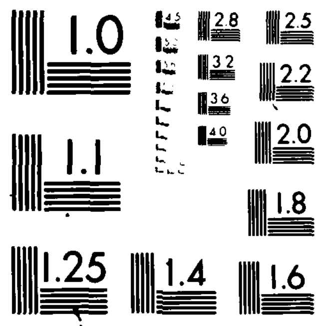
AD-A098 708 AIR FORCE HOSPITAL WIESBADEN APO NEW YORK 09220 BIOEN--ETC F/G 6/10
AN INDUSTRIAL HYGIENE EVALUATION OF AIRCRAFT REFUELING INSIDE C--ETC(U)
JAN 81 J A MARTONE
UNCLASSIFIED BEES(W)-81-03 NL

END
DATE
FILMED
8-81
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

LEVEL II

12

TECHNICAL REPORT BEES (W) 81-03

AD A098708

AN INDUSTRIAL HYGIENE EVALUATION OF AIRCRAFT REFUELING INSIDE CLOSED AIRCRAFT SHELTERS

JOSEPH A. MARTONE
BIOENVIRONMENTAL ENGINEERING SERVICES

JANUARY 1981

FINAL REPORT

AUGUST 1980 - DECEMBER 1980

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

USAF HOSPITAL WIESBADEN
APO NEW YORK 09220

NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The mention of trade names or commercial products in this publication is for illustration purposes and does not constitute endorsement or recommendation for use by the United States Air Force.

Do not return this copy. Retain or destroy.

Please do not request copies of this report from the USAF Hospital Wiesbaden. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government Agencies and their contractors registered with the (DTIC) should direct requests for copies of this report to:

Defense Technical Information Center (DTIC)
Cameron Station
Alexandria, Virginia 22314

A

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: (14) Technical Report BEES(W)-81-03	2. GOVT ACCESSION NO.: AD-A098708	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): (6) An Industrial Hygiene Evaluation of Aircraft Refueling Inside Closed Aircraft Shelters.		5. TYPE OF REPORT & PERIOD COVERED: (9) Final Report, Augu[redacted]980 — Dec[redacted]198
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): (10) Joseph A. Martone Major, USAF, BSC		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: USAF Hospital Wiesbaden/SGP APO, New York 09220		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: USAF Hospital Wiesbaden/SGP APO, New York 09220		12. REPORT DATE: (11) Jan[redacted]81
		13. NUMBER OF PAGES: 21
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 26		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Availability of this report is specified on reverse of front cover

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aircraft shelters	Fuel vapors	Aircraft
Jet fuel	Industrial hygiene	Aviation fuel
Refueling	Exposure	Charcoal tubes
		Monitoring

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes and gives the results of an industrial hygiene evaluation of aircraft refueling inside closed TABVEE and third generation aircraft shelters. The primary concern was with breathing zone concentrations of fuel vapors displaced from aircraft fuel tanks during refueling. The major conclusions are that refueling with JP-8 is acceptable under any conditions but that refueling with JP-4 should be conducted only when the ambient temperature is less than 25°C to assure concentrations well below the permissible short term exposure level for fuel vapors.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

412332

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

This industrial hygiene survey was conducted as part of a NATO evaluation of aircraft refueling in closed aircraft shelters. The study involved many NATO and USAF personnel in addition to our bioenvironmental team. Special graditude is extended to Mr. Tom Mitchell at HQ USAFE/DEMO for his role in coordinating the entire effort.

The individuals from the USAF Hospital Wiesbaden making significant contributions to the industrial hygiene survey and this report were:

Major Dean D. Nelson, Bioenvironmental Engineer
MSgt Franklin L. Watson, Technician
TSgt David J. Hawkins, Technician
SSgt Dennis Jones, Technician
Herr Dr Klippel, Chemist
Ms Carol Savakes, Secretary
Ms Debbie Wilson, Secretary

We are also grateful for the analytical support and supplies provided by the USAF School of Aerospace Medicine (SAM) and the USAF Occupational and Environmental Health Laboratory (OEHL) both at Brooks AFB, Texas.

This report has been reviewed by the public affairs officer and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

Joseph A. Martone

JOSEPH A. MARTONE, Major, USAF, BSC
OIC, Industrial Hygiene Engineering

D. Nel

DEAN D. NELSON, Major, USAF, BSC
Chief, Bioenvironmental Engineering Services

(The reverse of this page is blank)

TABLE OF CONTENTS

SECTION		PAGE
I.	INTRODUCTION	1
II.	BACKGROUND	2
III.	SHELTER DESCRIPTION AND TEST SCENARIOS	3
IV.	INDUSTRIAL HYGIENE CONSIDERATIONS	5
V.	TEST PROCEDURES AND ANALYTICAL METHODS	7
VI.	RESULTS AND DISCUSSION	8
VII.	CONCLUSIONS AND RECOMMENDATIONS	15
	REFERENCES	16

APPENDIX

A.	CALCULATIONS	17

LIST OF TABLES

TABLE		PAGE
I.	IN-SHELTER REFUELING TEST CONDITIONS	4
II.	FUEL VAPOR CONCENTRATIONS MEASURED DURING AIRCRAFT REFUELING IN CLOSED AIRCRAFT SHELTERS	9
III.	COMPARISON OF MEASURED AND CALCULATED FUEL VAPOR CONCENTRATIONS	10
IV.	NORMALIZED JP-4 FUEL VAPOR DATA	12
V.	COMPARISON OF WORKDAY PERMISSABLE EXPOSURE LEVELS (PEL) WITH CALCULATED FUEL TRUCK EMISSIONS FOR IN-SHELTER REFUELING	14

SECTION I
INTRODUCTION

Headquarters USAFE/DEMO requested an industrial hygiene survey as part of a NATO evaluation of aircraft refueling inside of closed aircraft shelters. Tests were conducted at three locations in order to cover a wide range of environmental and physical conditions. Warm weather tests were done at Larissa, Greece in August 1980. A moderate climate was studied at RAF Alconbury, UK in October 1980. A cold weather test was performed at Bardufoss, Norway in December 1980. This report describes and gives the results of the industrial hygiene evaluation.

The tests involved different combinations of aircraft, shelters, and fuel. At Larrissa, F-4 Aircraft were fueled with JP-4 in a TABVEE shelter (i.e. first generation shelter). At RAF Alconbury, F-4 aircraft were fueled and defueled with JP-8 in a third generation aircraft shelter. The tests at Bardufoss involved F-104 aircraft, Jet B fuel and a TABVEE type shelter.

SECTION II
BACKGROUND

In many NATO countries special concrete shelters housing single aircraft have been constructed to keep tactical aircraft dispersed and to protect them from attack by bombs and guerilla action. For maximum security it would be desirable to conduct every support operation, including refueling, inside such shelters with doors closed, if permissable from a safety and health standpoint. Under current USAF and NATO regulations and directives, based upon what information is available, such procedures would be strictly prohibited. Any relaxation of these safety and health measures could be justified only by better data or combat urgency.

Past studies (References 1 and 2) have concentrated mostly on the safety aspects of in-shelter and in-hanger refueling. Relatively little attention has been given specifically to the health aspects of in-shelter refueling. Other industrial hygiene evaluations (References 3 and 4) have included refueling as part of more complex test programs but in general, have not isolated and independently evaluated the case of closed door in-shelter refueling as was done in the present study. Jackson (Reference 4) for example, concludes that fuel vapor levels in TABVEE shelters during closed door refueling have not been well defined and recommends additional testing. Where possible, data from previous studies have been compared with data obtained in this survey.

SECTION III
SHELTER DESCRIPTION AND TEST SCENARIOS

The test scenario at each location (i.e. Larissa, Alconbury, and Bardufoss) was in principal the same. Immediately after landing, the aircraft was parked in the shelter and refueled. Both the front and exhaust port doors of the shelter were closed during refueling and no additional ventillation was present.

Each test differed in detail. Table I lists the most important conditions. Also included in Table I is information about tests done in previous evaluations of in-shelter refueling (References 2 and 4).

Only test E involved aircraft defueling. During defueling an AM32A-60 turbine generator provided electrical power. The generator was positioned near the partially opened shelter exhaust port to increase the likelihood of generator exhaust exiting the shelter.

The Jet B fuel used at Bardufoss has bulk properties basically the same as JP-4 (Reference 5).

TABLE I

IN-SHELTER REFUELING TEST CONDITIONS

Test	Location	Aircraft	Shelter* Type	Shelter Volume (m^3)	Fuel Type	Ambient Air Temp °C	Fueling Mode	Fueling Time (min)	Fuel Transferred (m^3)	Ref.	Remarks
A	Larissa	F-4	I	1850	JP-4	26.7	Fuel truck outside shelter	9	8.8	-	
B	Larissa	F-4	I	1850	JP-4	26.7	Fuel truck outside shelter	8	7.8	-	
C	Alconbury	F-4	III	5100	JP-8	10.0	Fuel truck outside shelter	6	7.1	-	
D	Alconbury	F-4	III	5100	JP-8	10.0	Fuel truck inside shelter	12	7.1	-	
E	Alconbury	F-4	III	5100	JP-8	10.0	Fuel truck inside shelter	20	Unknown	-	Aircraft was defueled AM32A-60 generator used.
F	Bardufoss	F-104	I	1500	Jet B	-5	Fuel truck outside shelter	6	4.0	-	10-20 liter fuel spill
G	Bardufoss	F-104	I	1500	Jet B	-5	Fuel truck inside shelter	6	4.0	-	10-20 liter fuel spill
H	Ramstein	F-4	I	1850	JP-4	12.8	Unknown	13	11.3	2	
I	Camp New Amsterdam	F-15	III	5100	JP-4	16.6	Fuel truck inside shelter	Unknown	5.3	4	
J	Camp New Amsterdam	F-15	I	1850	JP-4	16.6	Fuel truck inside shelter	Unknown	1.8	4	
K	Spangdahlem	F-4	III	5100	JP-4	16.1	In-shelter plumbing	30	11.2	4	Difficulty with fueling system caused delay.
L	Spangdahlem	F-111	III	5100	JP-4	16.1	In-shelter plumbing	10	13.4	4	

* I = TABVEE
III = 3rd generation

SECTION IV
INDUSTRIAL HYGIENE CONSIDERATIONS

On tests in which the fuel truck remained outside the shelter the only pollutant released into the shelter was fuel vapor displaced from the aircraft fuel tanks or evaporated as a result of a fuel spill. Significant spills (i.e. 10 to 20 liters) did occur at Bardufoss when aircraft fuel tanks overflowed through vent holes before the fuel supply was shut off. On tests in which the fuel truck or AM32A-60 generator operated inside the shelter, combustion generated pollutants (i.e. carbon monoxide (CO), unburned hydrocarbons (UBHC), and oxides of nitrogen (NO_x)) were also released into the shelter environment.

Since the amounts of combustion generated pollutants could be estimated from known emission factors and previous data, the major effort in this study was directed at measuring fuel vapor concentrations in the breathing zone of personnel in the shelter. Unfortunately there is no short term exposure limit (STEL) or workday permissable exposure limit (PEL) established specifically for jet fuel vapors. However, the limits developed for refined petroleum solvents is the most appropriate criteria for aviation fuels. The recommended standard (Reference 6) is 350 mg/m^3 for a 10 hour time weighted exposure (i.e. PEL) and 1800 mg/m^3 for a short term exposure (15 minutes) of personnel (i.e. STEL).

Considering the short time required for an in-shelter refueling (see Table I), the health criteria which best applies is the STEL. The STEL (Reference 7) is the maximal concentration to which workers can be exposed for a period up to 15 minutes continuously without suffering irritation, irreversible tissue change or narcosis of sufficient degree to increase accident proneness or reduce work efficiency provided that no more than four exposures per day are permitted, with at least 60 minutes between exposure periods, and provided that the PEL is also not exceeded.

Benzene deserves special mention since it has toxic properties thought to be unique among hydrocarbon compounds. At high enough exposures over sufficient time periods, benzene exerts a toxic effect on the body's blood forming organs causing aplastic anemia and other severe disorders. Benzene is present in aviation fuels but most refiners find it more valuable as a petrochemical feedstock and so separate it from fuel streams for other uses. Experience in USAFE indicates the benzene content of JP-4 and JP-8 never to be greater than 0.37 volume percent and typically less than 0.2 volume percent. Current Air Force directives (ETAFOSH Standard 161-7) exempts work areas where the benzene containing materials have less than 1% bezene by volume and initial measurements or calculations verify that the PEL is not exceeded. It can be readily calculated that if the benzene content is below 0.5% by volume the airborne concentration will always be below 1 ppm PEL. Therefore, benzene exposure was not specifically considered in this study.

Eye irritation can be a problem in aircraft shelters (Reference 3). Unfortunately it is very difficult to pinpoint the chemical species responsible for eye irritation. Experience indicates that eye irritation is associated with combustion generated pollutants and not fuel vapors alone. Eye irritation is frequently attributed to aldehydes and acrolein in the exhausts of combustion sources.

sources. No permanent eye injury is connected with photochemical air pollution (Reference 8) and presumably this same guideline applies to eye irritation noted during certain in-shelter operations. Because of the potential for eye irritation, subjective attention was given to this possibilty during the surveys.

The use of JP-8 rather than JP-4 or Jet B is an advantage in considering fuel vapors. The vapor pressure of JP-8 is an order of magnitude less than JP-4 at 311K (100°F) (Reference 9). This means substantially less fuel vapor is vented from a JP-8 fueled aircraft during refueling compared with JP-4 or Jet B.

Temperature has a dramatic effect on fuel vapor pressure and is an important factor in determining the amount of fuel vapor vented during refueling (see Appendix A). For example at -5°C (i.e. Bardufoss ambient temperature) the vapor pressure of JP-4 is 41 mmHg while at 27°C (i.e. Larissa ambient temperature) the vapor pressure of JP-4 is 103 mmHg.

Shelter volume is important from a pollutant dilution aspect. A third generation shelter contains almost three times the interior volume of a TABVEE shelter and offers three times the dilution volume.

SECTION V
TEST PROCEDURES AND ANALYTICAL METHODS

Prior to each test, fuel crew members were outfitted with personal air sampling equipment designed to measure fuel vapor concentrations in their breathing zones. Only crew members who stayed inside the shelter during a test were outfitted. For example if the fuel truck and driver were inside the shelter then the driver was equipped, if the fuel truck and driver were outside the shelter then the driver was not outfitted with sampling equipment. Typically, two or three crew members were involved on each test. As soon as practicable after each test, the personal sampling gear was removed from the crew members. The sampling time was about 20 minutes.

In addition to the crew member samples, two or three other samples for fuel vapors were obtained on each test. In some cases the sampling equipment was attached to bioenvironmental team members who randomly walked about the shelter during a test, in other cases the sampling equipment was set up at a fixed location in the shelter. The samples obtained by both these methods are referred to as area samples.

The method for sampling fuel vapors involved sorption on charcoal tubes. This is the procedure recommended by the National Institute for Occupational Safety and Health (NIOSH) for refined petroleum solvents (Reference 6). DuPont Model P-4000 personal sampling pumps were used to produce flow at a nominal rate of 0.5 liters per minute through the charcoal tube. A precision rotameter was used to measure the flow. The exact sample volume at standard temperature and pressure (i.e. 25°C and 760 mmHg) was calculated post test.

Charcoal tube analysis was performed at the USAF Hospital Wiesbaden. The technique requires fuel vapor desorption with carbon disulfide and detection by a gas chromatograph equipped with a non-polar column.

On test G (i.e. fuel truck in-shelter), carbon monoxide (CO) levels were measured with a direct reading instrument (Ecolyzer Model 2000) which uses an electrochemical detector to measure CO in two ranges: 0-100 ppm (low scale) and 0-600 ppm (high scale). The instrument was calibrated with factory supplied 50 ppm CO calibration gas at frequent intervals during the test period.

On certain tests hydrocarbon vapors were also sampled using tenax tubes and organic vapor passive dosimeters. Tenax is a solid sorbent material which permits subsequent analysis of hydrocarbon vapors by chemical class and by individual components. The passive dosimeters use charcoal as the sorbent material and rely on molecular diffusion to deposit organic vapors. Both the tenax tubes and passive dosimeters were used to support an experimental passive dosimeter evaluation program conducted by the USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas and the USAF Hospital Wiesbaden. Since the complete results from these samples are not yet available and because they are not essential to the evaluation of in-shelter refueling, this data is not presented in this report.

SECTION VI
RESULTS AND DISCUSSION

FUEL VAPORS: Table II gives breathing zone concentrations of fuel vapors measured during in-shelter aircraft refueling. Table II includes fuel vapor breathing zone levels measured on previous studies (References 2 and 4). All results are reported in milligrams fuel vapor per cubic meter and have been corrected to standard conditions of 298 K and 760 mmHg. The test at Ramstein (Reference 2) used a Beckman Model 400 total hydrocarbon analyzer to measure fuel vapors but all other measurements used the charcoal tube technique described in Section V.

The results show that the average fuel vapor concentration in a closed shelter never exceeded the STEL (i.e. 1800 mg/m^3) on any test although individual samples on test B did exceed the STEL. The high concentrations occurred during warm weather tests (tests A & B) in a TABVEE shelter using JP-4. High fuel vapor concentrations are expected at high temperatures because the fuel vapor pressure is greater and there is better convective mixing in the shelter. Reference 2 showed that there can be quite a stratification (i.e. high levels near the floor) of fuel vapor concentrations in closed TABVEE shelters at moderate temperatures (i.e. 12.8°C). At higher temperatures, better mixing would be expected to result in higher breathing zone fuel vapor concentrations.

This suggested effect of better in-shelter mixing at elevated temperatures is supported by data in Table III which compares average measured breathing zone fuel vapor concentrations with calculated values. An example calculation is shown in Appendix A. The calculated concentrations assume a well mixed shelter and therefore at higher temperatures the calculated and measured values tend to agree better. Although this comparison is not conclusive it is certainly apparent that calculated values are consistently higher than measured breathing zone levels indicating that some stratification (i.e. incomplete mixing) is likely even in warm shelters.

Except for tests A, B, and K, the workday permissable exposure level (PEL) of 350 mg/m^3 was not exceeded by any individual samples. The relatively high levels measured on tests A and B can be attributed to the use of a volatile fuel (JP-4) on a warm day in a small shelter. The high value of 620 mg/m^3 reported for Test K maybe atypical because Jackson (Reference 4) reports that refueling difficulties were experienced during the test and that the process took 30 minutes to complete versus the normal 3 to 5 minutes. An exposure level of 620 mg/m^3 would meet the workday PEL if the duty day exposure period was less than 5.5 hours.

The high levels encountered on tests A and B resulted in some breakthrough of fuel vapors on the charcoal sampling tubes. The charcoal in an individual tube is divided into two sections called a front half and a back half. Normally all of the sampled material is collected on the front half, however when breakthrough occurs, some of the material penetrates to the back half and so it is not certain whether the collection efficiency was 100% (i.e. some material

TABLE II

BREATHING ZONE FUEL VAPOR CONCENTRATIONS MEASURED DURING AIRCRAFT REFUELING IN CLOSED AIRCRAFT SHELTERS

FUEL VAPOR CONCENTRATION
(mg/m³)

SAMPLE LOCATION / TEST	A	B	C	D	E	F	G	H	I	J	K	L
Cockpit	1110	653	-	-	-	45	78	-	-	-	-	-
Crew Chief	-	-	<23	<22	<18	174	55	-	71	41	620	120
Refueler Technician	1160	2090	-	<22	<16	-	214	-	267	25	190	90
Area	671	1140	<25	12	<19	213	60	-	75	-	-	-
Area	533	3090	12	-	-	327	256	-	-	-	-	-
Area	1000	1560	-	-	-	-	-	-	-	-	-	-
Average	896	1710	<20	<19	<18	190	133	277	138	33	405	105
Fuel Type	JP-4	JP-4	JP-8	JP-8	JP-8	JET B	JET B	JP-4	JP-4	JP-4	JP-4	JP-4
Shelter Type	I	I	III	III	III	I	I	I	III	I	III	III
Ambient Temp. °C	26.7	26.7	10.0	10.0	10.0	-5.0	-5.0	12.0	16.6	16.6	16.1	16.1

TABLE III

COMPARISON OF MEASURED AND
CALCULATED FUEL VAPOR CONCENTRATIONS

TEST	AVERAGE MEASURED CONCENTRATION (mg/m^3)	CALCULATED CONCENTRATION (mg/m^3)	AMBIENT TEMP. (°C)	% DIFFERENCE $\frac{\text{calc - measured}}{\text{calc.}} \times 100$
A	896	1870	26.7	52
B	1710	1714	26.7	2
C	<20	<25	10.0	-
D	<19	<25	10.0	-
F	190	462	-5.0	59
G	133	462	-5.0	71
H	277	1793	12.8	85
I	138	303	16.6	54
J	33	278	16.6	88
K	405	640	16.1	37
L	105	769	16.1	86

may have penetrated both parts of the charcoal tube). On tests A and B the worst breakthrough found 25% of the total catch on the back half of the charcoal tube. Under these circumstances many would simply add the amount collected on the front and back portion of the tube and assume that no material was lost. In our case we used a method (Reference 10) that estimates the amount of fuel vapor that may have been lost and adds it to the amounts found in the front and back sections to determine the total. Appendix A gives a sample calculation.

The results of tests C, D and E illustrate the advantage of using JP-8. The extremely low measured levels as compared with JP-4 are attributed to the relatively low vapor pressure of JP-8. JP-8 was not used in a TABVEE shelter during this study but theoretically (see calculations in Appendix A) the level of JP-8 vapors would be only 117 mg/m^3 even if the ambient temperature was 38°C and as much as 11.3 m^3 of JP-8 was transferred.

This study did not experimentally address the possibility of fuel spills inside a closed shelter. Reference 2 did consider this potential hazard using JP-4 in a closed TABVEE shelter at an ambient temperature of about 13°C. Measurements were made at elevations of 5 cm and 30.5 cm from the shelter floor following the spill of 95 liters of JP-4. This amount (i.e. 95 liters) was considered to be 50% in excess of the maximum spill possible during an in-shelter refueling. During a 1/2 hour period after the spill the average concentration at the 5 cm level was 4500 mg/m^3 and at the 30.5 cm level 625 mg/m^3. Thus, the fuel vapor concentration at the breathing zone level (i.e. about 150 cm) should be well below the STEL and probably below the PEL.

The data presented in this report indicates that in-shelter refueling using JP-8 would not pose a health problem regardless of the shelter type or ambient temperature. The case for JP-4 is not as clear cut. The data for JP-4 is not directly comparable mostly because each test involved a different combination of the amount of fuel transferred, shelter volume, and ambient temperature. In an attempt to normalize the data and make a general conclusion, the measured average fuel vapor concentrations were divided by the shelter and fuel volume and plotted versus temperature. The results are shown in Table IV and Figure 1.

If we arbitrarily select 50% of the STEL as the level not to be exceeded inside of a shelter then Figure 1 shows that the ambient temperature must be less than 25°C. This will be true regardless of the shelter type or amount of fuel transferred within the limits of the data. It is noteworthy that the Royal Netherlands Air Force (Reference 11) strictly prohibits in-shelter refueling or defueling of aircraft at ambient temperatures above 25°C.

COMBUSTION GENERATED POLLUTANTS: Combustion generated pollutants were released into the shelter environment on tests in which the fuel truck operated in the shelter and on test E when an AM32A-60 turbine generator operated during the only defueling procedure studied. Test E was not preplanned and therefore a thorough evaluation was not possible with the available monitoring equipment. The generator is known to produce hazardous noise levels (Reference 12) and ear protection is required. Ear muffs were worn during test E. Data presented in Reference 12 shows that carbon monoxide will increase at a rate of 7.3 ppm per minute in a closed TABVEE shelter when the AM32A-60 is operated. Taking into account the added dilution volume of a third generation shelter this means that the average carbon monoxide level after a 20 minute defueling would be about 50 ppm. This is well within 125 ppm carbon monoxide for 3 hours, a level which the Aerospace Medical Research Laboratory (AMRL) (Reference 13) has determined will not cause performance degradation. It is also below the STEL for carbon monoxide which is 400 ppm (Reference 7).

Based on experience (Reference 3) with an aircraft turbine engine operated in a closed third generation shelter, the AM32A-60 would not be expected to generate unhealthful oxides of nitrogen levels. The AM32A-60 is known to produce significant levels of aldehydes (Reference 12) which can result in transient eye and respiratory tract irritation. Subjectively this did occur on test E, however the irritation was not of sufficient duration or severity to impair judgement or job performance.

The above discussion indicates that operation of a AM32A-60 in a closed shelter during aircraft defueling maybe acceptable from a health standpoint. Two points of caution must be noted. In a TABVEE shelter with its limited dilution volume, a 20 minute defueling would result in a room average carbon monoxide concentration of about 150 ppm; considerably above the AMRL 3 hour standard (Reference 13). The workday PEL for carbon monoxide (i.e. 50 ppm) could also be exceeded depending on the total exposure time during a workday. Eye irritation would also be expected to be more severe in a TABVEE shelter.

TABLE IV

NORMALIZED JP-4 FUEL VAPOR DATA

TEST	SHELTER VOLUME (m^3)	FUEL TRANSFERRED (m^3)	MEASURED AVERAGE CONCENTRATION (mg/m^3)	AMBIENT TEMPERATURE (°C)	A NORMALIZED CONCENTRATION $\frac{mg}{m^3\text{-}m^3 \text{ fuel-}m^3 \text{ shelter}} \times 10^3$	B NORMALIZED STEL $\frac{mg}{m^3\text{-}m^3 \text{ fuel-}m^3 \text{ shelter}} \times 10^3$	% OF STEL (A/B) x 100
A	1850	8.8	896	26.7	55	111	50
B	1850	7.8	1710	26.7	118	125	94
F	1500	4.0	190	-5.0	32	300	11
G	1500	4.0	133	-5.0	22	300	7.3
H	1850	11.3	277	12.8	13	86	15
I	5100	5.3	138	16.6	5.1	67	7.6
J	1850	1.8	33	16.6	9.9	541	1.8
K	5100	11.2	405	16.1	7.1	32	22
L	5100	13.4	105	16.1	1.5	26	5.8

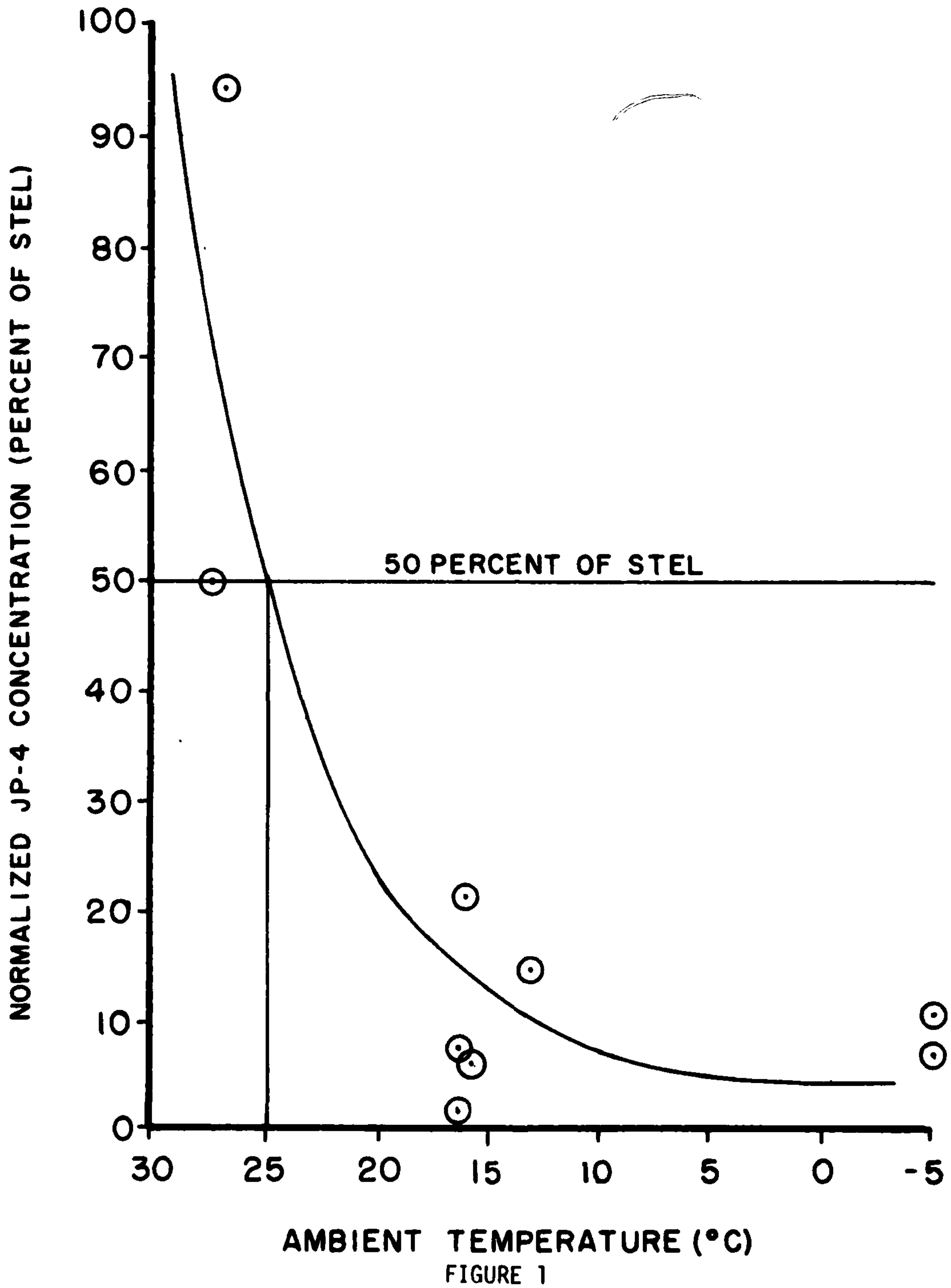


FIGURE 1

NORMALIZED JP-4 CONCENTRATIONS AS A FUNCTION OF TEMPERATURE

Another important point is that US Air Force technical orders require an operator near the AM32A-60 when it is running. The exposure to noxious gases that this individual receives maybe considerably higher than room average levels. For example, Reference 12 reports a peak concentration of 320 ppm CO in a closed TABVEE shelter with an AM32A-60 operating. For these reasons the use of the AM32A-60 during defueling in closed shelters requires further experimental evaluation.

On test G carbon monoxide levels were measured while a diesel powered fuel truck operated inside the shelter during refueling. The highest carbon monoxide level measured was about 50 ppm. This level was measured within two meters of the fuel truck exhaust pipe. In general, carbon monoxide levels in the vicinity of the fuel truck peaked at about 20 ppm by the end of the fueling period. These levels are well below the PEL for carbon monoxide. Other noxious gases were not measured but Table V shows an estimate of expected concentrations based on emission factors for a warmed heavy duty diesel vehicle at idle (Reference 14). The computations, given in Appendix A, assume a shelter volume of 1500 m^3 (i.e. worst case). The results show that the diesel exhaust should not result in unhealthful concentrations of oxides of nitrogen and carbon monoxide and that it contributes only minimally to the total hydrocarbon level. The fuel truck exhaust did cause slight eye irritation by the end of the fueling period but by subjective evaluation the irritation was not of sufficient duration or severity to impair judgement or job performance.

TABLE V

COMPARISON OF WORKDAY PERMISSABLE EXPOSURE LEVELS (PEL) WITH CALCULATED FUEL TRUCK EMISSIONS FOR IN-SHELTER REFUELING

POLLUTANT	CALCULATED CONCENTRATION	PEL
carbon monoxide	3.7 ppm	50 ppm
hydrocarbons	2.1 mg/m^3	350 mg/m^3
nitric oxide	3.5 ppm	25 ppm
nitrogen dioxide	0.3 ppm	5 ppm

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

Based on the information presented in this report the following conclusions and recommendations concerning the industrial hygiene aspects of aircraft refueling in closed aircraft shelters can be stated:

1. Because of the low vapor pressure of JP-8 compared with JP-4, refueling with JP-8 is acceptable in both TABVEE and 3rd generation shelters regardless of ambient air temperature.

2. In-shelter fuel spills of JP-4 or JP-8 should not result in unhealthful breathing zone fuel vapor concentrations before spill clean-up and opening the shelter.

3. Fuel truck exhaust generated inside either a TABVEE or 3rd generation shelter during refueling should not result in unhealthful concentrations of exhaust pollutants.

4. Refueling with JP-4 in a TABVEE or 3rd generation shelter should be conducted only when the ambient air temperature is below 25°C to assure breathing zone fuel vapor concentrations well below the permissable short term exposure limit.

5. Some eye irritation will occur when a diesel fuel truck is operated in closed shelters during refueling. The eye irritation is not severe and is not known to result in any permanent eye injury.

6. Additional tests are needed to determine if operating an AM32A-60 turbine generator inside a closed shelter during defueling is acceptable from a health standpoint.

REFERENCES

1. "Requirements for Explosion-Proof Electrical Equipment in Air Force Hangers". AFWL-TR-72-135, 1972.

2. Eggleston, LA. and Pish, M.D., "Requirements for Explosion-Proof Electrical Equipment in Aircraft Shelters." AFWL-TR-72-209, July 1973.

3. Martone, J.A., "An Evaluation of A-10 Aircraft Integrated Combat Turn Scenarios in Hardened Shelters," TR BEES(W) 80-31, August 1980.

4. Jackson, J.W., "An Environmental Evaluation of Refueling Aircraft in Hardened Shelters with Ballistic Doors Closed and Personnel Cubicles in Hardened Shelters," TR BEES(W) 79-49, Sept 1979.

5. Treager, Irwin E., Aircraft Gas Turbine Engine Technology, McGraw-Hill, Inc. 1970.

6. "Criteria for a Recommended Standard: Occupational Exposure to Refined Petroleum Solvents," NIOSH TR 77-192, 1977.

7. Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1980, American Conference of Governmental Industrial Hygienists, 1980.

8. Stern, A.C., Wohlers, H.C., Boubel, R.W. and Lowry, W.P., Fundamentals of Air Pollution, Academic Press, New York, 1973.

9. Lewanodowski, G.H., and Stauffer, T.B., "Control of JP-4 Emissions from Underground Storage Tanks," ESL-TR-74-03, April 1979.

10. Peterson, J.E., "Calculation of Vapor Penetration in Charcoal Sampling Tubes", AIHA Journal June, 1980.

11. "Aircraft Refuel and Defuel Procedures," Royal Netherlands Air Force, M.O. No. 0-0-9-(1)35B Annex F, April 1977.

12. Naugle, D.F., Haney, J.T. and Carroll, G.B., "Environmental Testing in Aircraft Shelters," AFWL-TR-73-96, July 1973.

13. Theodore, J. et al: "Toxicological Evaluation of Carbon Monoxide in Humans and Other Mammalian Species," J Occup Med 13: 242-254, 1971.

14. "Compilation of Air Pollutant Emission Factors:, USEPA Report AP-42, 2nd Ed., Sup 5, Dec 1975.

APPENDIX A

CALCULATIONS

A. Example Calculated Fuel Vapor Concentration

Fuel vapors expelled during refueling equals the vapor pressure of the fuel divided by atmospheric pressure (745 mmHg) times the volume of fuel transferred:

Given: 4 m^3 of fuel transferred on test F
Vapor pressure of JP-4 at 268 K (23°F) is 41 mmHg (Reference 9)

$$\text{Fuel vapor expelled} = \frac{41}{745} \times 4 = 0.22 \text{ m}^3$$

The weight of fuel vapor expelled equals the volume of vapors divided by the liters of gas per molecular weight (22.4 liters) times the molecular weight of vapors (70 grams assumed Reference 9).

$$\text{Grams of vapor expelled} = \frac{0.22 \text{ m}^3}{22.4} \times 10^3 \times 70 \text{ g} = 694 \text{ g}$$

Concentration in a Norwegian shelter if uniformly mixed is the mass divided by the shelter volume (1500 m^3):

$$\text{Vapor concentration} = \frac{694 \text{ g}}{1500 \text{ m}^3} \times 10^3 = 462 \text{ mg/m}^3$$

B. Estimated Mass of Fuel Vapors Collected When Charcoal Tube Breakthrough has Occurred

The total mass of fuel vapors the charcoal tube should have collected is:

$$t = f^2/(f - 2b) \qquad \text{(Reference 10)}$$

Where:

f = mass of fuel vapor collected in the front tube section

b = mass of fuel vapor collected in the back tube section

t = estimated total mass collected

For one of the area samples taken on test B:

f = 15.4 mg JP-4

b = 3.6 mg JP-4

Therefore,

$$t = 28.9 \text{ mg JP-4}$$

The volume of air sampled was 25.4 liters therefore, the estimated concentration, C, is:

$$c = \frac{28.9 \text{ mg}}{0.0254 \text{ m}^3} = 1138 \text{ mg/m}^3$$

C. Estimated Concentration of JP-8 Vapors During Refueling in a Closed TABVEE Shelter

Assume a worst case situation where 11.3 m^3 of JP-8 is transferred with an ambient temperature of 38°C.

Vapor pressure of JP-8 at 311K is 5.1 mmHg (Reference 9)

$$\text{Fuel vapor expelled} = \frac{5.1}{760} \times 11.3 \text{ m}^3 = 0.076 \text{ m}^3$$

Assuming a fuel vapor molecular weight of 70 (Reference 9),

$$\text{Grams of vapor expelled} = \frac{0.076 \text{ m}^3}{24.45 \text{ } \ell} \times 70 \times 10^3 = 217 \text{ g}$$

The fuel vapor concentration in a TABVEE shelter if uniformly mixed is the mass divided by the shelter volume (1850 m^3):

$$\text{Vapor concentration} = \frac{217 \text{ g}}{1850 \text{ m}^3} \times 10^3 = 117 \frac{\text{mg}}{\text{m}^3}$$

D. Estimated Contribution of Diesel Exhaust in Closed Aircraft Shelter During Aircraft Refueling.

Emission factors for a heavy duty diesel vehicle at idle from Reference 14 are:

Carbon monoxide (CO)	=	0.64 g/min
Hydrocarbons (HC)	=	0.32 g/min
Oxides of nitrogen (NO_x) (as NO_2)	=	1.03 g/min

Assuming the fuel truck runs about 10 minutes in the shelter, calculate the mass of pollutants generated:

CO	0.64 g/min	x	10 min	=	6400 mg CO
HC	0.32 g/min	x	10 min	=	3200 mg HC
NO_x	1.03 g/min	x	10 min	=	10,300 mg NO_x (as NO_2)

Since NO_x from combustion sources is normally 95% NO and 5% NO_2

$$NO_2 \quad 10{,}300 \text{ mg } NO_x \times 0.05 = 515 \text{ mg } NO_2$$

$$NO \quad 10{,}300 \text{ mg } NO_x \times 0.95 \times \frac{30}{46} = 6381 \text{ mg NO}$$

The shelter volume at Bardufoss was approximately 1500 m^3. Assuming a well mixed shelter the concentration of pollutants due to the fuel truck exhaust are:

$$CO \quad \frac{6400 \text{ mg}}{1500 \text{ m}^3} = 4.3 \text{ mg/m}^3 = 3.7 \text{ ppm}$$

$$HC \quad \frac{3200 \text{ mg}}{1500 \text{ m}^3} = 2.1 \text{ mg/m}^3$$

$$NO \quad \frac{6381 \text{ mg}}{1500 \text{ m}^3} = 4.3 \text{ mg/m}^3 = 3.5 \text{ ppm}$$

$$NO_2 \quad \frac{515 \text{ mg}}{1500 \text{ m}^3} = 0.34 \text{ mg/m}^3 = 0.3 \text{ ppm}$$

(The reverse of this page is blank)

DISTRIBUTION LIST

	COPIES
Hq USAFE/SGPA	1
USAF OEHL/CC	1
AFMSC/SGPA	1
AFMSC/SGB	1
AFESC/RDV	1
OL-AD/OEHL	1
Each USAFE Medical Facility	1
Hq USAFE/DE	1
Hq USAFE/LG	1
Hq USAFE/DEMO	25
Hq USAFE/LGM	1
USAF Clinic SGB, McClellan AFB	1
Hq AFLC/DEPV	1
Hq TAC/SGPA	1
Hq AFLC/SGB	2
Hq TAC/DEEV	1
Hq USAF/LEEV	1
USAFSAM/VNL	1
Hq PACAF/SGPE	1
DTIC/DDA	12

LMED

8