-HOUR WATCH

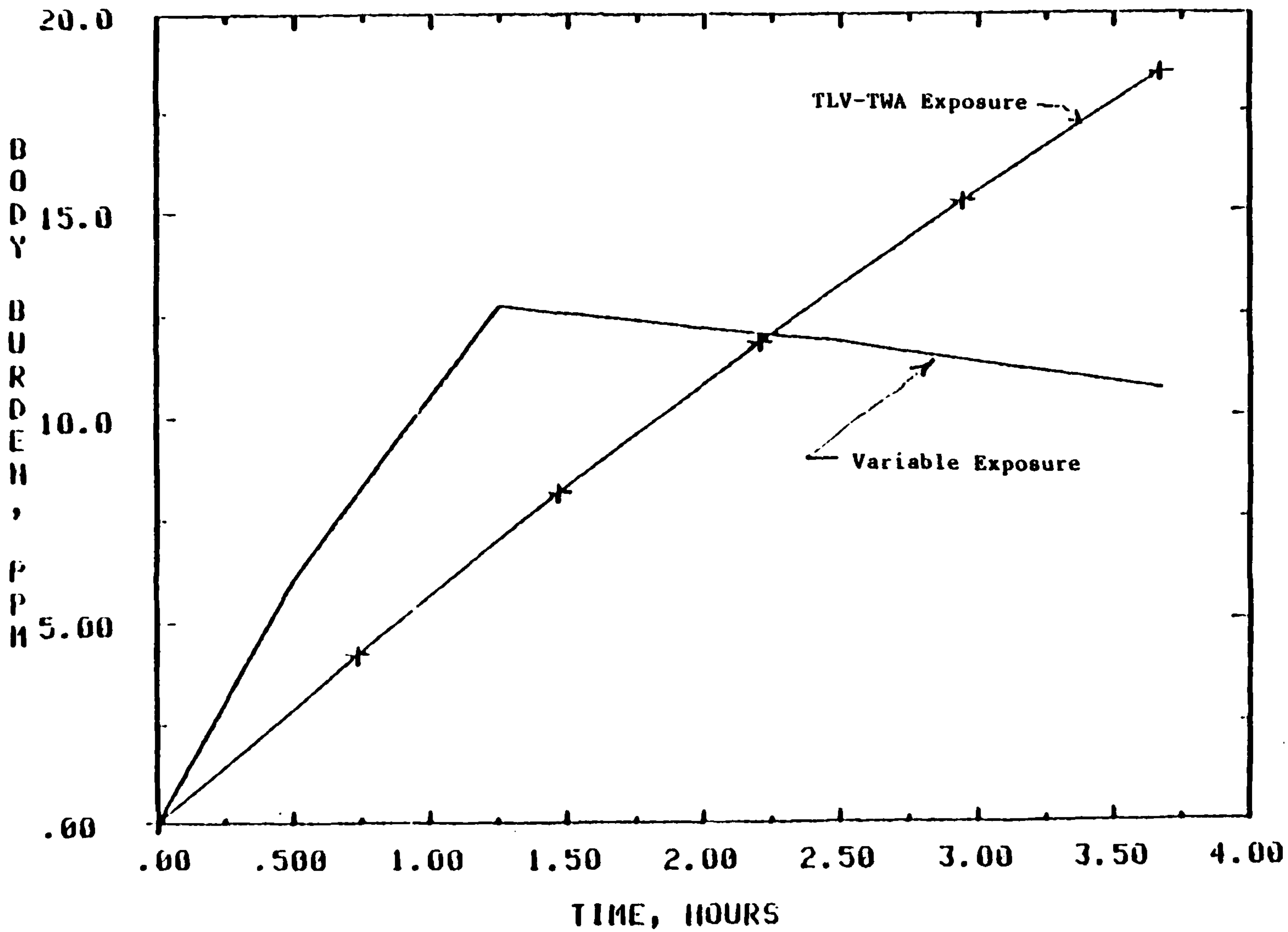

FIGURE 2. CUMULATIVE BODY BURDEN FOR A TLV-TWA EXPOSURE AND THE EXPOSURE PROFILE FROM FIGURE 1.

The main purpose of this section has been to introduce some of the factors that impede the application of established exposure limits (or their adjustment) to the maritime work environment. A conservative interpretation method based on the use of existing TLVs was developed in Reference 15. This method is described and applied to the exposure data in Section IV.

IV. DATA INTERPRETATION

The occupational exposure data in Volume II - Part B were collected on six independent voyages. All of the exposure concentrations and durations have been duplicated in this section. To the maximum extent possible, the data from these six voyages were combined and then grouped according to major work activities, e.g. tank gauging, tank entry, etc. The interpretation method that is defined in Section IV.1 was then applied to all of the data from the six voyages that were included under a given work activity heading. In the remainder of this section, the results are presented separately for each work activity.

The work activities on Voyage 2 (Engine Room/Pump Room) and Voyage 4 (Sour Crude Oil) could not be conveniently grouped with data from other voyages. Therefore, the results from these two voyages are presented and discussed separately. The noise monitoring data have also been combined in a single presentation.

IV.1 Ground Rules

The need for an appropriate exposure interpretation guideline for marine operations was documented initially in Reference 5 and then later in Reference 6. The previous section of this report summarized some of the issues that form the basis of that need. An exposure interpretation method, based on existing TLVs, was developed and applied to marine chemical exposures in Reference 14. That method consists of the following elements and logic.

- Exposure interpretation is based on the current ACGIH Threshold Limit Values or Company Occupational Exposure Limits (OEL) if the product has no published ACGIH TLV.

- A "medical monitoring response level" is defined to be one-half of the TLV-TWA for individual chemicals or vapor mixtures regardless of exposure duration.

- Exposure concentrations less than the medical monitoring response level are not considered to be toxicologically significant.

- Exposures greater than or equal to the medical monitoring response level are considered to be toxicologically significant and are designated occupational exposures for medical monitoring purposes. The precedent for this criterion is contained in Chapter 12 of the USCG Medical Manual (COMDTINST M6000.1) dated 8 August 1984.

- Detailed exposure durations are not considered in this initial screening process because it is assumed that the individual encounters similar concentrations for a cumulative exposure duration of 3 days/calendar quarter. This assumption is consistent with the USCG Medical Manual.

- If an exposure concentration exceeds the TLV-TWA, then a potential hazard is presumed to exist in addition to the exposure being subject to a medical monitoring requirement.

- After the mechanics of the above screening have been completed, then those exposures that are greater than the TWA are reviewed toxicologically on an individual basis. This review, which considers exposure duration, utilizes known effects of exposure to a given vapor, and the results of the review determine if any change in the classification is justified, i.e. did the presumed hazard exist.

This interpretation procedure is conservative. Being conservative is adaptable to maritime organizations that do not have the full-time services of a resident toxicologist.

The results of applying this scheme to the voyage data are presented in the next several subsections. The initial classification and any toxicological adjustment to this classification are presented in tables that contain the exposure data for a given work activity. These results have been categorized by major work activities such as confined space entry, which can include cargo tanks, ballast tanks and other void spaces.

The summary table for a given work activity contains a column labeled "Toxicological Hazard Assessment". Those exposures that exceed a TLV-TWA (for individual compounds or mixtures) will have an entry in this column. The entry represents the results of a toxicological assessment of the exposure to determine whether or not the presumed hazard did indeed exist. The code contains an alphabetical prefix and a numerical suffix. One of the following prefixes is associated with each evaluation.

NH - Nonhazardous
PH - Potentially hazardous
VH - Very hazardous

None of these hazard classifications negate the medical monitoring requirement because the exposure still exceeds the medical monitoring response level. The numerical suffix provides toxicological basis for the hazard assessment, and one of the following numerical codes will be indicated.

Suffix	Description
1.	The exposure concentration and duration are below threshold reported for toxic effects.
2.	The exposure may result in eye, nose and throat irritation and dizziness.

Suffix	Description
3.	The exposure is unlikely to cause more than slight eye irritation.
4.	The exposure may result in upper respiratory tract irritation with cough and hoarseness.
5.	The exposure may cause moderate irritation of eyes, nose and throat.
6.	The exposure concentration is sufficiently high to cause anesthetic and narcotic effects.
7.	Significant absorption is possible through the skin; chronic exposures to low concentrations may produce severe central nervous system and hematologic effects.
8.	Significant absorption is possible through the skin; the exposure may result in eye irritation and headache. Also, hearing loss has been reported for chronic exposures to low concentrations.
9.	Adverse respiratory effects possible from high concentration of particulates.
10.	The exposure is sufficiently high to produce anesthetic effects.
11.	The exposure is considered potentially hazardous because of the high concentration, although the short duration exposure may not cause toxic effects.
12.	The excessively high concentration may produce central nervous system effects and elevated carboxyhemoglobin levels despite the short exposure duration. Smoking of tobacco products can compound this problem.
13.	The exposure concentration is sufficiently high to cause central nervous system effects.

Suffix	Description
14.	The exposure is considered potentially hazardous even though the duration is short because toxic effects have been reported at lower concentrations. There are large differences in individual susceptibility to this chemical, and a wide variety of organs may be affected.
15.	The exposure concentration is sufficiently high to cause eye irritation, light headedness, drowsiness and other symptoms.

In addition, the number and percentage distribution of exposures relative to the various TLV indices is presented. When comparisons involve products that do not have a TLV-STEL then an excursion limit of three times the TLV-TWA was assumed. This approach is consistent with the recommendations made by the ACGIH in 1984. Company occupational exposure limits have been used in the analyses when the products involved have no ACGIH TLV.

IV.2. Tank Gauging - Loading

A preloading conference is held on the tanker prior to the start of loading. One of the purposes of this conference is to confirm the quantity and tank assignment of each cargo that is to be loaded. This information defines the final ullage (distance measured from a deck reference point down to the liquid surface) for each tank.

Tank gauging is the process of measuring the ullage. During the initial and intermediate stages of tank loading, the ullage is measured periodically. The frequency is determined by the loading rate, size of the tank and the amount of cargo to be loaded into the tank, and it may be one or two times per hour or more. As the final stage of a tank loading is reached, the gauging process may be conducted continuously until the correct amount of cargo has been loaded; then the transfer is terminated. This latter stage of relatively continuous ullage measurement is termed tank topoff.

There are basically three methods for measuring cargo ullage.

- o Open gauging - In this method, a graduated tape is lowered into the tank through an open ullage port. Since cargo is being loaded while gauging is taking place, vapors are forced out of the open ullage port into the breathing zone of the crew member who is conducting the gauging. During tank topoff at the end of loading, the vapor concentration at the ullage port may approach or equal the saturation concentration for the cargo temperature. Open gauging was performed on Voyages 1 and 5.

- o Restricted gauging - Two restricted gauging methods were observed on this project. The most common method, and the one that was used on Voyage 3, utilizes a small diameter sounding tube that penetrates the deck and extends into the tank to within one meter of the tank bottom. The liquid ullage is gauged through the sounding tube using a graduated tape. The potential for vapor exposure with a sounding tube is less than with the open gauging method. The second restricted gauging system consisted of a portable device, that permitted the gauging tape to penetrate the deck into the ullage space. Sounding tubes were not involved. An audible signal sounded when a transducer at the end of the tape contacted the liquid. The tape slides between two elastomeric wipers. These wipers plus the mechanical fixturing are intended to minimize vapor release to the work environment. This second system was in use on Voyage 6 for most of the tank topoffs.

- o Closed gauging - On closed gauging systems, electro/mechanical sensing devices are encapsulated in structural housings such that there are no openings through which cargo vapor or liquid can escape. A visual indication of ullage is displayed at each tank and perhaps remotely in the cargo control room. Two closed gauging systems were installed on each tank on Voyage 6, and these systems were used primarily for periodic gauging.

Seventy-two vapor exposure samples were collected during gauging of tanks that were being loaded. These samples reflect the use of all three classes of gauging systems for periodic and topoff gauging. The numerical distribution of the samples was as follows.

Gauging Activity	No. Samples
Periodic Open Gauging	22
Open Tank Topoff	21
Periodic Restricted Gauging (Sounding Tube)	5
Periodic Closed Gauging	10
Restricted Tank Topoff (Sounding Tube)	5
Restricted Tank Topoff (Portable Device)	9

The exposure monitoring data are presented in Table III. Each exposure data point was evaluated using the interpretation mechanics outlined earlier. The results of this evaluation relative to the medical monitoring response level and the various exposure indices are also shown in Table IV. Table IV is based on Table III and presents the results in summary form.

TABLE III. SUMMARY OF OCCUPATIONAL VAPOR EXPOSURES DURING GAUGING WHILE TANKS ARE BEING LOADED

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Code*	TWA/2	TWA/2-TWA	TWA-STEL	STEL	Toxicological Hazard Assessment
3M	Gasoline**	107.0	177	300	500	PO	X				
	Benzene	1.2		10	25						
3M	Gasoline	296.1	57	300	500	PO			X		NH-1
	Benzene	1.2		10	25						
3M	Gasoline	5.0	56	300	500	PO	X				
	Benzene	ND		10	25						
3M	Gasoline	122.2	231	300	500	PO/B		X			
	Benzene	1.1		10	25						
AB	Gasoline	199.4	173	300	500	PO		X			
	Benzene	1.1		10	25						
AB	Gasoline	907.5	43	300	500	PO				X	PH-2
	Benzene	5.7		10	25						
CM	Gasoline	ND	76	300	500	PO/B	X				
	Benzene	ND		10	25						
Pumpman	Stoddard Solvent	111.1	49	100	200	PO/B			X		NH-3
3M-1	Vinyl Acetate	21.4	184	10	20	PO				X	PH-4
3M-1	Isopropyl Alcohol	112.6	164	400	500	PO	X				
2M	Isopropyl Alcohol	376.4	115	400	500	PO		X			
3M-2	Isopropyl Alcohol	656.8	62	400	500	PO				X	PH-5
A/B-2	Isopropyl Alcohol	221.3	73	400	500	PO		X			
2M	n-Propyl Alcohol	ND	67	200	250	PO	X				
3M-2	Methyl Ethyl Ketone	1.4	159	200	300	PO	X				
2M	Butanol	ND	126	C50***	-	PO	X				
3M-1	Butanol	36.2	96	C50	-	PO		X			
3M-2	Butanol	17.0	81	C50	-	PO	X				

* PO - Periodic Open Gauging
OTO - Open Tank Topoff
PR - Periodic Restricted Gauging
RTO - Restricted Topoff
B - Ballasting of Cargo Tanks
PC - Periodic Closed Gauging

** Gasoline is used generically to include any of three grades of motor fuel or jet fuel and combinations thereof.
*** C Denotes Ceiling Threshold Limit Value.

TABLE III. SUMMARY OF OCCUPATIONAL VAPOR EXPOSURES DURING GAUGING WHILE TANKS ARE BEING LOADED (Continued)

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Code*	TWA/2	TWA/2-TWA	TWA-STEL	STEL	Toxicological Hazard Assessment
AB-5	Ortho Xylene	15.5	142	100	150	PO	X				
AB-7	Ortho Xylene	2.2	138	100	150	PO	X				
3M-2	Ortho Xylene	6.5	110	100	150	PO	X				
3M-1	Ortho Xylene	4.7	146	100	150	PO	X				
3M	Gasoline	4839.0	31	300	500	OTO				X	VH-6
	Benzene	20.8		10	25						
3M	Gasoline	2997.0	47	300	500	OTO				X	VH-6
	Benzene	16.5		10	25						
3M	Gasoline	81.3	88	300	500	OTO	X				
	Benzene	0.7		10	25						
A/B	Gasoline	428.3	177	300	500	OTO			X		PH-2
	Benzene	0.3		10	25						
A/B	Gasoline	46.9	50	300	500	OTO	X				
	Benzene	ND		10	25						
C/M	Gasoline	2662.0	52	300	500	OTO				X	VH-6
	Benzene	16.5		10	25						
2M	Cellosolve Acetate	12.9	7	5(skin)	-	OTO			X		PH-7
2M	Ethanol	ND	26	1000	-	OTO	X				
2M	Vinyl Acetate	0.5	12	10	20	OTO	X				
3M-2	Isopropyl Alcohol	238.7	9	400	500	OTO		X			
3M-1	HPH Fuel	ND	26	See Appendix E of Vol. II - Part B		OTO	X				
3M-2	Methyl Ethyl Ketone	50.0	57	200	300	OTO	X				
C/M	Butanol	13.2	10	C50***	-	OTO	X				
3M-2	Butanol	81.6	22	C50	-	OTO			X		PH-8
3M-2	Butanol	5.2	17	C50	-	OTO	X				
3M-2	Butanol	181.7	6	C50	-	OTO				X	PH-8

* PO - Periodic Open Gauging
OTO - Open Tank Topoff
PR - Periodic Restricted Gauging
RTO - Restricted Topoff
B - Ballasting of Cargo Tanks
PC - Periodic Closed Gauging

** Gasoline is used generically to include any of three grades of motor fuel or jet fuel and combinations thereof.

*** C Denotes Ceiling Threshold Limit Value.

TABLE III. SUMMARY OF OCCUPATIONAL VAPOR EXPOSURES DURING GAUGING WHILE TANKS ARE BEING LOADED (Continued)

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Code*	TWA/2	TWA/2-TWA	TWA-STEL	STEL	Toxicological Hazard Assessment
3M-2	Orthoxylene	119.9	12	100	150	OTO			X		NH-1
3M-2	Orthoxylene	9.2	4	100	150	OTO	X				
2M	Orthoxylene	111.0	104	100	150	OTO			X		NH-1
2M	Orthoxylene	116.4	29	100	150	OTO			X		NH-1
3M-2	Orthoxylene	42.4	15	100	150	OTO	X				
2M	Methylene Chloride	0.2	97	100	500	PR	X				
3/M-1	Six Chemicals+	ND	227	NA	NA	PR	X				
2M	Acetone	7.7	149	750	1000	PR	X				
PRO-1	Styrene	ND	132	50	100	PR	X				
3/M-2	Methylene Chloride	0.3	221	100	500	PR	X				
	Perchloroethylene	0.1		50	200						
AB2	****	10.7	204	100	-	PC	X				
	Paraxylene	0.1		100	150						
AB2	Heptane	1.1	201	400	500	PC	X				
	****	12.6		100	-						
	Paraxylene	1.0		100	150						
AB6	Hexane	0.4	249	50	-	PC	X				
	****	1.7		100	-						
	Paraxylene	0.2		100	150						
ABS	Hexane	ND	249	50	-	PC	X				
	****	13.5		100	-						
	Paraxylene	ND		100	150						
AB3	****	20.3	76	100	-	PC	X				
	Paraxylene	1.5		100	150						
AB1	****	3.3	209	100		PC	X				
	Paraxylene	0.7		100	150						

+ The following chemicals were not detectible: acetone, ethylene dichloride, styrene, methylene chloride, perchloroethylene, and 1,1,1-trichloroethane.

* PO - Periodic Open Gauging
OTO - Open Tank Topoff
PR - Periodic Restricted Gauging
RTO - Restricted Topoff
B - Ballasting of Cargo Tanks
PC - Periodic Closed Gauging

** Gasoline is used generically to include any of three grades of motor fuel or jet fuel and combinations thereof.

*** C Denotes Ceiling Threshold Limit Value.

**** Several wide boiling point range products with various TWAs were involved during these samples. The TWA figure shown is the lowest for all products involved and may be either an ACGIH TWA or a corporate occupational exposure limit.

TABLE III. SUMMARY OF OCCUPATIONAL VAPOR EXPOSURES DURING GAUGING WHILE TANKS ARE BEING LOADED (Concluded)

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Code*	TWA/2	TWA/2-TWA	TWA-STEL	STEL	Toxicological Hazard Assessment
AB4	****	28.7	147	100	-	PC	X				
	Paraxylene	11.8		100	150						
AB1	Heptane	1.3	176	400	500	PC		X			
	****	94.8		100	-						
	Paraxylene	1.3		100	150						
PM1	Heptane	0.5	309	400	500	PC	X				
	****	7.6		100	-						
	Paraxylene	0.8		100	150						
PM2	Hexane	2.7	471	50	-	PC	X				
	****	15.2		100	-						
	Paraxylene	2.5		100	150						
3/M-1	Acetone	176.6	36	750	1000	RTO	X				
PRO-1	1,1,1-Trichloroethane	58.4	21	350	450	RTO	X				
PRO-2	Styrene	7.5	28	50	100	RTO	X				
PRO-2	Styrene	6.6	14	50	100	RTO	X				
PRO-1	1,1,1-Trichloroethane	56.9	44	350	450	RTO	X				
3M3	Stoddard Solvent B	25.2	5	200++	-	RTO	X				
ABG	Paraffinic Solvent	7.9	10	300++	-	RTO	X				
3M2	Methyl Ethyl Ketone	66.4	29	200	300	RTO	X				
AB5	Stoddard Solvent A	33.7	29	100	200	RTO	X				
AB1	Extra Unleaded Gas	220.9	28	300	500	RTO			X		NH-1
	Benzene in Gasoline	1.0	28	10	25						
	Hexane in Gasoline	48.0	28	50	-						
OS2	Gasoline Blend Stock	73.1	25	100++	-	RTO		X			
AB5	Hexane	23.0	19	50	-	RTO	X				
AB5	Gasoline Blend Stock	809.3	14	100++	-	RTO				X	PH-2
	Benzene in Blend Stock	0.3	14	10	25						
	Hexane in Blend Stock	399.1	14	50	-						
AB4	Paraxylene	51.6	43.0	100	150	RTO		X			

* PO - Periodic Open Gauging
OTO - Open Tank Topoff
PR - Periodic Restricted Gauging
RTO - Restricted Topoff
B - Ballasting of Cargo Tanks
PC - Periodic Closed Gauging

** Gasoline is used generically to include any of three grades of motor fuel or jet fuel and combinations thereof.
*** C Denotes Ceiling Threshold Limit Value.
**** Several wide boiling point range products with various TWAs were involved during these samples. The TWA figure shown is the lowest for all products involved and may be either an ACGIH TWA or a corporate occupational exposure limit.

TABLE IV. PERCENTAGE DISTRIBUTION OF GAUGING EXPOSURES DURING LOADING ARRANGED ACCORDING TO GAUGING METHOD

Gauging Method	<TWA/2	TWA/2-TWA	TWA-STEL	>STEL
Periodic Open Gauging (22)*	54.5	22.7	9.1	13.5
Open Tank Topoff (21)	47.6	4.8	28.6	19.0
Periodic Restricted Gauging with Sounding Tube (5)	100.0	--	--	--
Periodic Closed Gauging (10)	90.0	10.0	--	--
Restricted Tank Topoff with Sounding Tube (5)	100.0	--	--	--
Restricted Tank Topoff (Portable Device) (9)	55.6	22.2	11.1	11.1

*Numbers in parentheses indicate total number of samples for each gauging method.

The following observations pertain to these gauging data.

- o It is clear that restricted gauging devices that employ sounding tubes are effective engineering controls for maintaining gauging exposures below the medical monitoring response level during product loading.
- o Conversely, 45.5 percent of the periodic open gauging and 52.4 percent of the open tank topoff exposures exceeded the medical monitoring response level and would be toxicologically significant for medical monitoring purposes.
- o Workplace documentation did not reveal the source of vapor or work activity that produced the one closed gauging exposure above the medical monitoring response level. Based on the assumption that it was unrelated to the actual gauging, then the results confirm the effectiveness of closed gauging systems.
- o The portable restricted gauging device that was observed was not as effective as the sounding tube in reducing topoff exposures. The portable device had an audible alarm that was triggered when the tape bob contacted the liquid surface. A

high background noise, such as from high velocity vapor vents, masked the alarm such that it could not be heard within two to three feet of the device. To compensate, the gauger put his ear next to the alarm. In this position, his breathing zone was adjacent to the localized stream of product vapor that escaped from between the tape and the two elastomeric wipers/ seals. This situation could be remedied by redesigning the portable device to add a visual alarm that is triggered along with the audible alarm. The effectiveness of other restricted gauging devices which do not make use of a sounding tube is unknown.

- The toxicological assessment of exposures greater than the TLV-TWA (individual components or mixtures) indicates that the presumed hazard did exist in 11 out of 17 of the exposures so classified.

IV.3. Tank Washing and Ventilating

Following product discharge, it may be necessary to clean one or more cargo tanks. Tanks may be cleaned in preparation for inspection or in-tank repairs or as a safety measure. The predominant reason, however, for cleaning tanks is to maintain cargo purity by minimizing contamination. Tank cleaning is conducted more frequently on parcel chemical tankers and product tankers than on vessels that carry crude oils.

The cleaning process usually involves three operations.

- The tank is washed with portable or fixed washing machines, and the water/cargo residue is removed from the tank via the main cargo pump and an eductor or fixed in-tank stripper pump. If portable washing machines are used, they are manually lowered into the tank according to a predetermined time/depth plan.
- After the tank is washed, forced ventilation is applied to the tank primarily for the purpose of evaporating remaining moisture on the tank walls and bottom and removing vapors from the tank atmosphere.
- Finally, the tank may be entered for manual mucking of residual water/cargo slops or for inspection or repair.

This section addresses the measured exposures during the washing and ventilating operations. Both of these operations may be conducted simultaneously on several tanks. Thus, the vapor environment on deck can contain contributions from both the washing and ventilating operations.

A total of 67 occupational exposure samples were collected during the washing and ventilating operations. There was no detectible exposure on seven of these samples. This fact has been taken into account in the following analysis of the data, which are summarized in Table V.

TABLE V. SUMMARY OF TANK WASHING AND VENTILATING EXPOSURES

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	<TWA/2	TWA/2-TWA	TWA-STEL	>STEL	Toxicological Hazard Assessment
AB	Gasoline	146.8	354	300	500		X			
	Benzene in Gasoline	0.7	354	10	25					
OS	Gasoline	143.2	333	300	500		X			
	Benzene in Gasoline	0.7	333	10	25					
OS	Gasoline	63.5	309	300	500	X				
	Benzene in Gasoline	0.3	309	10	25					
AB	Gasoline	63.3	261	300	500	X				
	Benzene in Gasoline	0.6	261	10	25					
OS	Gasoline	42.4	341	300	500	X				
	Benzene in Gasoline	0.2	341	10	25					
CM	Gasoline	201.5	344	300	500		X			
	Benzene in Gasoline	2.08	344	10	25					
OS	Gasoline	83.6	285	300	500	X				
	Benzene in Gasoline	0.48	285	10	25					
CM	Gasoline	409.4	84	300	500				X	PH-5
	Benzene in Gasoline	6.1	84	10	25					
CM	Naphtha (Stoddard)	49.9	95	100	200	X				
Bosun	Naphtha (Stoddard)	36.9	77	100	200	X				
CM	Naphtha (Stoddard)	38.5	64	100	200	X				
Bosun	Naphtha (Stoddard)	35.8	50	100	200	X				
O/S-1	Naphtha (Stoddard)	23.0	132	100	200	X				
Bosun	Naphtha (Stoddard)	>89.8	149	100	200		X			
O/S-2	Naphtha (Stoddard)	18.0	57	100	200	X				
O/S-1	Naphtha (Stoddard)	7.8	90	100	200	X				
O/S-3	Naphtha (Stoddard)	14.0	50	100	200	X				
C/M	1,1,1-Trichloroethane	34.0	154	350	450	X				
	Methylene Chloride	29.2	154	100	500					
A/B-5	1,1,1-Trichloroethane	191.2	65	350	450		X			
A/B-5	Perchloroethylene	4.5	43	50	200	X				
Bosun	1,1,1-Trichloroethane	49.8	66	350	450	X				
	Methylene Chloride	0.3	66	100	500					
Bosun	1,1,1-Trichloroethane	138.3	85	350	450			x		NH-1
	Methylene Chloride	68.5	85	100	500					
Pumpman	1,1,1-Trichloroethane	181.7	115	350	450		X			
	Methylene Chloride	14.7	115	100	500					

TABLE V. SUMMARY OF TANK WASHING AND VENTILATING EXPOSURES (Continued)

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	<TWA/2	TWA/2-TWA	TWA-STEL	>STEL	Toxicological Hazard Assessment
Pumpman	1,1,1-Trichloroethane	21.0	40	350	450	X				
	Methylene Chloride	18.2	40	100	500					
	Perchloroethylene	0.5	40	50	200					
O/S-2	1,1,1-Trichloroethane	113.8	66	350	450	X				
O/S-2	1,1,1-Trichloroethane	69.0	66	350	450	X				
	Trichloroethylene	0.7	84	50	200					
O/S-2	1,1,1-Trichloroethane	10.2	18	350	450	X				
A/B-5	1,1,1-Trichloroethane	0.2	43	350	450				X	NH-1
	Ethylene Dichloride	10.1	43	10	15					
Bosun	n-Propyl Acetate	5.9	56	200	250	X				
A/B-5	n-Propyl Acetate	2.7	56	200	250	X				
A/B-1	n-Propyl Acetate	2.9	56	200	250	X				
Pumpman-1	n-Propyl Acetate	29.5	28	200	250	X				
A/B-3	n-Propyl Acetate	8.7	56	200	250	X				
A/B-4	n-Propyl Alcohol	0.8	53	200	250	X				
A/B-1	n-Propyl Alcohol	1.9	52	200	250	X				
Bosun	n-Propyl Alcohol	1.2	78	200	250	X				
Pumpman-2	n-Propyl Alcohol	2.9	72	200	250	X				
Pumpman-1	Vinyl Acetate	69.2	61	10	20				X	PH-4
A/B-2	Vinyl Acetate	62.6	46	10	20				X	PH-4
Pumpman-1	Ethyl Acetate	37.2	36	400	-	X				
Pumpman-1	n-Propyl Acetate	2.9	22	200	250	X				
A/B-6	Methanol	113.9	24	200	250		X			
Pumpman-2	Methanol	73.7	12	200	250	X				
Pumpman-1	Hexane	319.1	39	50	-				X	NH-1
A/B-3	Hexane	104.2	23	50	-		X			NH-1
O/S-2	Hexane	37.4	22	50	-		X			
A/B-6	Xylene	79.2	25	100	150		X			
	Hexane	7.0	25	50	-					
O/S-2	Xylene	15.9	98	100	150	X				
	Hexane	4.8	98	50	-					
	Methyl Ethyl Ketone	0.6	98	200	300					

TABLE V. SUMMARY OF TANK WASHING AND VENTILATING EXPOSURES (Concluded)

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	<TWA/2	TWA/2-TWA	TWA-STEL	>STEL	Toxicological Hazard Assessment
AB1	*	6.5	212	50*	-	X				
AB5	*	13.9	297	50*	-	X				
	Paraxylene	4.4	297	100	150					
AB1	Acetone	4.1	117	750	1000	X				
	*	3.1	117	100*	-					
AB2	Acetone	15.8	107	750	1000	X				
	*	6.5	107	100*	-					
PM1	*	5.4	147	50*	-	X				
PM1	*	41.0	399	50*	-		X			
	Paraxylene	9.4	399	100	150					
PM2	*	3.9	147	50*	-	X				
PM2	*	24.4	398	50*	-		X			
	Paraxylene	7.8	398	100	150					
PM1	*	13.2	507	50*	-	X				
	Toluene	3.7	507	100	150					
PM2	*	5.3	526	50*	-	X				
	Toluene	0.5	526	100	150					
PM1	Gasoline	5.0	123	300	500	X				
PM2	Gasoline	0.8	124	300	500	X				

* Several wide boiling point range products with various TWAs were involved during these samples. TWA figure shown is the lowest value for all products involved and may be either an ACGIH TWA or a corporate occupational exposure limit.

- 49 of the 67 (73.1%) exposure samples were less than the medical monitoring response level and are, thus, not toxicologically significant.

- 18 of the 67 (26.9%) exposure samples exceeded the medical monitoring response level, are toxicologically significant and are classed as occupational exposures for medical monitoring purposes.

- 11 or 16.4% of the exposure concentrations fell between the medical monitoring response level (TWA/2) and the TWA.

- 3 or 4.5% of the 67 exposure samples fell between the TWA and the STEL (or 3(TWA) if the compound had no STEL) for individual compounds or mixtures.

- 6% or 4 exposures exceeded the STEL (or 3(TWA) if no STEL exists) for individual compounds or mixtures.

- In addition to being classed as occupational exposures for medical monitoring purposes, 10.5% or 7 of these exposures occurred under conditions where a potential hazard would be presumed to exist.

- The toxicological assessment of exposures greater than the TLV-TWA (individual components or mixtures) indicates that the presumed hazard did exist in 3 out of 7 of the exposures so classified.

Several of the samples that are represented in the above analysis contained a mixture of product vapors. For these samples, the following procedure was used to determine the appropriate category of the exposure. Two quantities were calculated for each sample mixture.

$$\text{Quantity 1:} \quad \sum_{i=1}^{n} C_1/TWA_i \quad \text{and}$$

$$\text{Quantity 2:} \quad \sum_{i=1}^{n} C_i/STEL_i$$

where C_i is the measured component concentration and TWA_i and $STEL_i$ are the corresponding time weighted average and short-term exposure limit, respectively.

- If the numerical value of Quantity 1 was less than 0.5, then the mixture exposure was not toxicologically significant.

- o If the numerical value of Quantity 1 was greater than 0.5 but less than 1.0, the exposure was greater than the medical monitoring response level but less than the mixture TWA.

- o If the numerical value of Quantity 1 was greater than 1.0, the exposure obviously exceeded the mixture TWA. The possibility also existed that the exposure could have exceeded the mixture STEL. If the numerical value of Quantity 2 was less than 1.0, the exposure fell in the TWA to STEL category. The exposure to the mixture exceeded the STEL if the numerical value of Quantity 2 was greater than 1.0.

Tank washing and ventilating were conducted on four voyages. The distribution of the 67 exposure samples was as follows.

Voyage No	No. Samples
1	8
3	20
5	27
6	12
	67

Motor and jet fuel were transported on several voyages. Motor fuels included regular, unleaded and super unleaded gasoline. In evaluating the exposures to these products, benzene was considered to be the second component in a benzene/"gasoline" vapor mixture. The rationale for this decision is as follows. The ACGIH TWA and STEL account for the presence of benzene at a presumed average concentration in the liquid. As the TLV for "gasoline" is very sensitive to the benzene content, and the products involved all grades of gasoline and a jet fuel all with unknown benzene levels that contributed to the vapor environment, it was felt that the additive approach to evaluating "gasoline" exposures would present the most conservative results. Accordingly, the equivalent of Quantity 1, which was defined earlier, was applied to these samples.

The data in Table V represent the vapor exposures during two types of washing procedures. The last 12 exposure entries correspond to a washing procedure that involved closed tank hatches, fixed washing machines and venting of displaced vapors at elevation above deck. The remaining entries in the table reflect manual lowering/removing of portable washing hoses, cracked or open hatches and venting of displaced vapor through the hatch and Butterworth openings in the deck. Sixteen of the 18 unacceptable tank washing and ventilating exposures were received during the manual type of procedure which requires that the tank be opened during washing. The tank hatch is also open during ventilation. This procedure is used on nearly all parcel chemical and product tankers. The closed washing and venting system on the state-of-the art tanker resulted in a proportionately lower percentage (2 of 12) of unacceptable exposures than were measured on the conventional tankers (16 of 55). A less conservative approach in evaluating the 12 state-of-the art exposures (lowest TWA or OEL) would have enhanced the advantages of the new technology and procedures. But the conservative approach was warranted.

The following products or product combinations were involved in the washing/ventilating exposures where a hazard was presumed to exist (TWA exceeded).

- o Gasoline/Benzene
- o 1,1,1-Trichloroethane/Methylene Chloride
- o Ethylene Dichloride/1,1,1-Trichloroethane
- o Vinyl Acetate
- o Hexane

IV.4. Confined Space Entry

A total of 63 individual confined space entries were monitored at sea and in port. All but three of these entries involved cargo tanks, which were entered for manual cleaning, inspection or testing. Both Subchapter D and the more highly regulated Subchapter O products are represented. The remaining three entries involved ballast tanks.

On occasion, SwRI project members also wore monitoring equipment during a tank entry. That exposure data has not been evaluated as a crew exposure unless it was obtained from the only piece of monitoring equipment in the tank and other crew members were also present.

The exposures to be considered for evaluation are summarized in Table VI. The distribution of entries by voyage is as follows.

Voyage No.	No. Entries
1	0
2	1
3	21
4	2
5	28
6	11
	63

The exposure limits that are shown are 1984-85 ACGIH values except where no current value exists; then the corporate occupational exposure limit is shown. The majority of the entries involved a single component product. When multiple chemicals are indicated for a single tank, it indicates that the parent cargo was a mixture that contained those components. While grab samples and passive dosimeters may have been used in parallel with charcoal tube samples, only the latter results are shown in Table VI except in isolated cases where a grab sample was the only feasible alternative.

Based on the data in Table VI and the evaluation scheme criteria, the following observations can be made regarding occupational exposures during tank entry.

TABLE VI. SUMMARY OF CONFINED SPACE ENTRY EXPOSURES

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Tank No.	<TWA/2	TWA/2-TWA	TWA-STEL	>STEL	Toxicological Hazard Assessment
SwRI	Gasoline	18.0	80.0	300	500	Ballast	X				
QM	Hydraulic/Crude Oil	3.4	27.0	300*	500*	Ballast	X				
SwRI	Hydraulic/Crude Oil	0.82	65.0	300*	500*	Ballast	X				
Rosun	1,1,1-Trichloroethane	65.5	6.0	350	450	5A	X				
	1,1,1-Trichloroethane	890.5	2.0	350	450	5B				X	PH-10
	Methylene Chloride	1479.0	2.0	100	500	7P				X	PH-11
	Methylene Chloride	11890.0	2.0	100	500	7S				X	PH-12
C/M	1,1,1-Trichloroethane	140.0	GRAB	350	450	1A	X				
	Trichloroethylene	657.0	GRAB	50	200	1D				X	PH-13
	Styrene	95.0	10.2	50	100	3S,3P			X		NH-1
	1,1,1-Trichloroethane	172.8	3.1	350	450	5A	X				
	Methylene Chloride	615.9	9.0	100	500	7S,7P				X	NH-1
	Ethylene Dichloride	301.6	4.35	10	15	1B				X	PH-14
	Acetone	ND**	3.0	750	1000	2D	X				
	Perchloroethylene	146.8	2.7	50	200	3A			X		NH-1
	1,1,1-Trichloroethane	48.5	3.3	350	450	5B	X				
	Ethylene Dichloride	83.4	7.7	10	15	1B				X	PH-14
	Perchloroethylene	194.3	4.2	50	200	3A			X		NH-1
A/B-2	1,1,1-Trichloroethane	1718.0	16.0	350	450	1A				X	PH-10
A/B-3	Trichloroethylene	752.2	15.8	50	200	1D				X	PH-13
A/B-2	Perchloroethylene	256.0	22.0	50	200	1B				X	PH-15
	Ethylene Dichloride	140.2	18.2	10	15	3A				X	PH-14
A/B-3	Perchloroethyene	267.4	20.8	50	200	1B				X	PH-15
	Ethylene Dichloride	144.2	19.0	10	15	3A				X	PH-14
AB3	Isobutanol	16.7	10.0	50	75	5CP	X				
AB2	Isobutanol	25.3	10.0	50	75	5CP		X			
SwRI	Ethyl Acetate	4.6	9.0	400	-	2P	X				
AB2	Butanol	99.3	10.0	50C++	-	3S			X		PH-8
AB3	n-Propyl Acetate	5.9	22.0	200	250	3CP	X				

* Assumed valid for these products
** ND = Not Detectable
++ C denotes Ceiling Threshold Limit Values

TABLE VI. SUMMARY OF CONFINED SPACE ENTRY EXPOSURES (Continued)

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Tank No.	TWA/2	TWA/2-TWA	TWA-STE	STEL	Toxicological Hazard Assessment
AB5	Ethanol	12.9	13	1000	-	6CS	X				
AB5	Cellosolve Acetate	161.8	14	5	-	1S				X	PH-7
B7	Ethanol	233.8	14	1000	-	1P	X				
AB3	Vinyl Acetate	2.4	9	10	20	10CS	X				
AB2	Vinyl Acetate	1.6	13	10	20	10CP	X				
AB3	Vinyl Acetate	1.9	11	10	20	10CP	X				
AB2	n-Propyl Alcohol	10.4	26	200	250	4P	X				
AB1	Isopropyl Alcohol	60.8	11	400	500	2S	X				
AB4	Isopropyl Alcohol	71.5	8	400	500	2S	X				
AB3	Isopropyl Alcohol	3.2	11	400	500	2P	X				
AB1	Butyl Cellosolve	8.4	15	25	75	4CS	X				
AB2	Methyl Ethyl Ketone	22.0	28	200	300	6CS	X				
AB3	Hexane	85.7	23	50	-	8CS			X		NH-1
AB4	Hexane	156.7	25	50	-	8CS				X	NH-1
AB3	Xylene	34.8	24	100	150	6CP	X				
AB7	Methanol	27.9	19	200	250	3CP	X				
Bosun	Isophorone	ND**	5	5C++	-	1CP, 1CS	X				
	Diisobutyl Ketone	ND		25	-						
	Dicyclopentadiene	1.6		5	-						
AB3	Isophorone	0.2	24	5C	-	1CP	X				
	Diisobutyl Ketone	ND		25	-						
	Dicyclopentadiene	1.9		5	-						
Bosun	Isophorone	0.2	22	5C	-	1CP	X				
	Diisobutyl Ketone	ND		25	-						
	Dicyclopentadiene	2.2		5	-						
AB3	Isophorone	ND	37	5C	-	1CP	X				
	Diisobutyl Ketone	ND		25	-						
	Dicyclopentadiene	2.4		5	-						

* Assumed valid for these products
** ND = Not Detectable
++ C denotes Ceiling Threshold Limit Values

TABLE VI. SUMMARY OF CONFINED SPACE ENTRY EXPOSURES (Concluded)

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Tank No.	<TWA/2	TWA/2-TWA	TWA-STEL	>STEL	Toxicological Hazard Assessment
Bosun	Isophorone	0.3	52	5C	-	1CP		X			
	Diisobutyl Ketone	ND**		25	-						
	Dicyclopentadiene	3.0		5	-						
AB6	Isophorone	0.4	37	5C	-	1CS		X			
	Diisobutyl Ketone	ND		25	-						
	Dicyclopentadiene	3.2		5	-						
AB3	Isophorone	0.4	25	5C	-	1CS			X		NH-I
	Diisobutyl Ketone	ND		25	-						
	Dicyclopentadiene	4.7		5	-						
PM2	Paraxylene	5.7	18	100	150	5CA	X				
AB2	Process Oil B	ND	73	($5mg/m^3$)	-	7P	X				
CM	RFS+	2.4	88	(100)	-	7P,8P	X				
CM	RFS	1.9	19	(100)	-	8P	X				
OSI	RFS	6.5	10	(100)	-	8P	X				
OSI	RFS	3.6	25	(100)	-	8S	X				
CM	RFS	1.4	12	(100)	-	8S	X				
AB6	Unleaded Gas	37.8	72	300	500	11C	X				
CM	Unleaded Gas	122.7	47	300	500	11C	X				
CM	Unleaded Gas	3.0	16	300	500	11C	X				
PM2	Paraxylene	3.5	16	100	150	11PF	X				

\+ Refinery Feed Stock
( ) Corporate Occupational Exposure Limit
* Assumed valid for these products
** ND = Not Detectable
++ C denotes Ceiling Threshold Limit Values

- Of the 63 entries, 39 (61.9%) resulted in exposures that were not toxicologically significant.

- The remaining 24 entries (38.1%) resulted in exposures that exceeded the medical monitoring response level of TLV-TWA/2, are thus toxicologically significant and are classed as occupational exposures for medical monitoring purposes. Within those 24 exposures, the distribution expressed as a percentage of the total number of observations was as follows.

    - 4.8% of all entry exposures fell between TWA/2 and TWA.

    - 11.2% of all entries exceeded the TLV-C or fell between the TWA and the STEL (or 3(TWA) if the compound had no STEL).

    - 22.2% of all entries exceeded the STEL or 3(TWA) if there was no STEL.

- The above distribution indicates that 33.4% of all entries occurred under conditions where a potential hazard would be presumed to exist, i.e. vapor concentration was greater than the TWA.

- The toxicological assessment of exposures greater than the TLV-TWA (individual components or mixtures) indicates that the presumed hazard did exist in 14 out of 21 of the exposures so classified.

Tank entry is a work activity that presents a high potential for occupational exposure. In fact, the data indicate that in roughly 22% or in about one out of every five tank entries, the vapor environment was hazardous according to both the assessment criteria in this report and the ACGIH position. A variety of activities were performed during these entries including atmosphere testing, hand mucking of wash residues and debris, sweeping, vacuuming sumps and brief entries for maintenance. The following chemicals were involved in the exposures that exceeded the STEL or 3(TWA).

- 1,1,1-Trichloroethane
- Methylene Chloride
- Trichloroethylene
- Ethylene Dichloride
- Perchloroethylene
- n-Hexane

Four of these products, methylene chloride through perchloroethylene are regulated by the USCG under Subchapter O. Those regulations specifically require that the confined spaces be free of toxic vapor levels (as determined by physical testing) prior to entry. Hexane is regulated under Subchapter D which does not contain an analogous pre-entry testing requirement. Finally, 1,1,1-trichloroethane is not regulated by the USCG under Title 46 of the Code of Federal Regulations.

Of the entries that resulted in vapor exposures that were not toxicologically significant, all involved Subchapter D products with one exception, vinyl acetate, which is classified under Subchapter O. In addition, four of the acceptable entries involved 1,1,1-trichloroethane, which is not regulated under either Subchapter D or O.

The following observations can be made based on the monitoring data.

- o Tank entry exposures tend to be clustered into two groups - one in which the concentration was less than TWA/2 and the other in which concentrations exceeded the TWA by varying amounts.

- o There is little representation in the TWA/2 to TWA range.

- o Subchapter D products tend to dominate the group of acceptable entries.

- o Subchapter O products tend to dominate the unacceptable entries.

- o The clustering of exposures that is implied by the two preceding observations is not black and white. There are crossovers of Subchapter O, D and unregulated products in both groups.

- o The results and the shipboard observations tend to confirm previous research that has concluded that thorough washing, stripping and ventilating are key elements in generating an acceptable entry atmosphere. The condition of tank walls and any coating materials has a strong influence on the ability to successfully gas free a tank to an acceptable level independent of the cargo classification.

IV.5. Product Discharge - Tank Gauging, Tank Stripping and Related Activities

During product discharge, fresh air is ingested into the tank through either open ullage ports or vacuum breakers if the tank is closed. In the former case, the product level is gauged manually through the open ullage port or through a restricted gauging system. This was the situation on Voyages 1 and 3. On Voyage 6, closed tanks, closed gauging systems and vacuum breakers were in effect during discharge. As the net flow of air is into the tank, the exposure potential during periodic discharge gauging should be minimal, in either case. Gauging of product ullage is performed periodically. The gauging frequency, which is influenced by product quantity and pumpout rate, is roughly one or two ullage measurements per hour.

After the majority of the tank contents have been discharged, any remaining product must be stripped from the tank bottom and/or sump and sent ashore. Three different gauging techniques were observed and monitored during stripping.

- In the first gauging technique, the remaining liquid level on the bottom of the tank was observed continuously through either the open ullage port or while lying on the deck viewing through a Butterworth opening. This technique was practiced on Voyage 1.

- The second technique involved intermittent viewing of the remaining liquid level through a Butterworth opening but while standing or squatting as was practiced on Voyage 3.

- The third technique, which was used on Voyage 6, did not require the tank to be opened. Stripping of the tank sump was accomplished by permanently installed stripper pumps in the tank. The pumps were pneumatically operated with discharge into the cargo line downstream of the main cargo pump. This technique required no visual siting into the tank. An audible change in the stripper pump sound signaled the end of the stripping process. Appendix F in Volume II - Part B describes the range of work activities associated with gauging and stripping with the closed systems. Because the time required to gauge or strip a tank was minimal, watch personnel participated in other discharge tending activities.

Table VII summarizes the results of 43 occupational exposure samples that were collected during periodic discharge gauging and tank stripping. These results were obtained on the three voyages cited above, and collectively they confirm the results of previous discharge monitoring efforts.

The distribution of discharge monitoring samples was as follows.

Voyage No.	No. Samples
1	13
3	16
6	14
	43

The data in Table VII are clustered and are presented in the same voyage order as shown above. The following observations pertain to the data in Table VII.

- 95.3% or 41 of 43 of the discharge gauging and tank stripping exposures were not toxicologically significant because measured concentrations were less than the medical monitoring response level.

TABLE VII SUMMARY OF OCCUPATIONAL VAPOR EXPOSURES DURING PRODUCT DISCHARGE (TANK GAUGING AND STRIPPING)

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Activity	<TWA/2	TWA/2-TWA	TWA-STEL	Toxicological Hazard Assessment
3M	Gasoline+	5.2	94	300	500	G,S*	X			
	Benzene	ND**	94	10	25					
3M	Gasoline	18.9	125	300	500	G	X			
	Benzene	ND	125	10	25					
3M	Gasoline	8.0	240	300	500	G	X			
	Benzene	ND	240	10	25					
3M	Gasoline	8.9	65	300	500	S	X			
	Benzene	ND	65	10	25					
A/B	Gasoline	3.5	215	300	500	G	X			
	Benzene	ND	215	10	25					
A/B	Gasoline	2.2	60	300	500	G	X			
	Benzene	ND	60	10	25					
A/B	Gasoline	41.0	225	300	500	G	X			
	Benzene	0.25	225	10	25					
C/M	Gasoline	73.3	25	300	500	G	X			
	Benzene	ND	25	10	25					
2M	Gasoline	ND	31	300	500	S	X			
	Benzene	ND	31	10	25					
2M	Gasoline	167.0	21	300	500	S			X	NH-1
	Benzene	7.0	21	10	25					
2M	Gasoline	147.5	45	300	500	S	X			
	Benzene	ND	45	10	25					
C/M	Gasoline	135.6	23	300	500	S	X			
	Benzene	ND	23	10	25					
C/M	Gasoline	ND	15	300	500	S	X			
	Benzene	ND	15	10	25					
2M	Styrene	ND	181	50	100	G	X			

\+ On the first 13 entries gasoline is used generically to include any of three grades of motor fuel or jet fuel and combinations, thereof.

* G = Gauging
S = Stripping

** ND = Not Detectable

TABLE VII SUMMARY OF OCCUPATIONAL VAPOR EXPOSURES DURING PRODUCT DISCHARGE (TANK GAUGING AND STRIPPING) (Continued)

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Activity*	<TWA/2	TWA/2-TWA	TWA-STEL	Toxicological Hazard Assessment
Pumpman	Styrene	ND**	55	50	100	G	X			
3/M-1	Styrene	ND	183	50	100	G	X			
PRO-2	Styrene	0.9	162	50	100	G	X			
C/M	Styrene	5.8	16	50	100	S	X			
C/M	Styrene	ND	19	50	100	S	X			
3/M-2	1,1,1-Trichlooethane	0.1	116	350	450	G	X			
	Methylene Chloride	26.1	116	100	500					
	Ethylene Dichloride	0.2	116	10	15					
3/M-1	1,1,1-Trichloroethane	0.2	123	350	450	G	X			
	Trichloroethylene	0.4	123	50	200					
	Perchloroethylene	0.1	123	50	200					
	Ethylene Dichloride	1.9	123	10	15					
	Styrene	5.8	123	50	100					
3/M-2	Styrene	2.4	203	50	100	G	X			
C/M	Methylene Chloride	26.1	130	100	500	G	X			
	Styrene	2.4	130	50	100					
PRO-3	Stytrene	8.1	116	50	100	G	X			
3/M-1	Styrene	3.1	112	50	100	G	X			
PRO-3	Styrene	0.7	77	50	100	G	X			
C/M	1,1,1-Trichloroethane	0.4	84	350	450	G,S	X			
	Methylene Chloride	0.4	84	100	500					
3/M-2	Perchloroethylene	0.2	215	50	200	G	X			
C/M	Styrene	7.1	65	50	100	S	X			
2M	Acetone	ND	195	750	1000	See Text	X			
	Gasoline	0.1	195	300	500	↓				
3M1	Acetone	5.0	122	750	1000	↓	X			
	Gasoline	5.1	122	300	500	↓				

* G = Gauging
S = Stripping
** ND - Not Detectable

TABLE VII. SUMMARY OF OCCUPATIONAL VAPOR EXPOSURES DURING PRODUCT DISCHARGE (TANK GAUGING AND STRIPPING) (Concluded)

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Activity*	<TWA/2	TWA/2-TWA	TWA-STEL	Toxicological Hazard Assessment
AB4	***	4.0	208	50***	-	See Text	X			
	Toluene	0.4	208	100	150					
AB2	***	4.8	231	100***	-		X			
AB1	Stoddard Solvent	1.4	170	100	200		X			
	p-Xylene	1.0	170	100	150					
AB3	***	4.2	201	50***	-		X			
	Toluene	0.3	201	100	150					
AB1	***	1.0	229	100***	-		X			
	Toluene	ND**	229	100	150					
AB5	Acetone	3.3	205	750	1000			X		
	***	84.9	205	100***						
AB6	Acetone	10.3	206	750	1000		X			
	***	32.2	206	100***	1000					
PM2	Stoddard Solvent	0.9	433	100	200		X			
	p-Xylene	0.3	433	100	150					
PM2	***	2.9	206	50***	-		X			
	Toluene	0.2	206	100	150					
PM1	***	4.0	241	100***	-		X			
PM2	Acetone	ND	390	750	1000		X			
	Gasoline	1.4	390	300	500					
PM1	Stoddard Solvent	1.4	374	100	200		X			
	p-Xylene	0.9	374	100	150					

* G = Gauging
S = Stripping

** ND - Not Detectable

*** Several wide boiling point range products with various TWAs were involved during these samples. The TWA figure shown is the lowest value for all products involved and may be either an ACGIH TWA or a corporate occupational exposure limit.

- One of the 43 samples occurred under conditions which, according to the assessment criteria in this report, represented a potential hazard. That sample was collected on the Second Mate (2M) during tank stripping. The work practice involved lying on the deck and viewing the liquid surface nearly continuously through a Butterworth opening. This exposure would also be categorized as toxicologically significant for medical monitoring purposes.

- The toxicological assessment of exposures greater than the TLV-TWA (individual components or mixtures) indicates that the presumed hazard did not exist in the one exposure so classified.

- One discharge exposure sample exceeded the medical monitoring response level for a vapor mixture but was less than the mixture TWA. This sample would be classed as significant for medical monitoring purposes. This sample from Voyage 6 was collected on a crew member who was not involved in the discharge gauging or stripping of tanks. The exposure resulted from primarily opening and draining drip tray contents onto the deck. As the composition of the liquid was unknown, the total hydrocarbon concentration was assessed against a corporate exposure limit of 100 ppm. The acetone contribution resulted from the release of acetone/wash water slops when the hose to the slop tank was disconnected at the manifold. The acetone tank (4CA) was being prepared for backloading of MEK.

These results indicate that the potential for a toxicologically significant exposure to cargo vapors is minimal during discharge gauging and tank stripping regardless of the technique used. Instances of more elevated exposures were associated with questionable work practices.

IV.6 Hose Hookup/Disconnect

At the majority of the terminals, cargo transfer hoses were handled by the dock employees who were responsible for hookup and disconnect of hoses at the ship's manifold prior to and at the conclusion of loading or discharge. However, on Voyages 1 and 3, the hose work at the manifold was performed by the ship's crew.

A hose hookup involves removing flange blinds from both the shore transfer hose and the appropriate header on the manifold. Any residual product in the transfer hose would be released into the drip tray beneath the manifold where it would evaporate into the work environment and present a potential exposure situation. It is less likely that residual product would be trapped behind the manifold blind because (1) if product is to be loaded, all cargo piping out to the manifold would have been washed prior to arrival or (2) if product is to be discharged to shore, residual product would have been released at hose disconnect at the previous loading terminal. Finally, the hose is bolted to the manifold.

A hose disconnect proceeds in the opposite order. When the connection is broken between the hose and the ship's manifold, there is a potential for release of product into the drip tray. In the case of a loading, the potential for product release will depend upon how thoroughly the transfer line was blown to the cargo tank by the shore. Some vessels have the capability to clear the lines with compressed gases after a discharge is completed. An analogous statement regarding release potential would apply to disconnect following discharge.

Frequently, several tanks may be scheduled to receive or discharge the same product. This can usually be accomplished with a single transfer hose/manifold connection if an additional piece of piping called a "cross-over" or "run-around" is used. This segment of piping may be flexible or rigid. The ship's deck crew installs the cross-over at the duplicate manifold on the water side of the ship. The cross-over joins manifold flanges that connect with the tanks that contain the same product. In this way, the same product can be transferred to or from multiple tanks simply by using deck valving. As with the hose connect/disconnect procedure for the main transfer hose, there is a potential for product release and vapor exposure when a cross-over is connected or disconnected from the piping system.

Twenty-one vapor exposure samples were collected on crew members who were involved in connecting or disconnecting cargo transfer hoses or cross-overs. The results are presented in Table VIII.

The following observations pertain to the data in Table VIII.

- None of the vapor exposures during hose connect/disconnect were of toxicological significance because concentrations were below the medical monitoring response level of TWA/2 for individual products or mixtures as appropriate. Similarly, two unacceptable exposures occurred during installation or removal of crossovers. Thus, 19 of 21 or 90.5% of the crew exposures that involved manifold work in preparation for or at the conclusion of cargo transfer were acceptable.

- 2 or 9.5% of the 21 exposures were unacceptable, and both involved change out of a crossover pipe.

- The toxicological assessment of exposures greater than the TLV-TWA (individual components or mixtures) indicates that the presumed hazard did exist in 1 out of 2 of the exposures so classified.

IV.7 Engine Room/Pump Room

One of the six project voyages (Voyage 2) included a combined observation of Engine Room and Pump Room operations.

TABLE VIII SUMMARY OF OCCUPATIONAL VAPOR EXPOSURES DURING HOSE CONNECT/DISCONNECT

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Code**	<TWA/2	TWA/2-TWA	TWA-STEL	>STEL	Toxicological Hazard Assessment
A/B	Gasoline*	4.7	29	300	500	HC	X				
	Benzene+	ND***	29	10	25						
A/B	Gasoline	96.8	42	300	500	HC	X				
	Benzene	1.6	42	10	25						
A/B	Gasoline	34.4	67	300	500	HD	X				
	Benzene	ND	67	10	25						
O/S	Gasoline	34.6	57	300	500	CC	X				
	Benzene	ND	57	10	25						
O/S	Gasoline	ND	31	300	500	CC	X				
	Benzene	ND	31	10	25						
A/B	Gasoline	6.0	40	300	500	HD	X				
	Benzene	ND	40	10	25						
O/S	Gasoline	501.3	41	300	500	CC				X	PH-2
	Benzene	6.4	41	10	25						
O/S	Gasoline	316.0	38	300	500	CC			X		NH-1
	Benzene	2.7	38	10	25						
A/B	Gasoline	21.5	42	300	500	HC	X				
	Benzene	ND	42	10	25						
O/S	Gasoline	22.1	76	300	500	HD	X				
	Benzene	ND	76	10	25						
A/B-1	Styrene	ND	34	50	100	HC	X				
A/B-2	Styrene	ND	17	50	100	HC	X				
A/B-3	Styrene	ND	11	50	100	HC	X				
A/B-4	Styrene	ND	10	50	100	HD	X				
A/B-1	Styrene	12.9	11	50	100	HD	X				

* Gasoline is used generically to include any of three grades of motor fuel or jet fuel.
\+ Benzene in gasoline
** HC = Transfer Hose Connect
HD = Transfer Hose Disconnect
CC = Crossover Change
*** ND = Not Detectable

TABLE VIII. SUMMARY OF OCCUPATIONAL VAPOR EXPOSURES DURING HOSE CONNECT/DISCONNECT (Concluded)

Individual	Product	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	Code**	TWA/2	TWA/2-TWA	TWA-STEL	STEL	Toxicological Hazard Assessment
A/B-1	1,1,1-Trichloroethane	9.9	82	350	450	HC	X				
	Methylene Chloride	2.8		100	500						
	Perchloroethylene	0.2		50	200						
	Ethylene Dichloride	0.2		10	15						
A/B-2	See Footnote ++	ND***	82	N/A	N/A	HC	X				
A/B-3	1,1,1-Trichloroethane	0.4	40	350	450	HC	X				
	Methylene Chloride	1.7		100	500						
A/B-4	Ethylene Dichloride	0.1	119	10	15	HC	X				
A/B-3	1,1,1-Trichloroethane	0.4	225	350	450	HD	X				
	Methylene Chloride	1.4		100	500						
	Perchloroethylene	0.3		50	200						
O/S-1	1,1,1-Trichloroethane	0.4	177	350	450	HC	X				
	Methylene Chloride	0.1		100	500						
	Perchloroethylene	0.1		50	200						

++ Seven product hoses were connected: acetone, ethylene dichloride, styrene, methylene chloride, perchloroethylene, trichloroethylene and 1,1,1-trichloroethane.

** HC = Transfer Hose Connect
HD = Transfer Hose Disconnect

*** ND = Not Detectable

Pumprooms tend to exist on vessels that carry a single product or a limited number of product grades but not on tankers that carry a wide range of products simultaneously. On the latter type of vessel, cargo tanks are serviced by individual deep well pumps. While the pumpman is usually considered to be a part of the Deck Department during product discharge, his work environment can vary considerably depending upon the cargo pump setup. On vessels with deepwell pumps, he works on deck in the open atmosphere. With a Pumproom, his work activities are essentially the same, but he may spend a substantial part of each shift in a quasi-confined space at the pump/bilge level. If the Pumproom control panel is topside, then frequent entries may be made to the bilge level to inspect cargo piping, valving and pump function.

Occupational exposure monitoring was performed on the pumpman during loading, lightering and primary discharging of motor and aviation fuels. These exposure samples were supplemented by area samples. All samples were analyzed for benzene and total hydrocarbon concentration as hexane. None of the Pumpman's exposures exceeded 15 percent of the 300 ppm gasoline TWA. The majority were less than three percent of that TWA. Benzene was either not detectable or was less than the medical monitoring response level. Based on these results, none of the Pumproom occupational exposures were toxicologically significant.

The chemical agents that were monitored in the Engine Room included total hydrocarbon vapor, airborne asbestos and oil mist. During loading, vapor monitoring was conducted to determine if cargo vapors vented on deck were infiltrating the engine room. On the laden voyage, vapor monitoring was performed to assess the general environment as it would be influenced by elevated temperatures that increase evaporation rates of various solvents and liquids that are used in the Engine Room. Oil mist monitoring reflected the use of lube oils and fuel oils on each watch. The source of airborne asbestos was the insulation and lagging on steam pipes and other surfaces that required thermal insulation.

The results of this monitoring indicated the following.

- None of the vapor exposure samples exceeded 3.2 ppm for any of the operations. These levels are not toxicologically significant relative to a gasoline medical monitoring response level of 150 ppm.

- Twelve, full-watch, airborne asbestos exposure samples were all less than 0.037 fibers/cc. Analysis of bulk insulation samples revealed the presence of both amosite and chrysotile. Based on ACGIH recommended exposure limits of 0.5 and 2.0 fibers/cc, respectively, none of the exposure concentrations exceeded a medical monitoring response level. Therefore, the asbestos monitoring results were not toxicologically significant.

- o Airborne oil mist concentrations did not exceed 0.46 mg/m^3 as mineral oil. This level is not of toxicological significance relative to the ACGIH mineral oil TWA of 5 mg/m^3.

Assistant Engineers, Firemen and Oilers participated in the monitoring program.

IV.8 Crude Oil Operations

A crude oil tanker voyage was included in this project because

- o the product represents a substantial proportion of the bulk liquid volume that is transported by water each year,
- o the crude oil was sour and the hydrogen sulfide gas represents an additional concern for inhalation exposures and
- o it represented an opportunity to observe Deck Department operations that involve an inert gas system.

While some of the activities that were addressed in Sections IV.2 through IV.6 also occurred during this voyage, a separate presentation and discussion of the crew's exposure to gases and vapors is justified because

- o there is no published exposure limit for crude oil vapors that is analogous to the ACGIH total hydrocarbon limit for gasoline and
- o parallel instrument measurements during dosimetry indicated that there were substantial excursions in gas and vapor concentrations above the time-averaged dosimetry results and these transient excursions may have toxicological significance.

Table IX summarizes the occupational exposures to hydrogen sulfide and crude oil vapor during a range of cargo related activities. Detailed descriptions of the work practices are contained in Appendix D of Volume II - Part B. In Table IX, H_2S exposures are grouped together followed by a series of vapor exposures on the same individuals for the same activities.

Hydrogen Sulfide

Fifteen hydrogen sulfide exposures were collected using passive dosimeters. Ten of those 15 samples resulted in exposures that were less than the medical monitoring response level of 5 ppm and could be judged as not being of toxicological significance. According to the assessment mechanics, the remaining five exposures would be significant for medical monitoring purposes; a hazard would have been presumed to exist in one of those five exposures. All of these latter five exposures were associated with full cargo tanks at the end of loading and prior to discharge.

TABLE IX. OCCUPATIONAL EXPOSURES TO GASES AND VAPORS DURING SOUR CRUDE OIL OPERATIONS

Individual	Activity	Compound	C(ppm)	t(min)	Excursions (ppm)*	TWA/2	TWA/2-TWA	TWA-STEL	Toxicological Hazard Assessment
Q/M	Tank stripping - end of discharge	H_2S	0.7	75	-	X			
O/S	Tank stripping - end of discharge		1.2	85	19-595	X			
C/M	Tank depressurization prior to loading		1.0	32	25	X			
3M	Bottom gauging prior to loading		0.9	47	-	X			
Asst. Bosun	Bottom gauging prior to loading		0.9	43	-	X			
A/B	General deck watch - loading		0.6	230	-	X			
Asst. Bosun	End of loading - insert thermometers in tanks		5.9	20	3-445		X		
Asst. Bosun	End of loading - gauging round with surveyors		13.0	83	1-495			X	NH-3
2M	End of loading - verify surveyor measurements		3.7	68	-	X			
Q/M	End of loading - clean up after surveyors		1.0	218	-	X			
Q/M	Tank pressure relief - laden voyage		3.0	14	-	X			
C/M	Gauging round with surveyor prior to discharge		6.0	44	5- 1895		X		
C/M	Gauging round with surveyor prior to discharge		8.1	27	20-595		X		
Asst. Bosun	Open ullage ports on full tanks for surveyor		1.5	79	-	X			
A/B	Predischarge gauging round and tank sampling	H_2S	10.0	75	1895		X		
Q/M	Tank stripping - end of discharge	THC	12.5	40	-				
		HXA	0.8						
		BNZ	0.04			X			
		TOL	0.03						
C/M	Tank depressurization prior to loading	THC	20.9	31	-				
		HXA	2.0						
		BNZ	0.1			X			
		TOL	0.1						
3M	Bottom gauging prior to loading	THC	ND	43	-				
		HXA	ND						
		BNZ	ND			X			
		TOL	ND						
Asst. Bosun	Bottom gauging prior to loading	THC	2.3	45	8				
		HXA	0.03						
		BNZ	ND			X			
		TOL	ND						

* Instantaneous breathing zone concentration as measured with direct reading instrument.

TABLE IX. OCCUPATIONAL EXPOSURES TO GASES AND VAPORS DURING SOUR CRUDE OIL OPERATIONS (Concluded)

Individual	Activity	Compound	C(ppm)	t(min)	Excursions (ppm)*	<TWA/2	TWA/2-TWA	TWA-STEL	Toxicological Hazard Assessment
A/B	General deck watch - loading	THC	15.4	230	-				
		HXA	2.0						
		BNZ	0.1			X			
		TOL	0.2						
Asst. Bosun	End of loading - insert thermometers in tanks	THC	216.5	20	15- 4000				
		HXA	21.0						
		BNZ	1.2				X		
		TOL	1.5						
Asst. Bosun	End of loading - gauging round with surveyors	THC	399.7,193.8	51,31	15- 4000				
		HXA	52.4,15.9						
		BNZ	2.6,1.2			X		X	NH-1
		TOL	2.8,1.6						
Q/M	End of loading - clean up after surveyors	THC	49.0	218	-				
		HXA	6.0						
		BNZ	0.3			X			
		TOL	0.4						
C/M	Gauging round with surveyor prior to discharge	THC	174.9	28	4000				
		HXA	17.7						
		BNZ	1.1			X			
		TOL	1.0						
C/M	Gauging round with surveyor prior to discharge	THC	11.8	20	50- 4000				
		HXA	0.8						
		BNZ	ND			X			
		TOL	ND						
C/M	Gauging round with surveyor prior to discharge	THC	110.0	26	4000				
		HXA	9.1						
		BNZ	0.6						
		TOL	0.6						
Asst. Bosun	Open ullage ports on full tanks for surveyor	THC	33.8	80	-				
		HXA	3.5						
		BNZ	0.3			X			
		TOL	0.3						
A/B	Predischarge gauging round and product sampling	THC	80.0	53	4000				
		HXA	7.3						
		BNZ	0.4			X			
		TOL	0.5						

* Instantaneous breathing zone concentration as measured with direct reading instrument.

Also shown in Table IX is a column labeled Excursions. Values in this column represent peak breathing zone concentrations that were measured with direct reading instruments calibrated to hydrogen sulfide. The instrument detector was an electrochemical cell, and the passive dosimeters sampled by diffusion. The interpretation that is given to these two sets of data is as follows.

- During the indicated activities, the work environment contained rapidly changing concentrations of H_2S.
- The sampling rate or time constant for the diffusion dosimeters is too slow to respond to instantaneous fluctuations of H_2S.
- The electrochemical cell responds much more rapidly to transients than does the passive dosimeter, but its rise time is still longer than the transient's rise time. Therefore, the cell does not "see" the true peak concentration; it "sees" something less.
- The above arguments suggest that instantaneous exposure peaks greatly exceeded the time-averaged dosimeter results.

Crude Oil Vapor

The second group in Table IX contains the results of 14 vapor exposure samples that were collected on charcoal tubes. The samples were analyzed for hexane, benzene, toluene and total hydrocarbon through xylene expressed as hexane. This total hydrocarbon concentration does not reflect the asphyxiant hydrocarbon vapors, e.g. methane, that are not trapped on charcoal. In general, the hexane vapor concentration is roughly one-tenth of the THC concentration. Benzene vapor was present at roughly one-half to one percent of THC, which is similar to typical results for gasoline. Also shown with the time integrated vapor exposure data are instantaneous breathing zone excursion concentrations measured with an instrument having an intrinsically safe FID (flame ionization detector). The FID data reflect the presence of all hydrocarbons heavier than methane. The excursion values are total hydrocarbon as hexane.

The interpretation mechanics were applied to each exposure sample considering all compounds except total hydrocarbon. A recognized ACGIH TLV does not exist for total crude oil vapor. The results of applying the procedure reflect the mixture of hexane, benzene and toluene, and the TWA and STEL apply to the mixture. On this basis, only two of 14 exposures exceeded the medical monitoring response level and both were associated with open gauging and measuring activities at the end of loading. The interpretation mechanics indicate that a presumed hazard existed during one of the exposure periods.

The excursion data that were obtained with real time organic vapor analyzers supports the previous conclusion that the work environment contained fluctuating vapor concentrations with substantial peak levels.

Inert gas systems were developed and installed on crude oil tankers to eliminate fire and explosion hazards. Product is close loaded and discharged beneath an inert blanket. Crude oil washing with fixed machines in an inert tank atmosphere minimized the potential for static buildup, discharge and explosion. The fire and explosion goals have been greatly reduced on crude carriers. However, the manual operations associated with opening cargo tanks, as well as open gauging of cargo ullage and temperature, are still performed according to tradition. The result is the type of exposures that were monitored and which could be avoided by relying on closed gauging systems.

The toxicological assessment of exposures greater than the TLV-TWA (individual components or mixtures) indicates that the presumed hazard did not materialize for either of the two exposures so classified.

IV.9 Deck Maintenance

During the course of normal operations, deck surfaces are exposed to salt water, the weather and cargo related materials such as tank washing slops. This exposure can result in both functional and aesthetic deterioration. Deck maintenance is performed to retard the deterioration rate and to preserve the working condition and appearance of the ship.

Rust and blistered paint may be removed from deck surfaces in preparation for primer and finish coats of paint. Alternately, the surfaces may not be stripped but may receive only a finish coat of paint. Rust and paint are most commonly removed by chipping with a pneumatic needle gun. Sandblasting may be used as the second step in a 2-step preparation procedure that is preceded by the use of needle guns. Paints and primers can be applied by brush or spray equipment.

The weather deck may become stained if liquids evaporate after being released on deck. Examples of such liquids include tank washing slops, residual cargo in drip pans that are drained on deck and cargo from leaks or ruptures in the transfer piping. To remove these stains, the deck can be scrubbed with a decreaser using long handled brooms.

The types of deck maintenance discussed above are normally performed on the ballast leg of a voyage. However, they are not necessarily performed on every voyage as other activities, such as tank cleaning, may have a higher priority.

Deck maintenance was observed and monitored as opportunities arose. A total of 17 exposure samples were collected during deck maintenance. Two of these samples were for respirable silica dust during sandblasting. Six respirable nuisance dust samples were collected during rust and paint chipping with a needlegun. Eight samples were collected for vapor exposure during spray painting. Finally, one sample was collected during deck cleaning with a degreaser. The results of these exposure samples are summarized in Table X. Manufacturers' Material Safety Data Sheets were used as a guide in selecting compounds for analysis. The paints and primers that had been used or were about to be used contained no lead or chrome compounds. The degreaser contained a 50-50 mixture of unspecified aliphatic and aromatic hydrocarbons.

TABLE X. OCCUPATIONAL EXPOSURES DURING DECK MAINTENANCE

Individual	Substance	C(ppm)	t(min)	TWA(ppm)	STEL(ppm)	<TWA/2	TWA/2-TWA	TWA-STEL	Activity	Toxicological Hazard Assessment
A/B	Xylenes	10.4	34	100	150	X			Spray Painting	
	Isobutanol	4.1		50	75					
A/B	Xylenes	5.1	13	100	150	X			Spray Painting	
OS	Xylenes	5.0	142	100	150	X			Spray Painting	
	Isobutanol	1.8		50	75					
A/B	Xylenes	5.9	61	100	150	X			Spray Painting	
	Isobutanol	3.0		50	75					
A/B	Xylenes	9.7	8	100	150	X			Spray Painting	
O/S	Xylenes	3.2	141	100	150	X			Spray Painting	
	Isobutanol	1.2		50	75					
	Gasoline	9.5		300	500					
O/S	Xylenes	1.9	68	100	150		X		Spray Painting	
	Isobutanol	3.2		50	75					
	Gasoline	156.5		300	500					
	Benzene	0.8		10	25					
O/S	Xylenes	6.8	130	100	150	X			Spray Painting	
	Isobutanol	3.2		50	75					
	Gasoline	2.3		300	500					
A/B	Respirable Nuisance Dust	ND*	127	$5mg/m^3$	-	X			Spray Painting	
A/B	Respirable Nuisance Dust	ND	93	$5mg/m^3$	-	X			Spray Painting	
O/S	Respirable Nuisance Dust	ND	45	$5mg/m^3$	-	X			Spray Painting	
A/B	Respirable Nuisance Dust	ND	84	$5mg/m^3$	-	X			Rust and Paint Chipping	
A/B	Respirable Nuisance Dust	ND	54	$5mg/m^3$	-	X			Rust and Paint Chipping	
A/B	Respirable Nuisance Dust	ND	28	$5mg/m^3$	-	X			Rust and Paint Chipping	
OS	Respirable Silica	$7.4mg/m^3$	94	$0.1mg/m^3$**	-			X	Sand Blasting	PH-9
AB	Respirable Silica	$6.7mg/m^3$	40	$0.1mg/m^3$**	-			X	Sand Blasting	PH-9
AB6	Degreaser	0.6+	132	200***	-	X			Deck Cleaning	

* ND - Not Detectable
** Based on 99% silica in source materials
\+ Total hydrocarbon through xylene as hexane
*** Manufacturer's total hydrocarbon exposure limit

Seven of the eight spray painting vapor exposures did not exceed the medical monitoring response level or one-half of the mixture TWA. Consequently, those exposures are not of toxicological significance. One paint spraying exposure sample exceeded the medical monitoring response level; however, the contribution due to paint vapor was minimal. The dominant portion of the exposure was due to gasoline vapors. Tank hatches, expansion trunks and valve stems were being painted. As the ship was a gasoline tanker, sources of vapor included leaks at ullage port or hatch seal surfaces or popoff venting of pressure/vacuum valves on partially filled tanks.

All six respirable nuisance dust samples that were collected during rust and paint chipping were not toxicologically significant. These samples were analyzed gravimetrically for nuisance dust after it had been concluded that they did not contain specific toxic metals.

Two sandblasting exposures to respirable silica were judged to be unacceptable. In addition, it would be presumed that a potential hazard existed during this operation. These exposures resulted from the use of (1) a loose fitting sandblasting hood that permitted dust to be entrained into the breathing zone and (2) an air-purifying respirator that was rated for vapor but not toxic dusts. The toxicological assessment of exposures greater than the TLV-TWA (individual components or mixtures) indicates that the presumed hazard did exist in both of the exposures so classified.

IV.10 Vapor Infiltration into Accommodation Spaces

Enriched vapor concentrations are discharged from the cargo tanks during loading and gas freeing operations as well as during ballasting into cargo tanks. High concentration vapors can also be vented from the ullage spaces above cargos that require inert gas blanketing. If atmospheric conditions, principally wind direction, are correct, there is a potential that vapors and gases can infiltrate into accommodation spaces. The physical conditions that would permit infiltration to occur include

- open make-up air intakes for the central air conditioning system,
- open doors between the wheelhouse and the bridge wing,
- forward facing access doors,
- open access doors, and
- poor seals between closed access doors and jambs.

The deckhouse environment was investigated during the above operations using combinations of passive dosimeters, charcoal tubes and direct reading instruments. The dosimeters functioned as area monitors. The instruments were used either in a survey mode or as real time stationary monitor with a strip chart recorder. The results that are presented and discussed below are not occupational exposures; therefore, they have not been evaluated for toxicological significance as have the personal exposures. The purpose of this presentation is to confirm the existence of infiltration, indicate measured levels and to suggest that the potential for infiltration could be minimized by addressing the physical conditions cited above.

Table XI summarizes the results of area monitoring in the deckhouse using dosimetry equipment. The following supplementary information applies to the indicated Entry Numbers.

Entry Number	Comment
1-4	Real time instrument surveys of the deckhouse environment during tank washing and ventilating resulted in gasoline concentrations that ranged from roughly 10 to 50 ppm.
5	During ballasting into cargo tanks, the maximum instantaneous gasoline vapor concentration in the stateroom was 180 ppm. Instrument surveys of the deckhouse throughout ballasting resulted in numerous gasoline vapor concentration measurements in the 100-200 ppm range with a peak reading of 850 ppm at an open forward facing access door leading to the deck.
8-10	During the loading operation, all six levels of the deckhouse were surveyed with direct reading instruments calibrated for hydrogen sulfide and total hydrocarbon as hexane. Hydrogen sulfide was not detectable on any level. Total hydrocarbon concentrations ranged from 12 to 20 ppm. The difference between these values and the total hydrocarbon values shown in Table XI is that the charcoal tubes do not trap the low molecular weight straight chain hydrocarbons that are detected by the direct reading instrument.
11	This entry represents the results of seven area monitoring samples for infiltration of H_2S and crude oil vapors on three occasions when the inert gas pressure head on the cargo tanks was relieved.

The data in Table XI indicate that infiltration of vapors and gases into the deckhouse does occur. Using dosimetry equipment in an area monitoring mode, concentration levels are detectable. The levels were relatively low over the sampling interval with the exception of one H_2S sample whose concentration approached TWA/2. While the amount of data from real time monitoring instruments is not extensive, there are indications that under the proper conditions instantaneous concentrations may exceed the time integrated levels obtained by dosimetry methods.

The vessels that are represented in Table XI range in age from roughly one year to 15 years.

TABLE XI. GAS/VAPOR INFILTRATION INTO ACCOMMODATION SPACES

Entry No.	Operation	Location	Substance	C(ppm)	t(min)
1	Tank washing and ventilating	Stateroom	Gasoline	5.8	482
			Benzene*	0.3	
2	Tank washing and ventilating	Control Room	Gasoline	9.1	489
			Benzene	0.4	
3	Tank washing and ventilating	Stateroom	Gasoline	1.08	247
			Benzene	ND**	
4	Tank washing and ventilating	Control Room	Gasoline	ND	238
			Benzene	ND	
5	Ballasting into cargo tanks	Stateroom	Gasoline	21.4	484
			Benzene	0.20	
6	Tank washing and ventilating	Stateroom	1,1,1-Trichloroethane	4.5	445
			Methylene Chloride	9.9	
7	Tank washing and ventilating	Stateroom	Methylene Chloride	0.2	434
8	Loading - sour crude oil	Pilot's Cabin - Three Sequential Samples	Hydrogen Sulfide	0.1-0.4	185-510
9	Loading - sour crude oil	Control Room - Three Pairs of Sequential Samples	Hydrogen Sulfide	0.1-0.3	191-495
10	Loading - sour crude oil	Control Room and Pilot's Cabin - Simultaneous Samples	Total Hydrocarbon+	4.1-4.7	185,188
			Hexane	0.4	185,188
			Benzene	0.02	185,188
			Toluene	0.04-0.05	185,188
11	Tank Pressure Relief:Laden Voyage - sour crude oil	Pilot's Cabin, Control Room and Wheel House	Hydrogen Sulfide	2.7-4.7	11-14
			Total Hydrocarbon	ND	11-13
12	Product Loading	Control Room	Total Hydrocarbon	3.6-5.2	306-436
			Paraxylene	0.1-0.5	306-436
			Hexane	0.4	306-436
			Heptane	0.2	306-436

* Benzene in Gasoline
\+ Total Hydrocarbon Concentration as Hexane
** ND = Not Detectable

IV.11. Noise

Noise exposure monitoring was conducted on two voyages. The primary purpose of this monitoring was to characterize the noise environment as opposed to collecting dosimetry data for compliance purposes. The monitoring equipment and technique met the USCG recommendations in Reference 15, but because of the stated purpose, monitoring periods were less than 24 hours. Consequently, the majority of the data were not evaluated relative to USCG noise exposure limits. There were a few notable exceptions where a cumulative exposure exceeded the allowable exposure within the monitoring periods. Even under optimal conditions of no exposure for the remainder of the 24-hour day, these exposures would exceed USCG recommended 24-hour limit of 82 dB(A).

The Engine Room noise data were collected on a steam powered vessel that had been in service for many years. The second noise monitoring effort was conducted in the Deck Department of a vessel that was roughly one year old.

The majority of the noise monitoring on Voyage 2 took place in the Engine Room. Data were collected on Assistant Engineers, Firemen and Oilers while the vessel was under way on the laden voyage. Project personnel wore the dosimetry equipment while accompanying the Oiler and Fireman during loading. In addition, noise monitoring was conducted on Deck Department personnel who were paint chipping with pneumatic needle guns. Table XII summarizes the cumulative effective exposures $L_{eff}(t)$ at the end of the monitoring period and other pertinent information. The brackets indicate the individuals that were simultaneously monitored for noise on the same Engine Room watch.

With the exception of the fifth Engine Room watch (the last entry in Table XII for the Oiler and Assistant Engineer), integrated noise levels ranged from roughly 91 to 96 dB(A) over the 4-hour watch. Peak (maximum two-minute average levels) ranged from 97 to 106 dB(A). The data suggest that the integrated noise levels over a watch did not vary appreciably between loading and in-transit operations.

The exposures for the Oiler and Assistant Engineer on the fifth Engine Room watch both exceeded the permissible level as specified by Reference 15. As hearing protection was not worn, these two full watch exposures imply that the 24-hour integrated levels would exceed 82 dB(A) as specified in Reference 15 even if no other noise exposure above 80 dB(A) was received during the remainder of the 24 hours.

Rust and paint chipping with a needle gun produced peak and integrated noise levels that are similar to those that are reported in Reference 3 for offshore rig and platform operations. The two rust and paint chipping noise samples exceeded the permissible level within the sample period. As such the 24-hour exposure would exceed the USCG recommended level of 82 dB(A) even if no other noise exposure above 80 dB(A) was received for the rest of the day and if no hearing protection were worn. Both workers wore hearing protection (plugs or muffs), but the adequacy or proper fit of these devices was not known.

TABLE XII. SUMMARY OF NOISE DATA FOR ENGINE ROOM AND DECK MAINTENANCE

Individual	Activity	t,hours	L(t)*,dB(A)	Permissible,** dB(A)	Peak,dB(A)
SwRI/Oiler	Loading	3.9	93.4	95.2	100
SwRI/Fireman	Loading	3.8	92.5	95.4	96
Fireman	Laden Voyage	3.8	92.4	95.4	99
AE+	Laden Voyage	4.0	91.2	95.0	97
Oiler	Laden Voyage	3.0	96.0	97.1	102
AE	Laden Voyage	3.0	95.0	97.1	110
Oiler	Laden Voyage	3.7	92.6	95.6	100
Fireman	Laden Voyage	3.6	93.6	95.8	100
Oiler	Laden Voyage	3.6	93.0	95.8	99
Fireman	Laden Voyage	3.6	91.4	95.8	106
Oiler	Laden Voyage	4.0	96.5	95.0	104
AE	Laden Voyage	4.0	98.4	95.0	110
A/B	Paint Chipping with Needle Gun	7.1	103.5	90.8	112
A/B	Painting in Vicinity of Needle Gun	3.5	82.5	96.0	96
A/B	Paint Chipping with Needle Gun	3.5	100.0	96.0	113

* Cumulative effective exposure at end of monitoring period, t
\+ Assistant Engineer
** Permissible cumulative exposure over monitoring period per Reference 15

Noise from the needle guns attenuates rapidly as evidenced by the significantly lower exposure of a painter who was working in the vicinity of the paint chipping.

The vessel in Voyage 6 was a state-of-the art tanker that incorporated several unique design features in the cargo handling system.

- o All cargo tanks were equipped with deep well pumps. Twenty of the 43 pumps were aligned roughly along the longitudinal axis of the ship. Adjacent to the pumps was an electrical cable run with solid walls that also extended from the deckhouse to the forward most pump. This structure extended above the top of the pump motors.

- o All cargo tanks were equipped with individual high velocity vapor vents to discharge and disburse product vapors well above the deck during loading.

- o Permanently installed in-tank stripper pumps were in place on many cargo tanks. The purpose of these pumps was to permit efficient stripping of liquids (cargo or wash slops) from the main cargo pump sump. Installation of permanent stripper pumps was planned for the remaining tanks. In the interim, tank sumps were stripped with portable diaphragm pumps.

The cargo pump configuration, vapor vents and portable stripper pumps represent noise sources. The data in Table XIII address these three points. The data are separated into four groups.

The first two groups, Discharge and Tank Processing, involved simultaneous operation of multiple cargo discharge pumps. The cumulative effective exposure data reflect the noise contribution from individual pumps as well as the noise reflected from the cable run structure. These data also reflect the fact that the pumps had to be restarted frequently because of trip-out of the low pressure switches. This situation required numerous manual restarts and more frequent observation than if the cargo pumps were functioning properly.

On those tanks that did not have permanent intank stripper pumps, it was necessary to strip the sumps using portable pneumatic diaphragm pumps. The data under the activity, Tank Entry, represents the noise exposures resulting primarily from the action of these pumps with an estimated minor contribution from the tank ventilation system. This is not a routine operation; tank entry with these portable pumps will not be necessary when the retrofit program has been completed.

The final group of data in Table XIII, reflects the noise exposure environment when high velocity vents pop off during product loading. The data were collected on individuals involved with tank topoff using the portable restricted gauging device. The noise from the vents made it difficult for the crew member to hear the audible alarm on the gauging device

TABLE XIII. SUMMARY OF NOISE DATA FOR STATE-OF-THE ART TANKER: DECK DEPARTMENT

Individual	Activity	t,hours	L(t)*,dB(A)	Permissible,** dB(A)	Peak,dB(A)
2M	Discharge	7.6	89.8	90.4	112
3M1	Discharge	2.75	92.8	97.7	107
2M	Discharge	3.3	78.8	96.4	92
AB4	Discharge	3.6	85.6	95.8	95
AB1	Discharge	3.6	85.5	95.8	95
AB5	Discharge	3.4	80.3	96.4	95
AB6	Discharge	2.2	84.3	99.3	94
AB3	Discharge	3.4	82.3	96.4	95
PM2	Discharge	3.6	86.1	95.8	100
PM1	Discharge	4.0	84.9	95.0	92
PM1	Discharge	7.5	87.3	90.5	109
PM2	Discharge	4.0	83.9	95.0	99
PM2	Discharge	6.7	86.5	91.3	110
PM1	Discharge	2.4	78.5	98.7	92
PM2	Discharge	7.2	87.7	90.8	110
PM1	Tank Processing	8.3	83.4	90.3	109
OS1	Tank Entry	0.4	95.0	111.6	106
AB2	Tank Entry	0.7	95.5	107.6	106
AB6	Tank Entry	0.6	101.0	108.7	110
3M2	Loading/Tank Topoff	0.4	82.3	111.6	84
AB6	Loading/Tank Topoff	4.0	82.7	95.0	95
PM2	Loading/Tank Topoff	7.9	86.3	90.1	101
3M2	Loading/Tank Topoff	3.0	82.6	97.1	90
AB1	Loading/Tank Topoff	2.8	87.8	97.6	100

* Cumulative effective exposure at end of monitoring period, t
** Permissible cumulative exposure over monitoring period per Reference 15

even if only one vent was being actuated. The majority of the data reflect simultaneous actuation of multiple vents. To hear the alarm, the crew members would put their ear next to the gauging device. In this position, their breathing zone was in close proximity to the product vapors that escaped from the device at the tape-wiper interface. It is postulated that the background noise from the vents resulted in the work practices modification that led to higher than expected topoff vapor exposures for a restricted gauging device.

V. WORK PRACTICES

This project consisted of monitoring occupational exposures primarily to cargo vapors during bulk liquid tanker operations. Particulate, noise and dermal exposures were also monitored for specific operations. As a part of the monitoring effort work practices were also documented. Consistent with good industrial hygiene procedures, work practice documentation included not only the manner in which a task was performed but also the extent to which protective equipment or clothing was involved, adherence to accepted or corporate procedures, the role of special equipment that may have been involved in the task as well as the use of specialized instrumentation. This documentation serves two purposes: it facilitates (1) data interpretation and (2) an assessment of the exposure potential for a work scenario. Therefore, the objective of this section is to review selected work practices emphasizing both good work practices and those that could be improved. Insofar as possible, the following discussion is independent of a particular vessel and represents a commentary on work practices in general.

Tank entry occurs frequently, especially on product or parcel chemical tankers. A wide range of work practices associated with the entries were documented during the various voyages and are summarized below.

- The atmosphere in a series of tanks was to be tested for oxygen content prior to entry. The 21m dropline that was used was not compatible with the oxygen meter. The thread size on the dropline screw connector was different from the thread size on the oxygen meter. As a result, a positive seal could not be achieved at the hose/meter interface. This condition could result in aspiration of ambient air instead of tank atmosphere. During the same testing sequence, the tank atmosphere was sampled by massaging an aspirator bulb. The bulb aspiration procedure was acceptable for a 2m dropline, but the number of aspirations was insufficient to sample the tank atmosphere using the 21m dropline. Generally, the oxygen meter bulb was aspirated seven to 12 times. According to accepted procedures, about 35 to 45 aspirations would have been more appropriate for a 21m sampling line.

- Corporately-developed tank entry procedures and entry permit systems were in place on two parcel chemical tankers and one product tanker. This is a very positive step and represents an increased awareness of confined space entry hazards. However, the actual permit was not used for any entry.

- Tank entries occurred without any testing of the atmospheres for oxygen content, combustible gas concentrations or toxic levels. Crew members on occasion entered tanks of their own volition without approval of a Deck Officer or Bosun.

- One atmosphere testing procedure involved entry into unknown atmospheres without respiratory protection to test the atmospheres for O_2, combustible gas and toxics (detector tube system). This hazardous practice could have been avoided by using droplines. Subsequent entries by crew members to clean the tanks resulted in unacceptable vapor exposures.

- On one vessel, a positive procedure for entry into unknown atmospheres involved the use of an SCBA. The tanks had previously been inerted. While in the tank, the Deck Officer tested the atmosphere for O_2, CO, NO_x, combustible gas and total hydrocarbon vapor concentrations.

- In general, a deck safety watch and forced ventilation were not consistently observed during tank entries.

- From vessel to vessel and within a given crew, there was an inconsistent use of glove materials to prevent dermal exposures during tank mucking as well as during tank washing. Some individuals wore no gloves or cloth work gloves. Rubber or chemical resistant gloves were occasionally used.

- Caustic tanks that had previously been washed were entered for final cleanup by crew members that were attired in either shorts and open short sleeved shirts or in slickers labeled "not for chemical use".

- When air-purifying respirators were worn during tank entries, the use practice was variable. On one extreme, the crew members wore clean, properly sized organic vapor respirators with fresh cartridges. At the other extreme, the face pieces had not been cleaned, the respirators had been previously used, the integrity of the filter medium was questionable and in one case the lower retention strap was not in place.

- Cargo Information Cards contain basically the same hazard information as Material Safety Data Sheets (MSDS). This information is required to be on board for all Subchapter O products, and MSDS sheets are usually on board for Subchapter D cargos even though they are not required by the USCG. A series of Subchapter D cargo tanks were entered without any atmospheric testing and without any knowledge on the part of the Deck crew as to the potential hazards.

The potential for vapor exposure during gauging of loading tanks depends on the type of gauging method that is used. Open and closed gauging represent the maximum and minimum potentials, respectively. The potential for exposure with true restricted gauging systems is close to that of closed systems. For products that are open gauged, there appears to be an increasing awareness on the part of the Deck Crew of the exposure potential. There is a growing tendency to stand upwind or crosswind of the open ullage port although this may not be possible in all situations because of equipment and hardware constraints. Some crew members attempt to minimize their open gauging exposures by standing on top of expansion trunk domes and by holding their breath especially in areas that are shielded from the ambient wind.

It is not a common practice for air purifying respirators to be used to avoid high concentration vapor environments that can exist when tanks are open gauged during the latter portion of loading and top off. In only one case has a crew member (Mate) been observed to consistently use an organic vapor cartridge respirator for open tank gauging. This Mate believed he was being protected. However, through absence of training on the use and care of such devices, he was unaware that the cartridges did not fit the face piece (thread mismatch) and the inhalation valves were damaged.

The portable restricted gauging devices that were used on one of the voyages are classified as a restricted gauging system. This device emits an audible sound when the tape bob contacts the liquid free surface in the tank. In the absence of background noise, the audible alarm can be easily heard, and the crew member's breathing zone is well removed from any vapor source. However, this alarm is easily masked as the background noise level increases, e.g. the action of high velocity vapor vents. In this situation, the crew member frequently and in some cases continuously puts his ear next to the device in an attempt to hear the alarm and read the ullage tape. In this position, he may receive an unacceptable short-term exposure because his breathing zone may be less than six inches from a directed vapor source. The source is the vapor that escapes from the ullage space between the gauging tape and two elastomeric seals or tape wipers. Noise masking of the audible alarm results in a work practice with exposure potential that need not occur if the manufacturer of the gauging device would incorporate a visual indication of bob/liquid contact. This option appears feasible because the unit has an LED readout for cargo temperature.

Tank washing with portable machines generates chemical/water spray that is ejected from the tank around the hose holder. The use of protective equipment for dermal/ocular protection is highly variable. Within a given crew, some individuals wear appropriate chemical goggles, others have goggles but wear them on their hat and some individuals do not have goggles. A similar situation exists with respect to hand and foot protection. Some individuals wear appropriate equipment. At the other extreme, street shoes may be worn instead of chemical resistant boots or there is no hand protection to prevent dermal exposures.

While a tank is being washed, the slops are pumped either overboard or to a slop tank. During the latter stages of washing, a member of the washing crew may open a spigot down stream of the pump and allow the water to accumulate in his unprotected hand. On two occasions, the slops were either smelled or tasted. The results of this test provide an indication of tank cleanliness. At best, any chemical is present in a very dilute state; nevertheless, this practice, which involves potential dermal and ingestion exposure, is not recommended.

Maintenance work is essential to the longevity of a vessel, and rust and paint chipping are fairly routine activities in the Deck Department during the ballast voyage. One one occasion, sandblasting was used to prepare surfaces for priming. In the case of sandblasting, silica exposure resulted from a loose fitting hood that permitted dust to enter the breathing zone. The worker wore an air purifying respirator, but the cartridges were rated for vapors not silica dust. Most crew members that chipped paint with needle guns also wore goggles and occasionally disposable masks for nuisance dusts. There was no indication that a nuisance mask was being worn because it had been determined that the paints being removed did not contain toxic metals.

The above discussions suggest that work practices fall into three categories.

- Acceptable or good work practices,
- Practices in which the intent was acceptable but the implementation should be reevaluated and upgraded,
- Work practices that are unacceptable.

Crew members in the middle category have demonstrated a concern for their occupational health, which may reflect some prior on-the-job training. Unacceptable work practices may reflect a lack of knowledge on material hazards, protective equipment, proper procedures, etc. In either of the latter two categories, development and implementation of maritime good work practices training programs is needed.

VI. CONCLUSIONS

This project included six at-sea voyages.

- Voyage 1: Gasoline Integrated Tug/Barge - Deck Department
- Voyage 2: Gasoline Tanker - Engine Room/Pump Room
- Voyage 3: Parcel Chemical Tanker - Deck Department
- Voyage 4: Sour Crude Oil Tanker - Deck Department
- Voyage 5: Parcel Chemical Tanker - Deck Department
- Voyage 6: State-of-the Art Product Tanker - Deck Department

These voyages represent a wide range of products (Subchapters O and D), operating conditions and equipment. There is a corresponding range in tonnage and age.

The results of 375 occupational exposure and area monitoring samples for vapors, gases, and particulates are contained in this report. The distribution of these samples is shown below.

Item	No. Samples
Tank Washing and Ventilating	67
Confined Space Entry	63
Product Discharge	43
Hose Hookup/Disconnect	21
Tank Gauging - Loading	72
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Engine Room Operations	26
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Sour Crude Oil Operations	29
Deckhouse Infiltration	27

The above samples reflect chemical substances. Noise, a physical agent, was monitored on Voyages 2 and 6.

Interpretation of vapor exposures was based on a procedure developed in Reference 14. The procedure used the current exposure limit guidelines of the American Conference of Governmental Industrial Hygienists (ACGIH). For compounds not addressed by the ACGIH, corporate-developed occupational exposure limits were used. A medical monitoring response level was defined to be equal to one-half of the time weighted average (TWA) 8-hour exposure limit. Exposure concentrations above the medical monitoring response level, regardless of duration, were classed as toxicologically significant for medical monitoring purposes. Exposures that exceed the TWA were taken to have occurred under conditions where a potential hazard was presumed to exist. Exposures in this latter category were then reviewed on an individual basis to determine if the presumed hazard did exist. This hazard assessment process considered known toxicity and duration of exposure.

In general, noise monitoring was conducted to characterize the environment for various operations or operation/equipment combinations. Consequently, monitoring duration was structured around either the watch period (roughly four to eight hours) or a specific work activity. Accordingly, noise profiles were not assessed relative to USCG 24-hour guidelines unless the cumulative exposure exceeded permissible levels within the sampling period. This latter situation occurred for a minority of the samples.

The following conclusions can be drawn from the observations and the monitoring results.

- The tank gauging exposure data clearly reinforce the advantages of restricted gauging with sounding tubes over open gauging through ullage ports. This statement applies equally to periodic (pre-topoff) as well as topoff gauging. Exposures received during restricted gauging with sounding tubes were all less than the medical monitoring response level, while only about 50 percent of the open gauging exposures were less than their respective medical monitoring response levels.

- To date, only one crew member has been observed using an air purifying respirator for protection during open gauging. It is concluded that this work activity is incorrectly perceived as not presenting an inhalation hazard that justifies respiratory protection. This conclusion acknowledges that not all cargos possess the volatility and exposure limit needed to generate an inhalation hazard.

- Tank topoff using one type of portable restricted gauging device resulted in a higher than anticipated proportion of exposures that exceeded the medical monitoring response level, i.e. 44 percent of exposures exceeded the TWA/2. This may have resulted from a work practice modification that was necessitated because background noise masked the audible alarm on the gauging device.

- Hose hookup/disconnect and normal product discharge operations do not represent primary concern areas with respect to vapor exposure. In both cases, in excess of 90 percent of the occupational vapor exposures were less than the medical monitoring response level and are not considered to be toxicologically significant.

- The data from this project confirm earlier findings that man-entry into cargo tanks is an area of concern with respect to vapor inhalation exposures. Thirty-eight percent of the entry exposures exceeded the medical monitoring response level with 22 percent of all entry exposures being above the STEL. The voyage reports in Volume II - Part B, document the factors that contributed to the exposures above the medical monitoring response level. Collectively, these include such items as

- o no pre-entry testing of the atmosphere for oxygen, combustible gas or toxic concentrations,
- o entry into an unknown atmosphere without respiratory protection to test the atmosphere to determine if it is acceptable for crew members to enter and work,
- o no ventilation during in-tank work,
- o crew members with and without respiratory protection in the same unacceptable tank atmosphere,
- o crew members entering tanks of their own volition and without direction and
- o entry decisions being based on odor.

o The factors that can contribute to unacceptable vapor exposures during tank entry can be addressed by developing good confined space entry procedures. The success of such a program depends upon commitment to training, education and program monitoring.

o Based on all tank entry observations, it is concluded that a potential for dermal exposure will continue to exist if open, short-sleeved shirts, shorts, street shoes, cloth work gloves or no gloves are used during in-tank work such as residue mucking.

o During tank washing and ventilating (gas freeing), the vapors in the tank can be dissipated to the atmosphere in several ways. The most common method is to discharge the vapors at deck level through cracked and open hatches during washing and gas freeing, respectively. Of the samples taken on deck during tank washing and ventilating, 27 percent resulted in exposures above the medical monitoring response level. The substances that were involved included Subchapter O, Subchapter D and unregulated products.

o The closed washing and venting system on the state-of-the art tanker resulted in a proportionately lower percentage (2 of 12) of unacceptable exposures than were measured on the conventional tankers (16 of 55).

o During tank washing, water spray may be ejected onto the deck especially at the beginning of washing when the washing machine is at its highest position in the tank. Crew members that manually adjust the hoses may risk eye and face contact with the spray, which could contain product in solution. When washing a given tank, the use of chemical goggles was not consistent. Some crew members wore the goggles properly, others wore them on their hats and others did not wear goggles. While tests were not conducted to determine the level of chemical in water, the presence of goggles suggests that an eye protection program could have been in place, but was not enforced by ship and corporate management.

- Airborne substances monitored during deck maintenance include silica from sandblasting, nuisance dust from rust and paint chipping, solvent vapors from spray painting and, finally, vapors from deck cleaning with a degreaser. The results of the monitoring show that the above maintenance operations, with the exception of sandblasting, resulted in acceptable exposure levels. Sandblasting as a surface preparation method was not routinely observed aboard the ships. Two unacceptable respirable silica exposures resulted from the use of a loose fitting blasting hood and an air purifying respirator that was rated for vapors.

- Instrument surveys and area monitoring indicate that vapors infiltrated accommodation spaces during tank washing, tank ventilation and ballasting into cargo tanks. Overall, the physical factors that contributed to the infiltration included open make-up air intakes, foreward facing or open access doors and incomplete seals between exterior doors and jambs. While not specifically observed during these tests, infiltration probably also occurs during product loading, given the correct environmental conditions.

- Occupational exposure monitoring of Pumproom operations indicated that the Pumpmen were not exposed to vapor concentrations above 15 percent of the TWA during loading, lightering and primary discharging. This level of exposure is not toxicologically significant.

- Monitoring of Assistant Engineers, Oilers and Firemen for hydrocarbon vapor, asbestos and oil mist exposure indicated that all Engine Room exposures were below medical monitoring response levels and were not toxicologically significant.

- While inert gas systems on crude carriers have mitigated a fire and explosion hazard, the occupational exposure situation has not been correspondingly remedied. Tanks are opened at the end of loading and before discharge commences so that product ullage and water content can be manually gauged. During these operations, hydrogen sulfide exposures from the sour crude exceeded the medical monitoring response level of 5 ppm. These integrated values were obtained with relatively slow responding passive dosimeters. Direct reading instrument measurements of H_2S concentration in the breathing zone indicated the presence of transient H_2S levels that approached or exceeded 1895 ppm. On the basis of the hexane, benzene and toluene components in crude oil, the mixture medical monitoring response level was exceeded on two occasions both of which were associated with the surveying operation at the end of loading. Breathing zone measurements of total crude oil vapor indicated that the work environment contained fluctuating vapor concentrations that ranged to 4000 ppm or more as hexane.

- The major conclusions from the noise monitoring efforts are as follows.

  - One Engine Room watch resulted in two noise samples whose cumulative effective exposures at the end of the watch exceeded the permissible cumulative exposure at the corresponding time as specified in USCG NVC 12-82 (Reference 15). This condition signifies that even if no further exposure were to be received for the remainder of the day, then the 24-hour USCG exposure limit of 82 dB(A) would have been exceeded. Hearing protection was not worn.

  - Paint chipping with pneumatic needle guns produced two noise samples with the same result as discussed above. However, both workers wore different types of hearing protection so the actual exposure is unknown.

  - Elevated, high velocity vents are effective at promoting dispersion and dilution of high concentration vapors. However, when these vents "popoff" they generate a significant amount of noise, especially when several vents "popoff" simultaneously. The noise level is not sufficient to be of concern in and of itself; however, the noise did mask audible gauging alarms which created other operational hazards.

- Merchant mariners generally consider chemicals regulated by Subchapter D to be of little or no respiratory hazard and Subchapter O chemicals to represent a great hazard. The results of this study show that significant overexposures are occurring to both Subchapter O and D (e.g. gasoline) cargos. The data indicate that a knowledge of the characteristics of individual chemicals in both Subchapter O and D is necessary to ensure the safety of the mariner.

- The mariner's assumption that all Subchapter D products are not respiratory hazards is incorrect, especially for open topoff gauging of cargo tanks. The measured occupational exposure data in Reference 6 were used to derive a mathematical expression for predicting the breathing zone vapor concentration at tank topoff. This expression, which appears in Reference 14, is as follows.

$$C_e^* = 6.9 \times 10^{-3}\ C_s$$

where C_e^* = predicted breathing zone vapor concentration at tank topoff, ppm

C_s = saturated vapor concentration corresponding to the cargo temperature, ppm

Assuming a cargo temperature of 20°C, the above expression was used to calculate C_e^* for two Subchapter D products. The results are summarized below.

Chemical	C_e^*(ppm)	TLV-TWA (ppm)	TLV-STEL (ppm)
Methyl Cellosolve	56	5 (skin)	--
n-Butyl Alcohol	79	C50	--

Methyl cellosolve does not have an STEL. The predicted exposure level of 56 ppm exceeds the ACGIH recommended not-to exceed limit of 5 x TLV-TWA (or 25 ppm) for short term exposures. Similarly, the predicted butanol exposure exceeds the ceiling TLV of 50 ppm (not be exceeded at any time). These two examples demonstrate that potential overexposures can result from open gauging of cargo tanks that carry these products. There are many other Subchapter D products that produce similar overexposure predictions.

VII. RECOMMENDATIONS

The results of this project and its predecessor, "A Crew Exposure Study - Phase I", form the basis for certain recommendations. One of the objectives of the study was to observe and monitor occupational exposures, primarily to chemical substances, for a wide range of cargos, vessels, equipment and operations. The rationale for this objective is that the results should be representative of bulk liquid tanker operations. Having achieved this objective, it follows that the recommendations can reflect operations in the broadest sense while retaining specificity when necessary.

The USCG provides both formal requirements and informal guidance to industry regarding tanker operations. Formal requirements appear in two subchapters of the Code of Federal Regulations.

- 46 CFR - Subchapter D - Tank Vessels
- 46 CFR - Subchapter O - Certain Bulk Dangerous Cargos

Throughout the project, work practices, procedures and operations were observed. The consequences of these actions were monitored in terms of occupational exposures. Therefore, it was logical to assess the exposure data not only from an industrial hygiene or toxicology viewpoint but also relative to these formal USCG recommendations for vessel operation. In so doing, it was clear that Subchapters O and D are collectively inadequate from an occupational health standpoint to fully protect the mariner.

Environmental monitoring indicates that 38 percent of the entries into tanks which had contained Subchapter D or O products resulted in vapor exposures in excess of the medical monitoring response level. A significant number of entries occurred with little or no pre-entry testing of the atmosphere or ventilation during in-tank work. To decrease the possibility of harmful exposure, at least the following elements of a tank entry procedure should be addressed in Subchapters D and O.

- The atmosphere to be entered should be tested to ensure that it contains at least 19.5 percent oxygen by volume and that the concentrations of appropriate toxic vapors are less than the current exposure limits as recommended by the American Conference of Governmental Industrial Hygienists or the best available information if a TLV does not exist. This is consistent with ANSI/NFPA 306 - "Control of Gas Hazards on Vessels".

- Personnel responsible for atmosphere testing should be able to demonstrate that they are knowledgeable in the proper use of the equipment and that the instruments (oxygen, combustible gas and toxicity) are correctly calibrated and are in working order.

- Forced ventilation should be provided continuously while crew members are in confined spaces such as cargo tanks.

- Any existing requirement for use of an SCBA (self contained breathing apparatus) or other respiratory protection equipment should be supplemented by a respiratory protection program similar to the programs in ANSI Z-88 (current edition) and 29CFR 1910.134.

- A deck safety watch should be in attendance at all times when crew members are in ship's tanks.

- Prior to entry into a confined space, an entry permit should be completed by the person entering the tank and a deck officer. The entry permit should be a formal record that proper confined space entry procedures (as stated above) have been followed.

Some elements of the recommended entry procedure are already included in Subchapter O. Subchapter D does not include any confined space entry procedure for vessels at sea.

All Subchapter D products can be open gauged. This is normally accomplished through an ullage port. On a fully loaded tank, the vapor concentration at the open port can approach or equal the saturated concentration corresponding to the cargo temperature at the end of loading. The open gauging data that were collected on this project indicate that 46 percent of the gauging exposures prior to tank topoff were greater than the medical monitoring response level and that the percentage above the medical monitoring response level increased to 52 percent at topoff. Conversely, none of the Subchapter O products resulted in exposures above the medical monitoring response level when restricted gauging with sounding tubes was used. To reduce vapor exposures during gauging, the cargos that permit open gauging should be reviewed. Currently some Subchapter O and all Subchapter D products can be open gauged. For those cargos that represent a vapor inhalation hazard (based on saturated vapor pressure, temperature and medical monitoring response level) engineering control such as restricted gauging should be required. If this is not practical and if open gauging is to continue as it is currently practiced, then it is recommended that Subchapter D be ammended to include the following considerations.

- When it can be shown that a certain product constitutes a respiratory hazard during open gauging, as described above, then appropriate respiratory protection equipment should be used.

- When respiratory protection is necessary, its use should be supported by a respiratory protection program comparable to ANSI Z-88 (current edition) or 29CFR 1910.134.

Additional recommendations are as follows.

- The USCG currently requires a Cargo Information Card system for all products that are regulated under Subchapter O. These cards are basically Material Safety Data Sheets. This system should be extended to include Subchapter D products. In addition, there should be a requirement for these information sheets to be posted in a conspicuous place where all crew members can read them. Currently, the cards need be available only to the person in charge of a watch. The purpose of this recommendation is to promote an increased awareness on the part of all the ship's employees of the properties and hazards of the cargos that are being handled.

- Currently, there is a regulatory requirement for periodic fire and boat drills. We recommend that a similar program be initiated for periodic safety and health drills. Suggested topics for these sessions could include

  - proper use and care of air purifying respirators and self contained breathing apparatus,
  - maintenance, calibration and proper use of oxygen meters, combustible gas indicators and detector tube systems,
  - review of proper confined space entry procedures and entry permit system, and
  - review of good work practices that are designed to minimize occupational exposures.

  These periodic "hands-on" sessions could be part of a continuing education program.

- The degree curriculum at Merchant Marine Academies should include a core course in industrial hygiene and occupational safety/health as applied to cnemical/product tanker operations. This course, which would be taken by all degree candidates, would include topics such as chemical hazards, potential exposure hazards, instruments for testing gas/vapor atmospheres, confined space entry procedures, protective clothing, respirators, work practices, etc.

- Deck Officers should be required to take a refresher course every five years as a condition for license renewal. The scope of a course for deck officers should probably be quite different than one given to cadets if for no other reason than the difference in experience levels. Further, unlicensed personnel in the Deck Department should take a tailored version of this course on a periodic basis.

- All owners/operators of parcel chemical/product tankers should develop and implement a confined space entry procedure and permit system. Some owners/operators have already taken the initiative.

- Colorimetric detector tubes have a finite shelf life, and it may not be practical for a vessel to maintain a current stock of tubes for all of the chemicals that may be transported. This situation would be alleviated if the loading terminal were to provide the ship with valid tubes for each product that is transferred to the ship. These tubes would then be available for testing tank atmospheres prior to entry. Compatibility of the detector tubes and pump is assumed.

Numerous recommendations have resulted from this study. Some of the recommendations are already being implemented by industry on a voluntary basis. Whether the remainder of these recommendations can be implemented on a voluntary basis or whether regulations are required is beyond the scope of this study.

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