



DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010-6422



REPLY TO
ATTENTION OF

HSHB-ME-AQ

FINAL REPORT
KUWAIT OIL FIRE **HEALTH** RISK ASSESSMENT
NO. 39-26-L192-91
5 MAY - 3 DECEMBER 1991

APPENDIX B
AMBIENT AIR SAMPLING AND AIR PATHWAY ANALYSIS

1. PURPOSE. The purposes of the ambient air sampling **program** were:

- a. To collect air samples in **Kuwait** and Saudi Arabia, **analyze** and use as data for completing the health risk assessment, and;
- b. To conduct an air pathway analysis of U.S. military and Department of Defense (DOD) civilian **exposures** to contaminants **associated with** the burning oil **wells**.

2. REFERENCES. A list **of** references used in this **appendix** is contained in Annex B-1.

3. BACKGROUND.

a. Project Scope.

(1) This report contains a **final** summary of work **completed** by the Air Pollution Assessment Team (**APAT**) in Kuwait and Saudi **Arabia** during **May** - December 1991. The **APAT** was an integral part of the U.S. Army Environmental Hygiene Agency (**USAEHA**) Health Risk Assessment team. The **USAEHA** published the Interim Kuwait Oil Fire **Health** Risk Assessment in June 1992 (reference 50). From July 1992 through November 1993, a series of work tasks were conducted to **include: revision** of the **site-specific** air monitoring data, **peer** review of the interim **report** by a **series** of agencies; development **of** work flow procedures to complete the **geographical** information system (**GIS**) exposure model; and a return trip to the Kuwait and Saudi Arabia sampling locations during November 1993.

(2) Additional background information on the **geographical** and **climatological description** of the sampling **area**, the air pathway analysis overview, ambient air **sampling equipment** and **methodology** are contained in the interim **report** (reference 50). In **summary**, **ambient air sampling was conducted at eight fixed sites and two temporary sites** (see Table B-1) using referenced U.S. **Environmental Protection Agency (EPA)** and **National Institute of Occupational Safety and Health (NIOSH)** sampling methods. **Approximately 4,000 air samples were collected and analyzed from May - December 1991. Figure B-1 is a map of the Kingdom of Saudi Arabia and associated sampling sites. Figure B-2 is a map of the Emirate of Kuwait and associated sampling sites.**

b. **Meteorological Data.** Wind speed and wind direction data for King Khalid Military City (KKMC), Saudi Arabia; Khobar Towers (Dhahran International Airport, Saudi Arabia); and Military Hospital (Kuwait International Airport, Kuwait) during May - December 1991 were summarized into windrose plots. The windrose plots display the frequency of occurrence of wind direction with predetermined wind speed classes (reference 51). These plots are displayed in Figures B-3 through B-5 for the respective cities. Both windrose plots for the Saudi Arabia sites display wind **blowing from the west through north directions.** The Kuwait windrose displays predominant northwest winds. Overall, these plots are consistent with historical windrose frequencies for the respective cities.

4. AIR SAMPLING DATA PREPARATION/VALIDATION.

a. All samples collected at the Kuwait and Saudi Arabia sampling sites in 1991 were subsequently input to both Lotus® spreadsheets and dBase III® database files. These contained the **administrative** [i.e., sample **identification**, collection **date(s)**, type, **air volumes**, etc.] and **analytical** (i.e., pollutant mass, **analytical code**) data values. Field blank and matrix spiked sample information were **included in these database files.** After a quality control check of the **raw database files**, the associated **pollutant-specific concentrations** were **calculated.** This included checking the **corresponding field blank data** values.

b. A series of dBase III computer programs were written to assist in validating the various media-specific raw data files. This was performed to provide validated data for subsequent pollution data summaries. The validation criteria were specific to the type of sample collection media, and a brief summary of the validation criteria follow.

• Lotus 1-2-3 is a **registered trademark** of the Lotus Development Corporation, Cambridge, Massachusetts.

• dBase III is a **registered trademark** of Borland International, Inc., Scot&s Valley, California.

TABLE 8-1. SAMPLE LOCATIONS AND SAMPLING DURATION

| Sampling Site | Site ID | Location | Sampling Period (1991) | Sample Duration (days) |
|---------------------------|---------|----------------|------------------------|------------------------|
| King Khalid Military City | 02 | KKMC, S.A. | 19 May - 25 Aug | 98 |
| Khobar Towers | 03 | Dhahran, S.A. | 06 May - 04 Dec | 212 |
| Eskan Village | 04 | Riyadh, S.A. | 25 May - 25 Aug | 92 |
| Camp 1/Jubayl | 05 | Jubayl, S.A. | 08 May - 04 Aug | 88 |
| Camp Abdaly ** | CA | Abdaly, Kuwait | 19 May - 05 Jun | 17 |
| Camp Freedom ** | CF | Subhan, Kuwait | 11 May - 17 May | 7 |
| Ahmadi Hospital | AH | Ahmadi, Kuwait | 06 Jun - 06 Jul | 30 |
| Camp Thunderock | CT | Doha, Kuwait | 06 Jun - 04 Dec | 181 |
| U.S. Embassy | EM | K.C., Kuwait | 19 May - 15 Jul | 57 |
| Armed Forces Hospital | MH | K.C., Kuwait | 17 May - 4 Dec | 201 |

S.A. = Saudi Arabia

K.C. = Kuwait City

* □ = Temporary Sampling Site

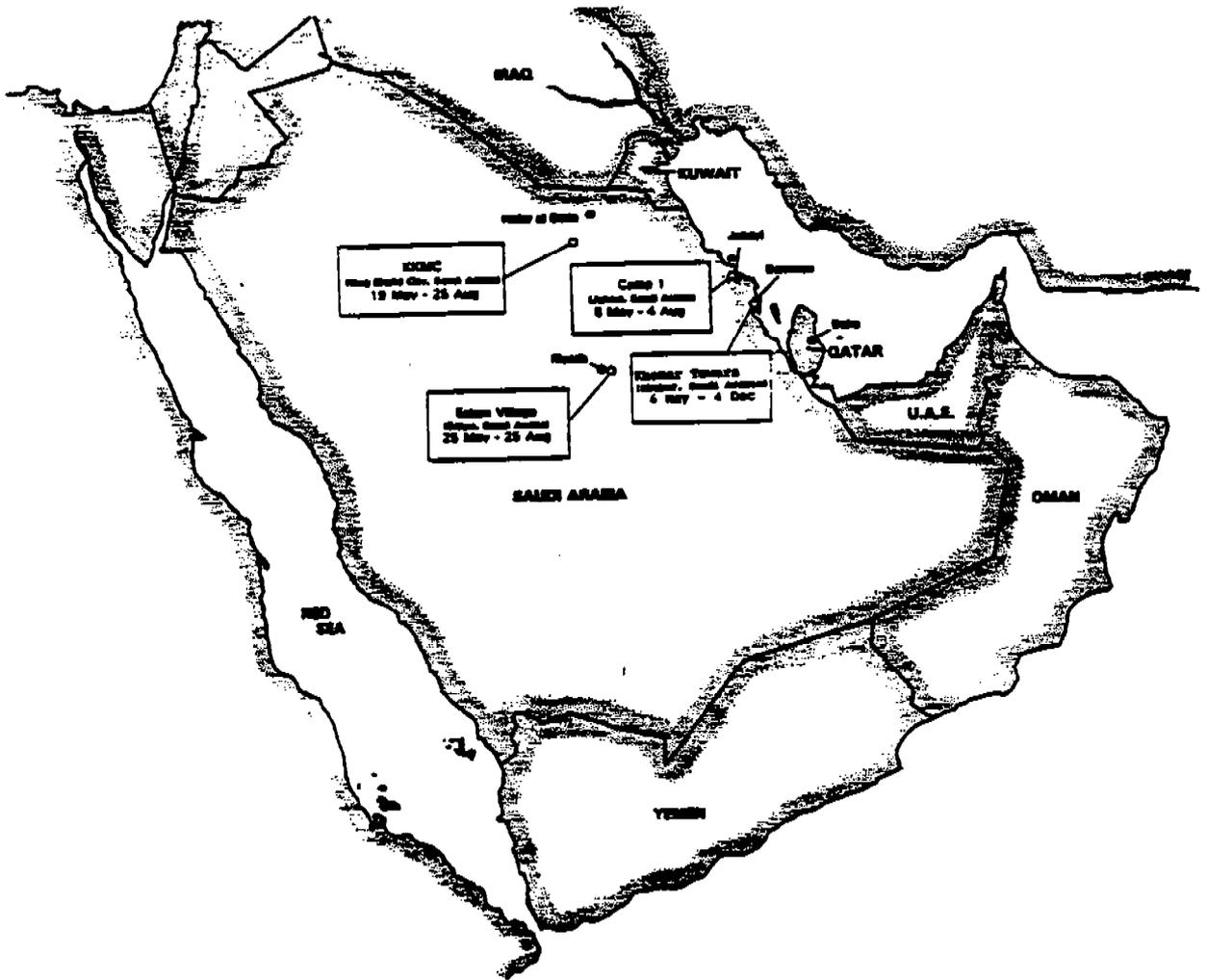


Figure B-1.

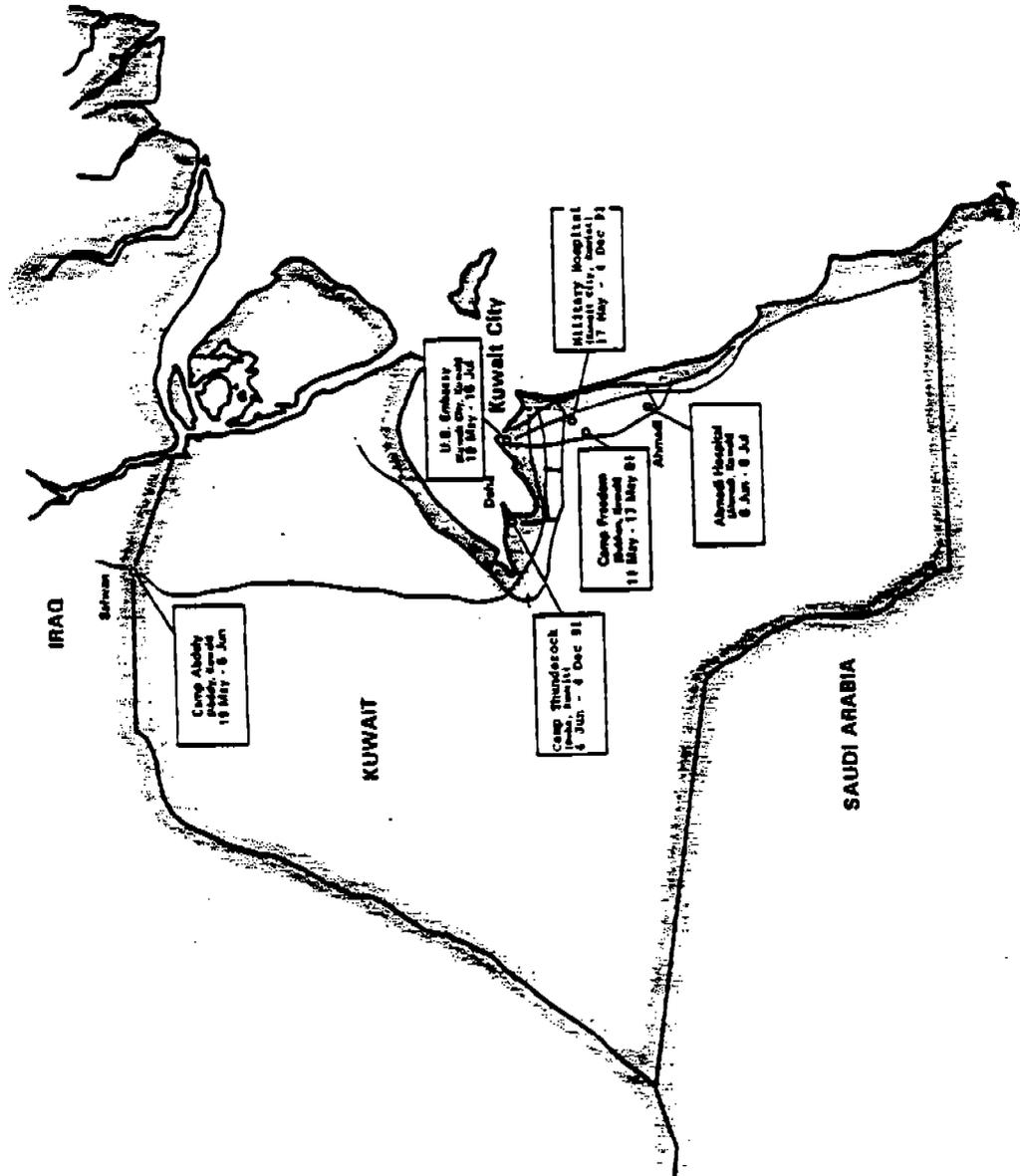


Figure B-2.

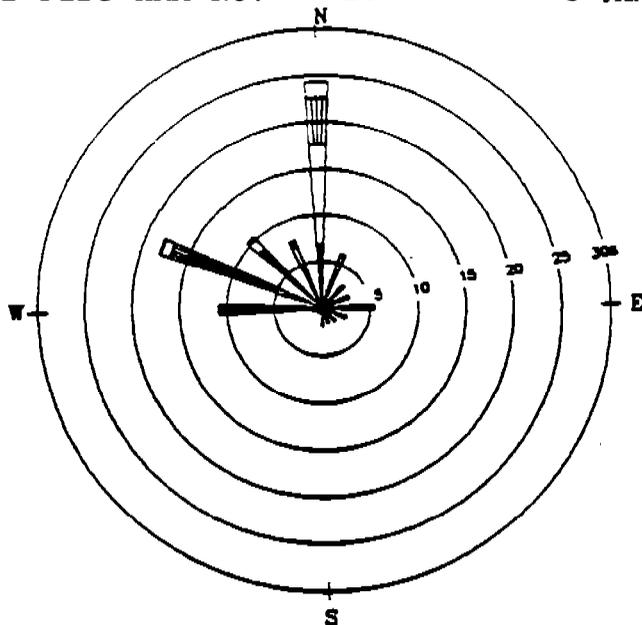
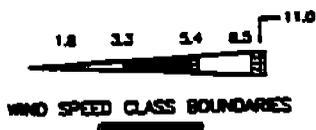


Figure B-3.



WINDROSE

STATION NO. 03

Dhahran

PERIOD: 1991

NOTE:
 DIAGRAM OF THE FREQUENCY OF OCCURRENCE FOR EACH WIND DIRECTION. WIND DIRECTION IS THE DIRECTION FROM WHICH THE WIND IS BLOWING. EXAMPLE - WIND IS BLOWING FROM THE NORTH 24.3 PERCENT OF THE TIME.

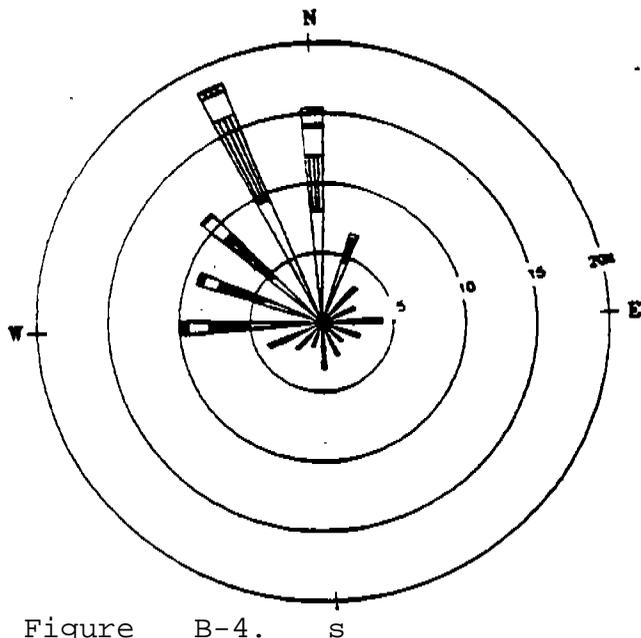
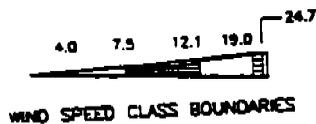


Figure B-4.



WINDROSE

STATION NO. 02

KQMC

PERIOD: 1991

NOTE:
 DIAGRAM OF THE FREQUENCY OF OCCURRENCE FOR EACH WIND DIRECTION. WIND DIRECTION IS THE DIRECTION FROM WHICH THE WIND IS BLOWING. EXAMPLE - WIND IS BLOWING FROM THE NORTH 18.3 PERCENT OF THE TIME.

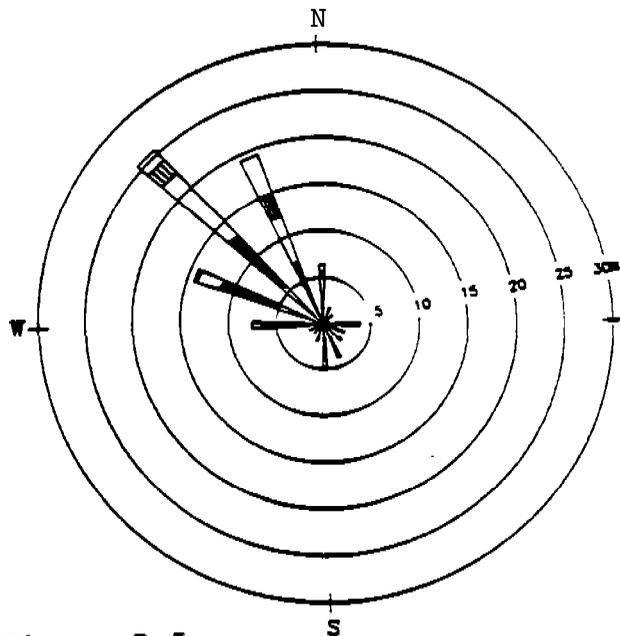
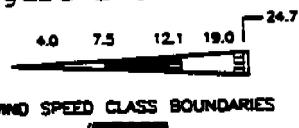


Figure B-5.



WINDROSE

STATION NO. M

Kuwait

PERIOD: 1991

NOTE:
 DIAGRAM OF THE FREQUENCY OF OCCURRENCE FOR EACH WIND DIRECTION. WIND DIRECTION IS THE DIRECTION FROM WHICH THE WIND IS BLOWING. EXAMPLE - WIND IS BLOWING FROM THE NORTH 6.3 PERCENT OF THE TIME.

(1) Sampling **Method** for Volatile Organic Compounds (**VOCs**). The ambient air sampling EPA Method TO-1 was used for **VOCs** (reference 19). The **first** validation step of the **VOC data** included: checking the Sample for **breakthrough** (mass of pollutant on front and **rear tubes**); sample duration; holding time **between collection** and analysis; and checking **the sample flow rate change between start and stop times**. **One significant modification to the EPA Method TO-1 media samples was** changing the holding **time** from the method's **specified value of 14 days to 28 days**. **This was validated in the USAEHA laboratories by a series of experiments** in which EPA Method TO-1 samples were spiked with known **pollutant masses; air volumes** drawn through **tubes**; and then subsequent **laboratory analysis** of the test samples. From **these experiments**, it was concluded that **no appreciable** loss of the spiked pollutant mass was **observed** when the sample was extended from the initial 14day window out to a 28 day window **between collection** and analysis. The **pre/post calibration** and **rear tube mass validation parameters were revised from the respective guideline values found in the EPA Method TO-1 methodology**. Table B-2 summarizes the validation criteria for the **VOC samples**. In addition, the **modifications** made to the EPA Method TO-1 **validation criteria were primarily to obtain a greater number of samples for generation of concentration summaries**.

TABLE B-2. **VALIDATION CRITERIA FOR VOC SAMPLES**

| validation criteria Parameter | Target Range | Comment |
|---|-----------------------|-------------------------------|
| Sample Time | 720 - 1800 min | - |
| Pre/Post Calibration | < 31 96 | Increased from 10% |
| Holding Time | < 29 days | Increased from 14 days |
| Rear Tube Mass | < 31 % | Increased from 20% |

(2) particulate **Matter Less Than 10 Microns (PM₁₀**, reference 26). The validation **steps** for the **PM₁₀** data included checking the **flow rate** to be **within** the 0.7 to 2.1 cubic meters **per minute (m³/min)** range and **the sample time to be** within the **720 to 1800 minute** range. These values were also applied to the high volume **polycyclic aromatic hydrocarbon (PAH)** particulate data.

(3) High Volume **Method** for Determination of **PAHs**. The EPA **Method TO-13** was **used for the determination** of **PAHs** (reference 19). **The** validation steps for the high volume EPA Method TO-13 PAH data included checking for the total volume to **be** less than 325 **m³** and the sample duration to **be** between 720 and 1800 minutes.

(4) Additional **Validation Criteria**. other validation **criteria** to include **field/trip blanks, shipment and laboratory preservation temperature(s)**, and holding times were targeted for use. Readers are referred to **Table B-7 of the interim report (reference 50)** for actual values of the sample media preservation time, holding times, and storage requirements.

(5) **Table B-3 contains a summary of the number of valid samples for each media and sample site. This table is not to be considered final due to continuing work on the acid gas data.**

TABLE B-3. NUMBER OF VALID SAMPLES FOR MAY - DECEMBER 1991

| SITE | TSP | PM ₁₀ | TO-1 | PAH (LOW) | PAH PART. | PAH TO-13 | HG 6009 | ACID GASES | NO/NO ₂ | SO ₂ /O ₃ |
|-------|-----|------------------|------|-----------|-----------|-----------|---------|------------|--------------------|---------------------------------|
| MH | 33 | 117 | 45 | 13 | 22 | 10 | † | * | 11 | 13 |
| EM | 37 | 39 | 5 | 13 | 5 | NA | † | * | 3 | 2 |
| CT | NA | 113 | 47 | 17 | 20 | 11 | † | * | 9 | 12 |
| AH | NA | 22 | 9 | 5 | 5 | NA | † | * | 1 | 2 |
| 02 | 44 | 66 | 27 | 15 | 8 | NA | † | * | 7 | 8 |
| 03 | 33 | 130 | 54 | 20 | 20 | 12 | † | * | 21 | 21 |
| 04 | 38 | 52 | 23 | 11 | 39 | NA | † | * | 3 | 5 |
| 05 | 39 | 52 | 23 | 18 | 12 | NA | † | * | 7 | 7 |
| TOTAL | 224 | 591 | 233 | 112 | 131 | 33 | † | * | 62 | 70 |

† No significant mass detected on mercury sample media

* Acid gas data to be provided in Addendum

TSP = total suspended particulate matter (covered in interim report)

PM₁₀ = particulate matter less than 10 microns

TO-1 = method for VOCs

PAH = polycyclic aromatic hydrocarbons

TO-13 = method for PAH

HG = mercury

NO/NO₂ = nitrogen oxide/nitrogen dioxide

SO₂/O₃ = sulfur dioxide/ozone

5. STATISTICAL METHODS APPLIED TO THE AIR SAMPLING DATA.

a. From the random variability of air pollution data, probability distribution functions were used to describe the Kuwait and Saudi Arabia data sets. From the literature, two of the most commonly used probability distribution functions to describe air concentration data are the lognormal and the Weibull (references 10 and 53). In addition, the Gaussian (normal) distribution can be applied.

b. A series of frequency distribution plots were made of the data sets to obtain a pictorial representation of the initial data distributions. For most of these, the data were skewed. Then the data were transformed using the lognormal function and the resulting frequency distribution plot was bell shaped. This procedure demonstrated that the lognormal function provides a "best-fit" to the Kuwait/Saudi Arabia air concentration data. For this portion of the final report, both the lognormal and normal probability distribution functions were applied to the air concentration data sets.

c. It was desired to obtain the monthly mean and 95 percent upper confidence limit (95 UCL) concentration values for each pollutant at each sampling site. The 95 UCL was needed as input to the air pathway analysis equations for the overall health risk assessment. These 95 UCL values were obtained by using the following equations for the lognormal and normal distributions.

$$\text{lognormal: } 95 \text{ UCL} = e^{(1.645 \times \sigma + U)} \quad (1)$$

$$\text{normal: } 95 \text{ u c L} = (1.645 \times \sigma + U) \quad (2)$$

where: e = natural logarithm

σ = standard deviation of pollutant

U = mean concentration of pollutant

The σ and U values are specific for each type of distribution. The Z-score value of 1.645 is applicable for a one-tailed 95 percent confidence limit. In general, the 95 UCL is defined as a value that, when Calculated repeatedly for random drawn subsets of data, equals or exceeds the true mean 95 percent of the time.

d. For selected data sets to include the particulate PAH and EPA Method TO-13 PAH, both the lognormal and normal distribution statistics were calculated due to the high frequency of analytical non-detects. For the passive dosimeter data, the normal distribution results are presented for discussion purposes.

6. DATA RESULTS.

a. Volatile Organic Compounds Data (EPA Method TO-1). The VOC data for **Khobar Towers, Dhahran, Saudi Arabia**, displayed a 2-month concentration maximum. The first peak occurred in August 1991 with the second peak in October 1991. Both of these maximum concentration months were followed by lower VOC concentration levels. The VOC levels generally increased with decreasing oil well fire emissions during May - November 1991. The monthly and overall VOC concentrations for **Khobar Towers** are summarized in Table **B-4**.

(1) The VOC data for the **Camp Thunderrock, Kuwait**, sampling location displayed minimum concentration levels during August 1991 with increasing levels prior to and after this month. The overall higher levels from October - November 1991 probably represent a return of industrial activities and processes in the region. The monthly and overall VOC concentrations for **Camp Thunderrock** are summarized in Table **B-5**.

(2) The VOC data for the **Military Hospital, Kuwait**, sampling location displayed overall increasing levels (excluding August 1991) during May - November 1991. The increasing VOC levels from September - November 1991 are probably a result of industrial activities and processes returning to Kuwait and are similar to **Camp Thunderrock**. The monthly and overall VOC concentrations for the **Military Hospital** are summarized in Table **B-6**.

(3) Tables B-2-1 through B-2-S (**Annex B-2**) display the monthly and overall VOC concentration values for the remaining sampling sites to include **KKMC, Riyadh, Jubayl** for the Saudi Arabia sites and **Ahamdi Hospital and U.S. Embassy** for the Kuwait sites. Table B-2-6 displays a comparison of VOC levels for Kuwait, Saudi Arabia, and selected U.S. cities:

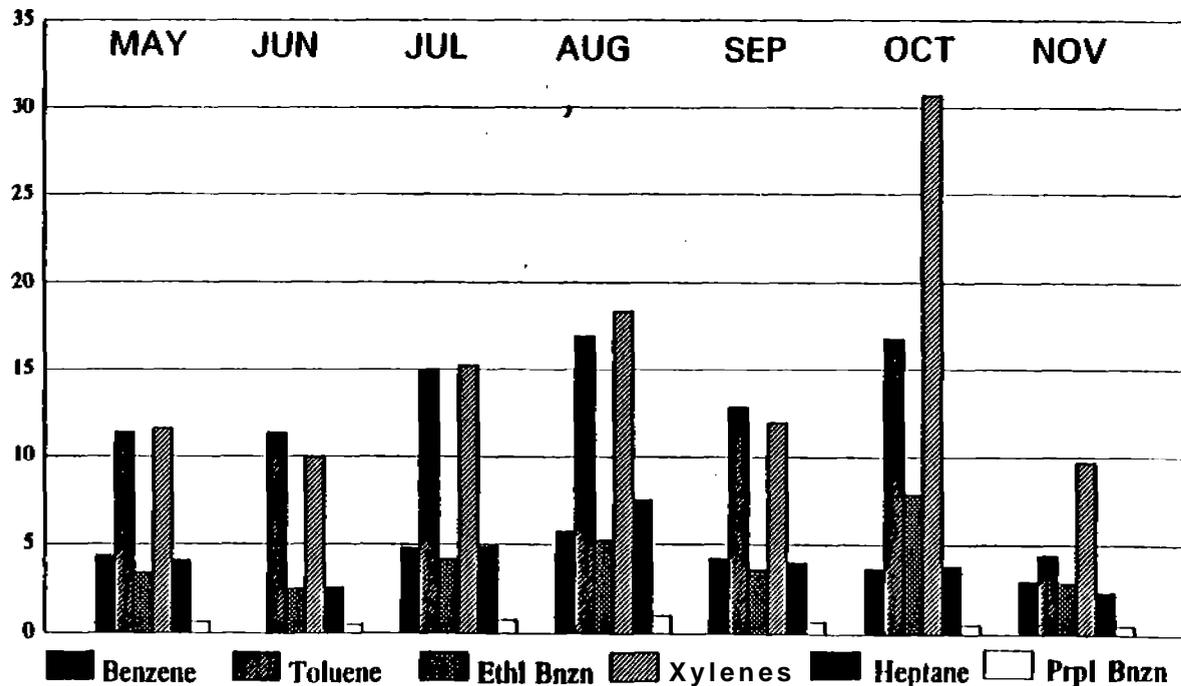
b. Sulfate, Nitrate, and Chlorides from PM₁₀ Filters and chloride concentration levels obtained from **PM₁₀ filters** are shown in Tables B-7 and B-8 for the lognormal and normal distributions, respectively. For the Kuwait sampling sites, the highest sulfate, nitrate, and chloride concentrations were observed at the **Ahmadi Hospital**. For the Saudi Arabia sampling sites, the highest sulfate, nitrate, and chloride concentrations were observed at **Jubayl**. The **KKMC** sampling site displayed the overall lowest **PM₁₀** and associated sulfate, nitrate, and chloride concentrations. In general, the oil well fires superplume (defined as the region where the individual oil well fire plumes merged) remained well east of the **KKMC** sampling site during the time in which sampling was performed there.

TABLE B - 4 .

TO-I: KHOBAR TOWERS

VOLATILE ORGANIC COMPOUNDS (EPA METHOD TO-1, TENAX)
(ug/m3)

| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
|---------------------|-------|------|-------|------|-------|------|--------|------|-----------|------|---------|-------|----------|-------|---------|------|
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| Benzene | 4.28 | 11.7 | NA | NA | 4.78 | NA | 5.78 | 10.4 | 4.18 | 7.88 | 3.80 | 7.21 | 2.84 | 4.62 | 4.26 | 8.6 |
| Toluene | 11.4 | 32.0 | 11.4 | 38.6 | 14.9 | 20.6 | 16.9 | 31.0 | 12.8 | 23.6 | 10.6 | 47.8 | 4.38 | 18.6 | 12.8 | 37.7 |
| Ethyl Benzene | 3.30 | a.2 | 2.47 | 6.62 | 4.11 | 6.77 | 6.24 | 11.2 | 3.66 | 6.66 | 7.86 | 27.92 | 2.88 | 3.81 | 4.12 | 9.5 |
| m,p-Xylene | 8.45 | 27.3 | 7.43 | 18.8 | 11.2 | 18.3 | 13.0 | 24.8 | 8.86 | 18.4 | 24.8 | 22.9 | 7.03 | 11.3 | 11.1 | 28.1 |
| o-Xylene | 3.14 | 7.41 | 2.61 | 8.69 | 4.02 | 6.76 | 6.39 | 10.6 | 3.20 | 8.97 | 5.99 | 22.9 | 2.97 | 4.34 | 3.74 | 8.9 |
| Heptane | 4.06 | 10.8 | 2.64 | 6.41 | 4.87 | 9.2 | 7.61 | 18.1 | 3.04 | 7.87 | 3.70 | 10.2 | 2.34 | 6.13 | 4.06 | 9.7 |
| n-Propyl Benzene | 0.818 | 1.46 | 0.484 | 1.38 | 0.733 | 1.21 | 0.883 | 1.97 | 0.06 | 1.19 | 0.607 | 1.04 | 0.480 | 0.130 | 0.840 | 1.39 |
| Non-target analytes | 61.2 | 109 | 43.1 | 101 | 71.0 | 89.7 | 101 | 684 | 68.75 | 133 | 132 | 462 | 43.7 | 76.7 | 83.0 | 196 |



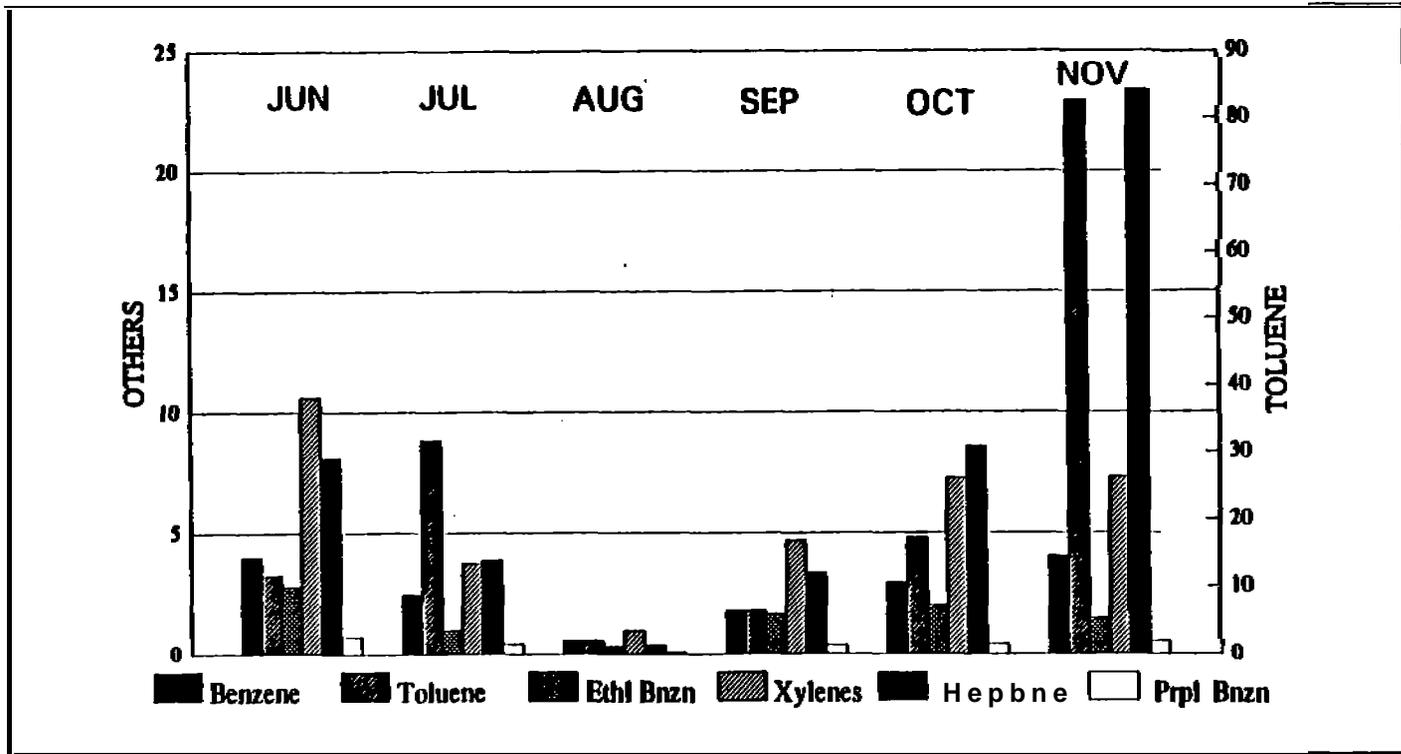
B-11

TABLE B- 5.

TO-1: CAMP THUNDEROCK

VOLATILE ORGANIC COMPOUNDS (EPA METHOD TO-1, TENAX)
(ug/m3)

| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
|---------------------|------|------|-------|------|-------|-------|--------|-------|-----------|------|---------|------|----------|-------|---------|------|
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| Benzene | | | 3.98 | 8.38 | 2.46 | 29.42 | 0.660 | NA | 1.78 | 6.03 | 2.93 | 6.08 | 4.05 | 10.8 | 3.35 | 11.5 |
| Toluene | | | 11.6 | 26.3 | 31.9 | 64.1 | 1.86 | 3.71 | 6.46 | 20.1 | 17.3 | 83.5 | 82.6 | 339.1 | 22.8 | 87 |
| Ethyl Benzene | | | 2.76 | 8.08 | 1.00 | 3.18 | 0.300 | 0.611 | 1.62 | 8.6 | 1.99 | 6.08 | 1.47 | 3.6 | 1.34 | 7.5 |
| m,p-Xylene | | | 7.68 | 17.6 | 2.02 | 8.5 | 0.660 | 1.00 | 3.29 | 16.0 | 4.65 | 18.4 | 6.06 | 18.8 | 6.01 | 20.4 |
| o Xylene | | | 3.02 | 7.03 | 1.08 | 2.78 | 0.300 | 0.300 | 1.40 | 5.96 | 2.58 | 7.8 | 2.24 | 17.1 | 2.22 | 9.1 |
| Heptane | | | 8.07 | 24.1 | 3.84 | 38.2 | 0.363 | 0.688 | 3.31 | 10.1 | 8.57 | 28.6 | 23.4 | 110 | 8.86 | 39.7 |
| n-Propyl Benzene | | | 0.707 | 1.89 | 0.423 | 1.63 | 0.0830 | 0.093 | 0.356 | 1.14 | 0.410 | 1.08 | 0.524 | 1.76 | 0.498 | 1.58 |
| Non-target analytes | | | 750 | 2390 | 189 | 233 | 16.4 | 18.8 | 55.7 | 137 | 133 | 636 | 113 | 324 | 251 | 890 |

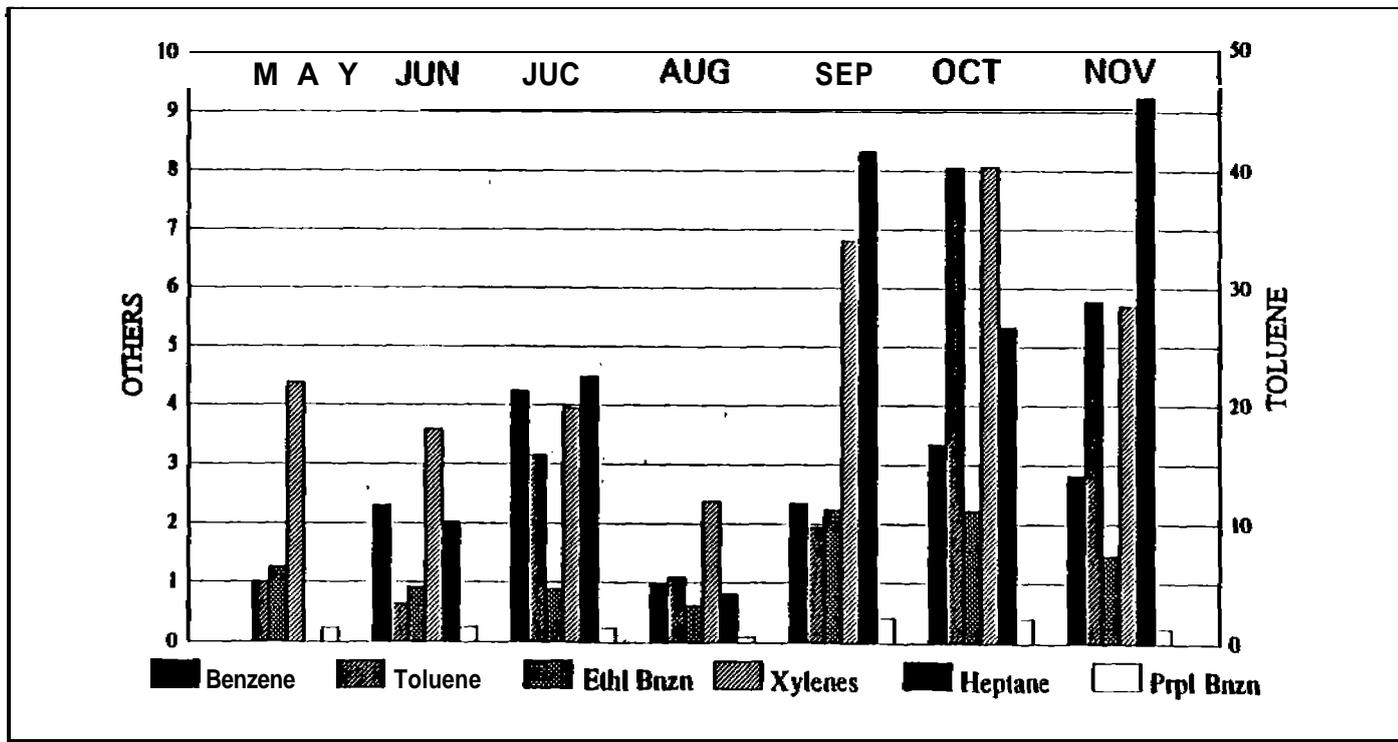


Sa collection averaging time: 12 - 30 hours
NA valid samples analyzed for this compound

TO-1: MILITARY HOSPITAL, KUWAIT

VOLATILE ORGANIC COMPOUNDS (EPA METHOD TO-1, TENAX)
(ug/m3)

| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
|---------------------|-------|------|-------|------|-------|-------|--------|-------|-----------|------|---------|------|----------|-------|---------|------|
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| Benzene | NA | NA | 2.31 | NA | 4.23 | NA | 0.997 | 1.31 | 2.36 | 4.62 | 3.38 | 6.62 | 2.82 | 4.87 | 2.05 | 5.37 |
| Toluene | 6.03 | 14.0 | 3.19 | NA | 15.0 | 68.7 | 6.48 | 18.0 | 9.72 | 41.6 | 40.3 | 198 | 28.9 | 119 | 19.3 | 70 |
| Ethyl Benzene | 1.25 | 2.03 | 0.910 | NA | 0.880 | 1.60 | 0.619 | 1.77 | 2.24 | 0.3 | 2.24 | 7.6 | 1.47 | 3.08 | 1.64 | 4.73 |
| m,p-Xylene | 3.11 | 6.62 | 2.63 | NA | 2.95 | 7.88 | 1.83 | 4.28 | 4.77 | 12.7 | 6.64 | 18.3 | 4.08 | 7.31 | 3.99 | 10.0 |
| o-Xylene | 1.28 | 2.07 | 1.0 | NA | 1.01 | 2.28 | 0.763 | 1.30 | 2.04 | 6.37 | 2.63 | 8.4 | 1.01 | 3.43 | 1.70 | 4.3 |
| Heptane | NA | NA | 2.03 | NA | 4.47 | 10.2 | 0.823 | 2.08 | 0.33 | 42.8 | 6.34 | 29.8 | 9.2 | 30.6 | 5.07 | 28.1 |
| n-Propyl Benzene | 0.243 | 0.46 | 0.260 | NA | 0.240 | 0.616 | 0.0843 | 0.468 | 0.420 | 1.34 | 0.410 | 1.28 | 0.248 | 0.453 | 0.301 | 1.10 |
| Non-target analytes | 23.84 | 38.3 | 48.7 | NA | 69.5 | 302 | 27.7 | 73.6 | 107 | 281 | 79.8 | 262 | 437.9 | 169 | 68.8 | 20% |



B-13

Sample collection averaging time: 12 - 30 hours
NA = no valid samples analyzed for this compound

TABLE B-7. **SUMMARIZED LOG-NORMAL 95% UCL for SULFATES, NITRATES, AND CHLORIDES FROM PM10 FILTERS**

| POLLUTANT | KKMC | KOHBAR | RIYADH | JUBAIL | AHMADI | CAMP THUNDEROCK | EMBASSY | MILITARY HOSPITAL |
|------------------|-------|--------|--------|--------|--------|-----------------|---------|-------------------|
| PM ₁₀ | 206 | 306 | 277 | 312 | 237 | 451 | 871 | 323 |
| SULFATES | 0.445 | 0.845 | 0.738 | 1.125 | 4.209 | 1.083 | 1.103 | 0.768 |
| NITRATES | 0.138 | 0.343 | 0.201 | 0.270 | 0.862 | 0.381 | 0.524 | 0.261 |
| CHLORIDES | 0.293 | 1.795 | 0.300 | 0.265 | 1.746 | 0.961 | 0.509 | 1.264 |

NOTE: Concentrations in micrograms per cubic meter (µg/m³)

TABLE B-B. **SUMMARIZED ARITHMETIC MEAN CONCENTRATIONS for SULFATES, NITRATES, AND CHLORIDES FROM PM10 FILTERS**

| POLLUTANT | KKMC | KOHBAR | RIYADH | JUBAIL | AHMADI | CAMP THUNDEROCK | EMBASSY | MILITARY HOSPITAL |
|------------------|-------|--------|--------|--------|--------|-----------------|---------|-------------------|
| PM ₁₀ | 116 | 128 | 174 | 163 | 204 | 209 | 301 | 149 |
| SULFATES | 0.337 | 0.509 | 0.400 | 0.641 | 1.260 | 0.453 | 0.767 | 0.422 |
| NITRATES | 0.064 | 0.141 | 0.118 | 0.216 | 0.205 | 0.084 | 0.185 | 0.121 |
| CHLORIDES | 0.135 | 0.137 | 0.138 | 0.165 | 0.796 | 0.283 | 0.313 | 0.204 |

NOTE : concentrations in micrograms per cubic meter (µg/m³)

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c. **PM₁₀ and Metals.** For this section, **selected** metals to include chromium, nickel, vanadium, and lead are chosen for discussion due to their potential toxicity significance and the fact that vanadium and nickel are contaminants of **Kuwait** crude oil. The remaining **metals are discussed, if necessary, and respective data are presented in associated annexes.**

(1) The **PM₁₀** concentration levels for Khobar Towers, Saudi **Arabia, decreased** during May - November 1991. Table **B-9** displays the monthly and overall **PM₁₀** and metal **statistics** for the **Khobar Towers sampling** site. The **vanadium** levels **displayed** an overall **decrease** during the **sampling period.** The nickel levels displayed two maximums over time with the highest levels **observed** during July and September **1991.** The total chromium levels also displayed **decreasing** levels, while the **lead levels** remained relatively constant over time.

(a) Additional time **series** plots of PM₁₀ and metal concentrations through time for Khobar **Towers** are shown in Figures B-6 through B-10. For the **PM₁₀** plot, the EPA pollution standard index (**PSI**) values for the National Ambient Air Quality Standard (**NAAQS**) and **significant** harm are **displayed** for **comparison (reference 54).** The **PSI** is a uniform method recommended to **classify** and **report** urban air quality. The air quality **evaluated is designated as presenting "hazardous conditions" if the PSI is greater than 300; "very unhealthful conditions" if the PSI is between 200 and 300; "unhealthful conditions" if the PSI is between 100 and 200; "moderate" if the PSI is 50 to 100; and "good" if the PSI is between 0 and 50.** A majority of time the daily average **PM₁₀ concentrations** exceeded the **PM₁₀ 24-hour NAAQS.** **There were** four days when the **PM₁₀** concentration exceeded the **significant harm** PSI value.

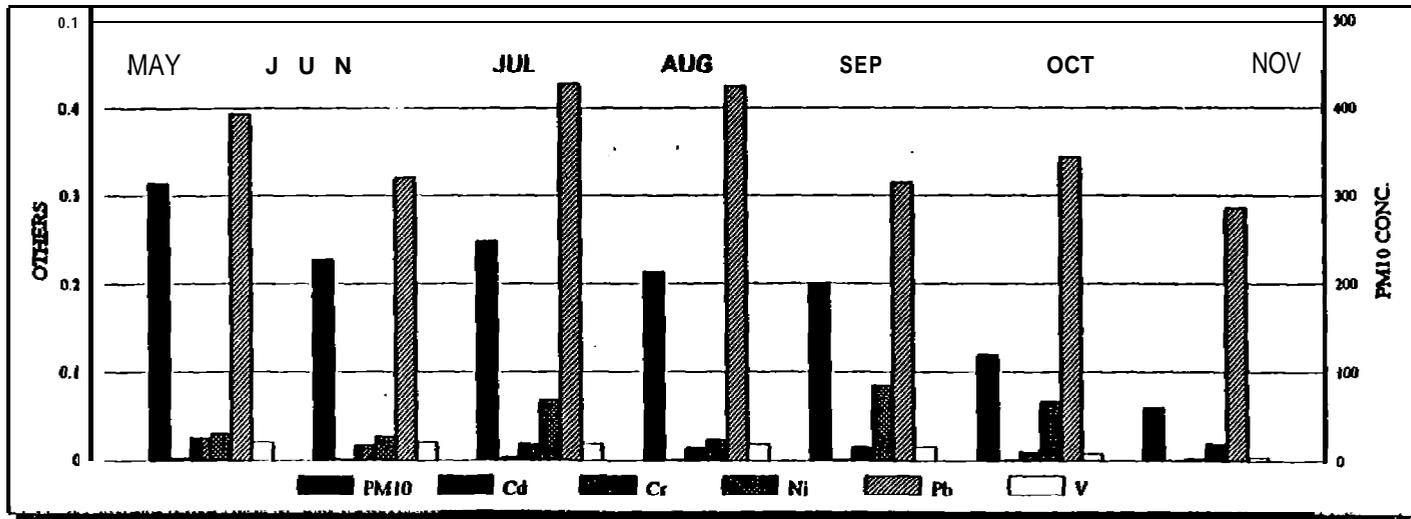
(b) **In** addition, these figures display' **the** total number of oil well **fires** and their extinguishment over time. This **is** designated as the **" + "** curve on the **PM₁₀** and metal concentrations versus time figures. It **can be** noted that the daily PM₁₀ concentrations remained below the **PM₁₀ 24-hour NAAQS** after the **mid-October** 1991 timeframe. The daily nickel concentrations displayed a large variation through time while the vanadium concentrations **displayed** an overall decrease. The vanadium concentrations fell to levels which corresponded to the **analytical detection** limit after the extinguishment of the oil well fires.

(2) The monthly PM₁₀ levels for Camp **Thunderrock** remained relatively constant from June - September 1991, then **decreased** from **October - November** 1991. The monthly total chromium levels displayed an overall **decrease** from June - November 1991. The nickel levels displayed maximum **concentrations** during July and September 1991. After September 1991, the nickel concentration levels **decreased,** but were above **the** previous levels. For vanadium, the **monthly** concentration levels displayed an overall **decrease** during June - November 1991. Table B-10 **displays** the monthly and overall **PM₁₀** and metal statistics for the Camp **Thunderrock** sampling site.

TABLE 5-9.

| PM10: KHOBAR TOWERS | | | | | | | | | | | | | | | | |
|---|--------|--------|--------|--------|--------|--------|--------|--------|-----------|--------|---------|--------|----------|--------|---------|--------|
| PM10 AND METALS DATA (HI-VOLUME REFERENCE METHOD) | | | | | | | | | | | | | | | | |
| (ug/m ³) | | | | | | | | | | | | | | | | |
| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| PM10 (Mass Conc.) | 308 | 722 | 228 | 399 | 267 | 495 | 214 | 433 | 203 | 424 | 120 | 221 | 62 | 103 | 188 | 45% |
| Aluminum (Al) | NA | NA | NA | NA | NA | NA | 2.04 | 5.79 | 2.76 | 7.22 | 1.81 | 8.11 | 0.83 | 1.03 | 1.98 | 5.65 |
| Arsenic (As) | NA | NA | NA | NA | NA | NA | 0.0016 | 0.0044 | 0.001% | 0.0037 | 0.0018 | 0.0043 | 0.0010 | 0.0022 | 0.0016 | 0.0037 |
| Beryllium (Be) | NA | NA | NA | NA | NA | NA | 0.0028 | 0.0062 | 0.0009 | 0.002% | 0.0002 | 0.0003 | 0.0002 | 0.0002 | 0.0011 | 0.0036 |
| Calcium (Ca) | NA | NA | NA | NA | NA | NA | 22.3 | 41.9 | 21.3 | 49.6 | 16.2 | 33.0 | 6.9 | 13.8 | 16.1 | 44.3 |
| Cadmium (Cd) | 0.0580 | 0.0134 | 0.001% | 0.0040 | 1.0042 | 0.0100 | 0.0017 | 0.0030 | 0.0028 | 0.0087 | 0.0014 | 0.0026 | 0.0010 | 0.0015 | 0.012% | 0.005% |
| Chromium (Cr) | 0.0772 | 0.0060 | 0.0169 | 0.0394 | 1.0177 | 0.0363 | 0.0164 | 0.0321 | 0.0168 | 0.0343 | 0.0106 | 0.0186 | 0.0034 | 0.0072 | 0.0269 | 0.0450 |
| Iron (Fe) | NA | NA | NA | NA | NA | NA | 2.00 | 6.16 | 3.14 | 0.62 | 2.21 | 5.53 | 0.64 | 1.38 | 2.1% | 0.1% |
| Magnesium (Mg) | NA | NA | NA | NA | NA | NA | 4.65 | 10.09 | 6.01 | 12.86 | 3.27 | 7.87 | 1.14 | 2.46 | 3.61 | 9.37 |
| Sodium (Na) | NA | NA | NA | NA | NA | NA | 16.50 | 20.09 | 5.43 | 11.20 | 3.46 | 0.81 | 1.09 | 2.74 | 8.04 | 19.98 |
| Nickel (Ni) | 0.0819 | 0.1161 | 0.0263 | 0.0802 | 0.0740 | 0.1872 | 0.0241 | 0.0702 | 0.086% | 0.1628 | 0.0873 | 0.344% | 0.0202 | 0.0574 | 0.0651 | 0.1873 |
| Lead (Pb) | 0.417 | 0.881 | 0.304 | 0.638 | 0.485 | 0.865 | 0.424 | 0.707 | 0.317 | 0.714 | 0.348 | 0.805 | 0.206 | 0.689 | 0.371 | 0.770 |
| Vanadium (V) | 0.0721 | 0.7220 | 0.0189 | 0.0486 | 0.0375 | 0.0810 | 0.0188 | 0.0316 | 0.0169 | 0.0358 | 0.0082 | 0.0181 | 0.0048 | 0.0048 | 0.0278 | 0.0449 |
| Zinc (Zn) | 0.1711 | 0.323% | 0.096% | 0.2106 | 1.0623 | 0.1878 | 0.1545 | 0.6204 | 0.0837 | 0.2884 | 0.0762 | 0.1383 | 0.0843 | 0.1768 | 0.1082 | 0.3105 |

B-16

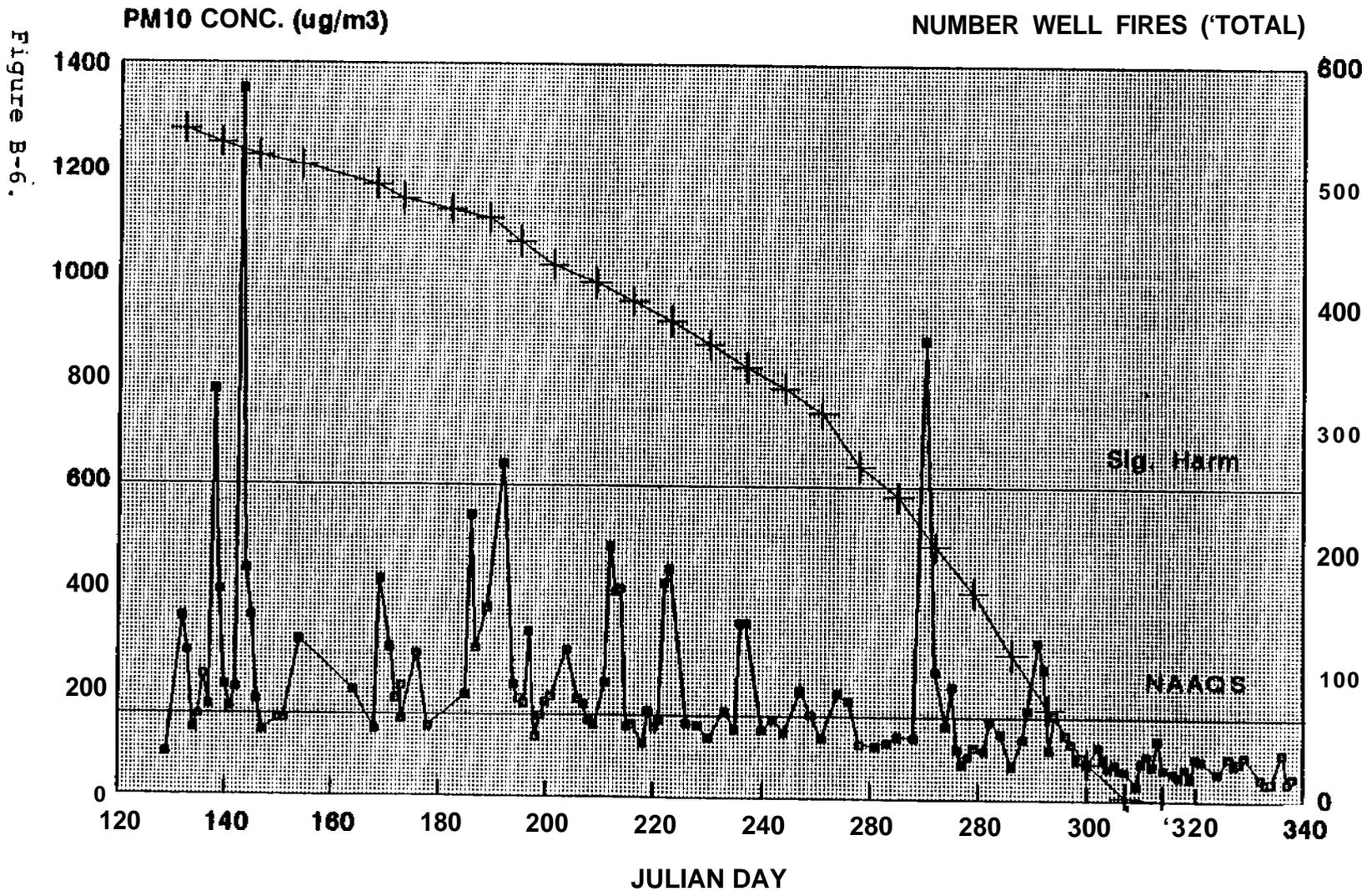


Sample collection averaging time: 12 - 30 hours
 NA analysis performed for this analyte
 Nf only one valid sample for chlorine (Cl) and nitrate (NO₃-) reported for July

PM10 CONCENTRATION vs TIME

KHOBAR TOWERS, SAUDI ARABIA
(MAY - DECEMBER 1991)

Final Rpt, Kuwait Oil Fire HRA No. 39-26-L192-91, 5 May - 3 Dec 91



TOTAL CHROMIUM vs TIME
KHOBAR TOWERS, SAUDI ARABIA
(MAY - DECEMBER 1991)

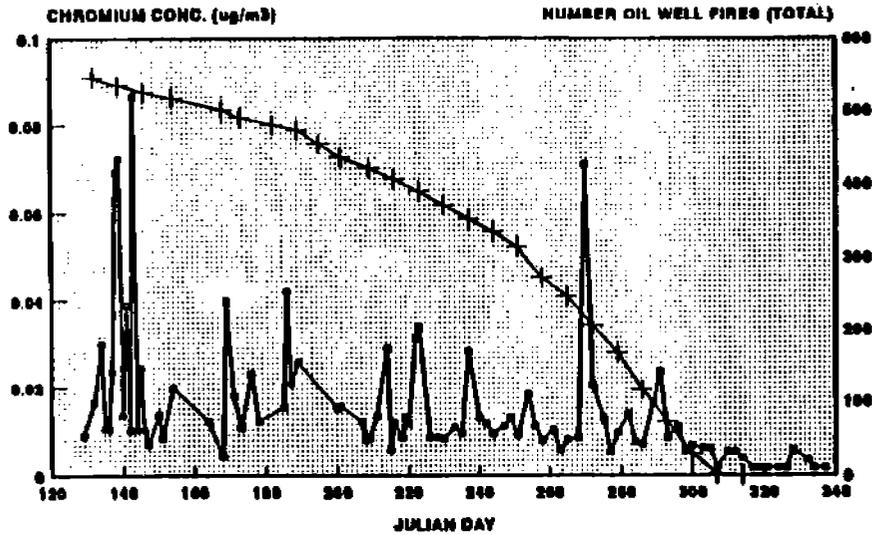


Figure B-7.

B-18
 DECEMBER 1993
 UBAEHA/APED

NICKEL CONCENTRATION vs TIME
KHOBAR TOWERS, SAUDI ARABIA
(MAY - DECEMBER 1991)

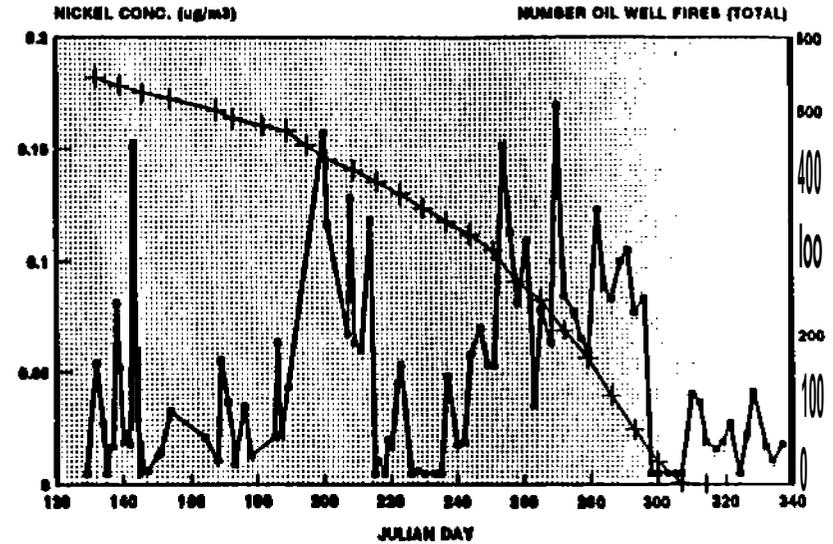


Figure B-8.

DECEMBER 1993
 UBAEHA/APED

VANADIUM CONCENTRATION vs TIME
KHOBAR TOWERS, SAUDI ARABIA
(MAY - DECEMBER 1991)

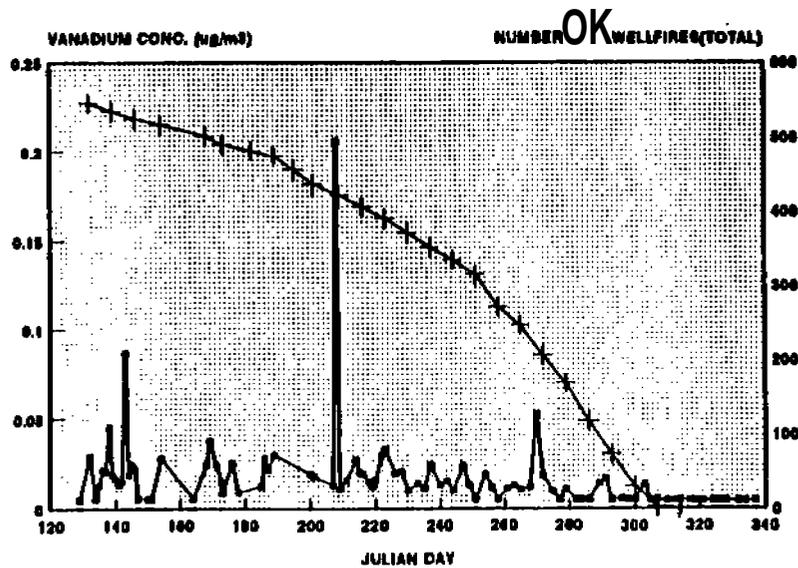


Figure B-9.

DECEMBER
 UBAEHA.

LEAD CONCENTRATION vs TIME
KHOBAR TOWER, SAUDI ARABIA
(MAY - DECEMBER 1991)

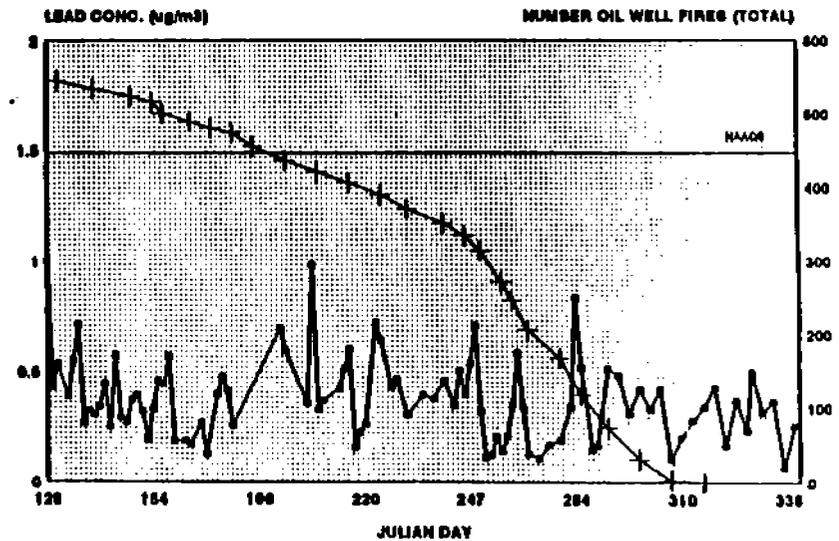


Figure B-10.

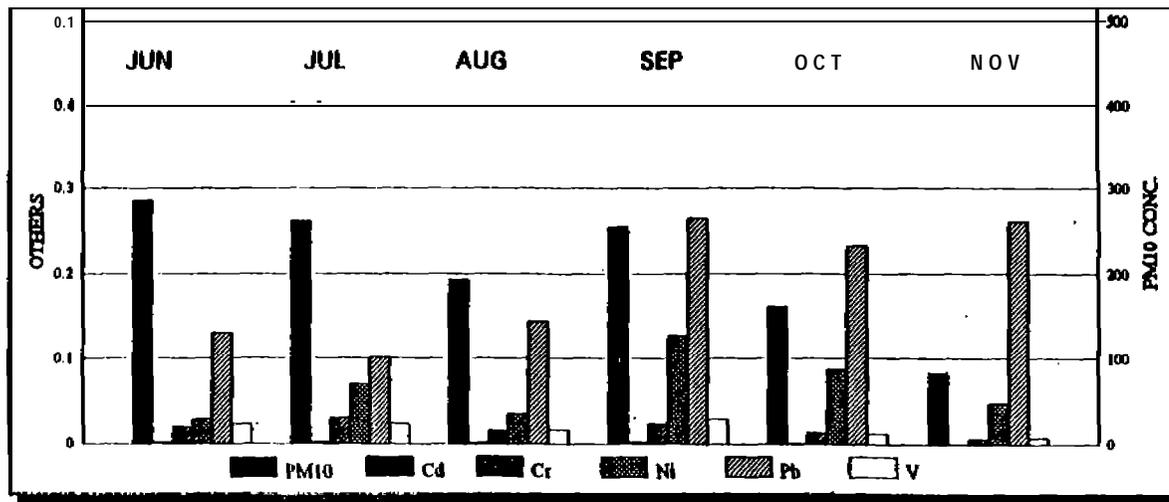
DECEMBER 1993
 UBAEHA/APED

PM10: CAMP THUNDEROCK

PM10 AND METALS DATA (HI-VOLUME REFERENCE METHOD)
(ug/m3)

| ANALYTE | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
|--------------------|--------|--------|--------|--------|--------|--------|-----------|--------|---------|--------|----------|--------|---------|--------|
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| PM 10 (Mass Conc.) | 207 | 462 | 253 | 568 | 103 | 497 | 265 | 671 | 162 | 331 | 84.0 | 208 | 194 | 483 |
| Aluminum (Al) | NA | NA | NA | NA | 2.79 | 8.93 | 4.82 | 13.6 | 2.05 | 4.41 | 1.38 | 2.98 | 2.63 | 6.38 |
| Arsenic (As) | NA | NA | NA | NA | 0.0014 | 0.0043 | 0.0022 | 0.0058 | 0.0011 | 0.0020 | 0.0009 | 0.0027 | 0.0013 | 0.0034 |
| Beryllium (Be) | NA | NA | NA | NA | 0.0028 | 0.0126 | 0.0011 | 0.0048 | 0.0004 | 0.0008 | 0.0002 | 0.0003 | 0.0012 | 0.0039 |
| Calcium (Ca) | HA | NA | NA | NA | 20.7 | 51.2 | 30.2 | 83.4 | 9.8 | 20.7 | 7.6 | 15.4 | 16.4 | 36.8 |
| Cadmium (Cd) | 0.0030 | 0.0070 | 0.0031 | 0.0077 | 0.0018 | 0.0043 | 0.0029 | 0.0072 | 0.0012 | 0.0018 | 0.0010 | 0.0012 | 0.0022 | 0.0052 |
| Chromium (Cr) | 0.0108 | 0.0398 | 0.0042 | 0.0050 | 0.0168 | 0.0440 | 0.0241 | 0.0531 | 0.0131 | 0.0277 | 0.0085 | 0.0174 | 0.0176 | 0.0613 |
| Iron (Fe) | NA | NA | NA | HA | 3.11 | 8.39 | 6.64 | 18.22 | 2.32 | 4.66 | 1.76 | 4.16 | 3.01 | 7.30 |
| Magnesium (Mg) | NA | NA | NA | NA | 4.67 | 12.12 | 8.26 | 18.06 | 2.52 | 6.07 | 1.07 | 6.12 | 3.70 | 9.00 |
| Sodium (Na) | NA | NA | NA | NA | 13.53 | 20.31 | 21.30 | 40.83 | 0.82 | 18.33 | 1.73 | 2.73 | 10.27 | 90.64 |
| Nickel (Ni) | 0.0203 | 0.0688 | 0.0690 | 0.1804 | 0.0360 | 0.1360 | 0.1261 | 0.2660 | 0.0880 | 0.5458 | 0.0485 | 0.1328 | 0.0682 | 0.2138 |
| Lead (Pb) | 0.131 | 0.443 | 0.102 | 0.193 | 0.144 | 0.687 | 0.266 | 0.772 | 0.234 | 0.802 | 0.282 | 1.133 | 0.181 | 0.573 |
| Vanadium (V) | 0.0231 | 0.0743 | 0.0514 | 0.1430 | 0.0624 | 0.2336 | 0.1600 | 0.0465 | 0.0100 | 0.0388 | 0.0290 | 0.0830 | 0.0736 | 0.1682 |

B-19



Sample collection averaging time: t 2-30 hours

NA = no analysis performed for this analyte

NOTE; only three valid samples collected at this site during July 1991 end analyzed for chlorine (Cl-), nitrate (NO3-), and sulfate (SO4-2-)

(a) Additional time series plots of **PM₁₀** and **metal** concentrations through time for **Camp Thunderrock** are shown in Figures B-11 through B-15. A majority of daily average **PM₁₀ concentrations were** above the **PM₁₀ 24-hour NAAQS**. There were three days where the daily **PM₁₀ concentration exceeded** the **PM₁₀ significant harm PSI**. The daily average **PM₁₀ levels dropped below the NAAQS after October 1991**.

(b) The chromium and vanadium plots display a **general decrease** of pollutant levels over time. The nickel concentrations displayed their **peak levels** during the **late summer/early fall seasons**. The lead concentration plot displayed a **general increase** with time. This is probably indicative of the **return of vehicle emissions which use lead-based gasolines**.

(3) The monthly **PM₁₀ levels** for the **Military Hospital** generally decreased from May - November 1991. The summer season **PM₁₀ concentrations** remained relatively constant at around **200 micrograms per cubic meter (µg/m³)**. The total chromium levels were neatly constant from May - August 1991; they then **decreased** through November 1991. The monthly vanadium levels displayed an **overall decrease** from May - November 1991. The monthly lead levels remained nearly constant, then **increased through October 1991**. This is similar to the trends observed at **Camp Thunderrock**. As with **Camp Thunderrock**, the monthly nickel levels **peaked** during July and September 1991, then **decreased** through November 1991. Table B-11 displays the monthly and **overall PM₁₀** and metal **statistics** for the **Military Hospital sampling site**.

(a) Additional time series plots of daily **PM₁₀** and metal concentrations through time for the **Military Hospital** are shown in Figures B-16 through B-20. A majority of the daily **PM₁₀ concentrations were** above the EPA **24-hour PM₁₀ NAAQS**. A total of six daily **PM₁₀ concentrations exceeded** the EPA **significant harm PSI**. The daily **PM₁₀ concentrations observed** at the **Military Hospital** fell to levels slightly above or below the **NAAQS** September - November 1991.

(b) The **Military Hospital** time series plots for metals are similar to the **Camp Thunderrock** plots. The chromium and vanadium levels for the **Military Hospital, Kuwait**, displayed a **general decrease** over time. The lead levels displayed a **general increase over time**.

(4) The **crustal metals** to include calcium, iron, **magnesium**, and sodium were analyzed on the **PM₁₀ filters** starting with those **samples** taken **after July 1991**. For all three long-term air sampling sites, the overall **concentrations** of these metals **decreased** from September - November 1991. This is attributed to the **decrease in the Shamal** wind events in the Persian Gulf region. The predominant **northwest to southeast** wind flow regime subsided. Without the atmospheric **circulation** patterns **transversing** the vast **desert areas**, the **overall particulate** loading in the atmosphere decreased; and subsequent **PM₁₀ levels decreased**.

PM10 CONCENTRATION vs TIME
CAMP THUNDEROCK, KUWAIT
JUNE - DECEMBER 1991

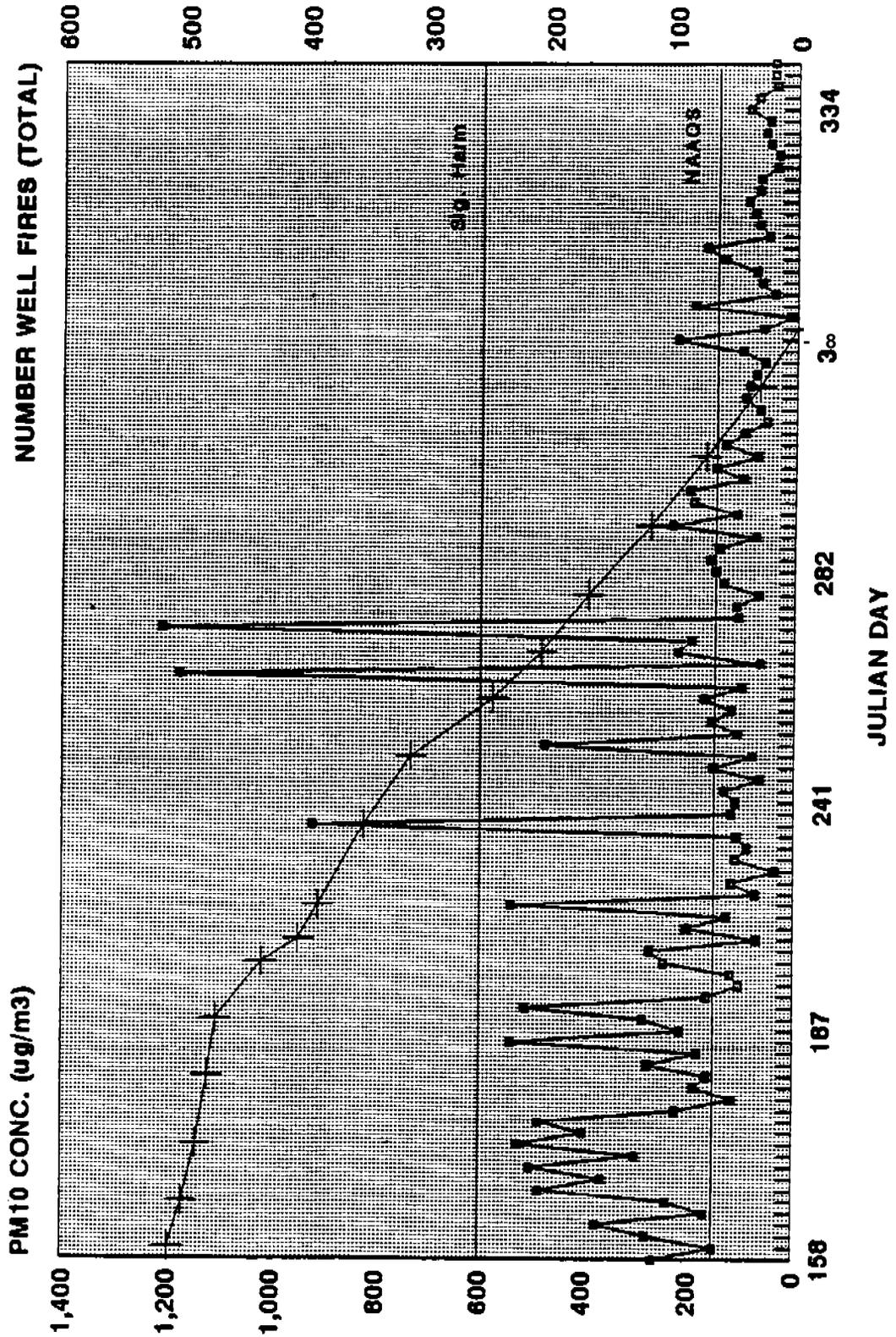


Figure B-11.

TOTAL CHROMIUM vs TIME

CAMP THUNDEROCK, KUWAIT
(JUNE - DECEMBER 1991)

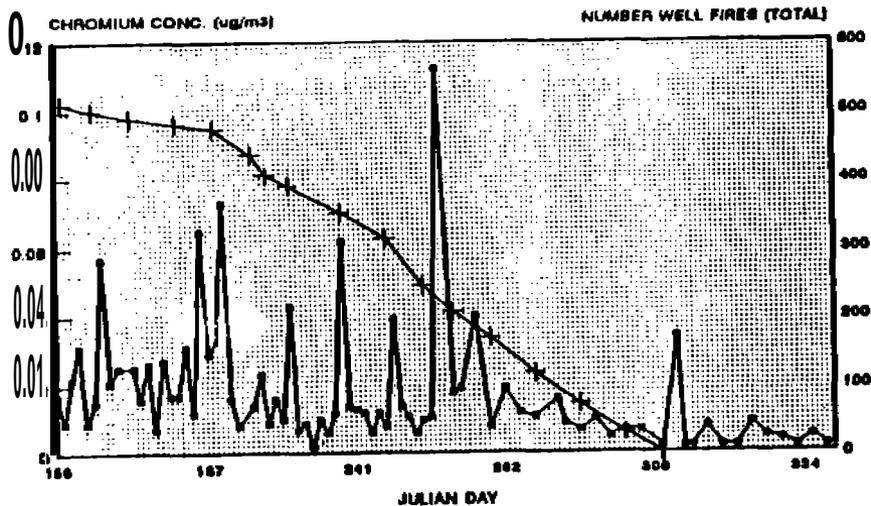


Figure B-12.

December 1993
USAHA/APED

NICKEL CONCENTRATION vs TIME

CAMP THUNDEROCK, KUWAIT
(JUNE - DECEMBER 1991)

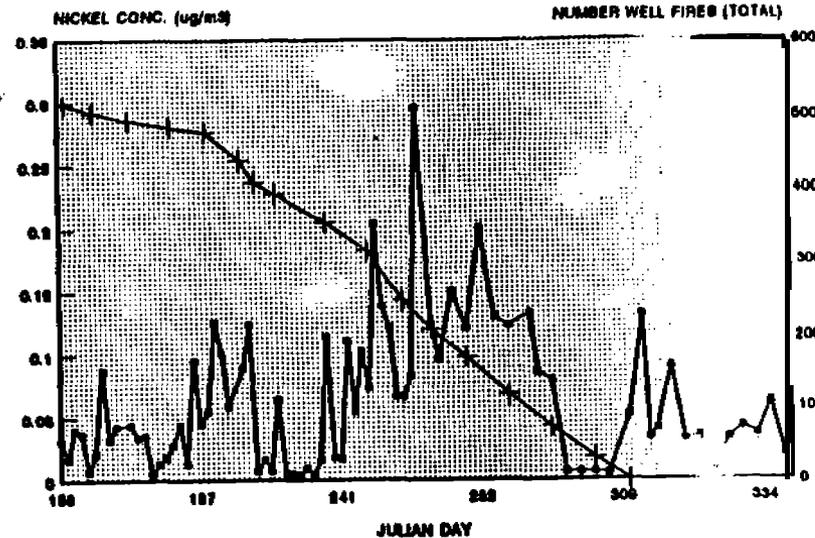


Figure B-13.

December 1993
USAHA/APED

VANADIUM CONCENTRATION vs TIME

CAMP THUNDEROCK, KUWAIT
(JUNE - DECEMBER 1991)

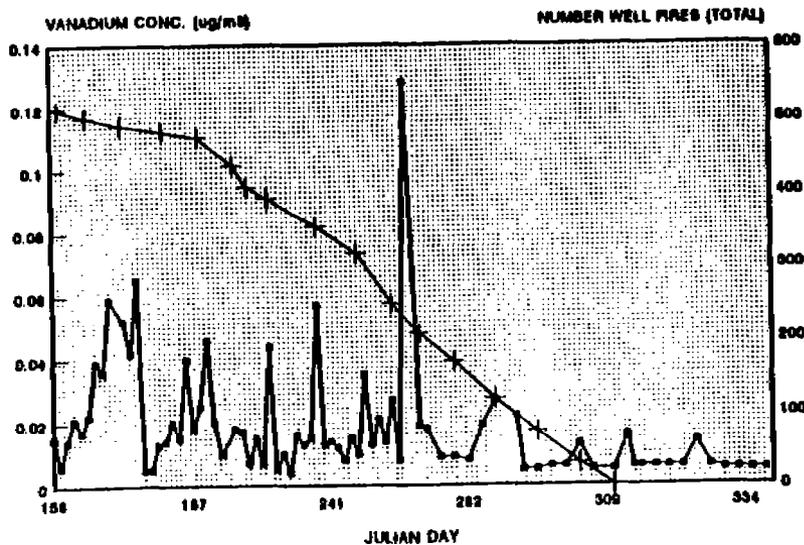


Figure B-14.

December 1993
USAHA/APED

LEAD CONCENTRATION vs TIME

CAMP THUNDEROCK, KUWAIT
(JUNE - DECEMBER 1991)

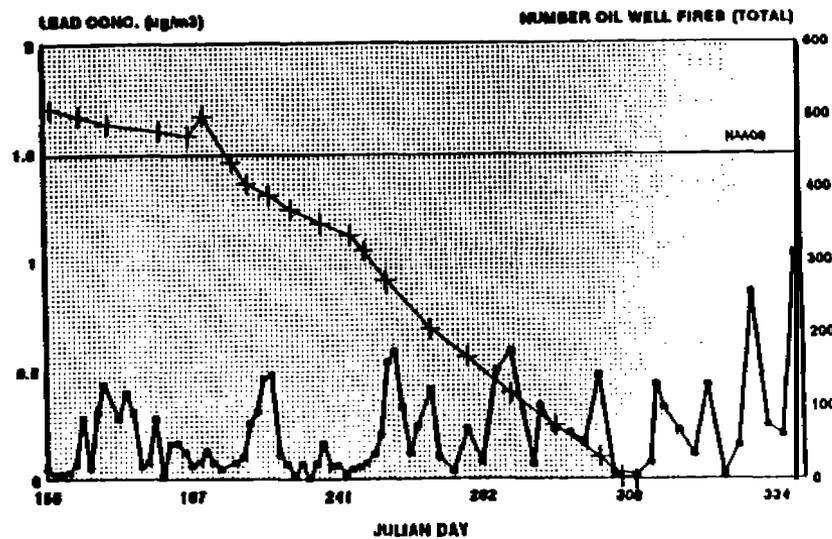


Figure B-15.

December 1993
USAHA/APED

Final Rpt, Kuwait Oil Fire HRA No. 39-26-L192-91, 5 May - 3 Dec 91

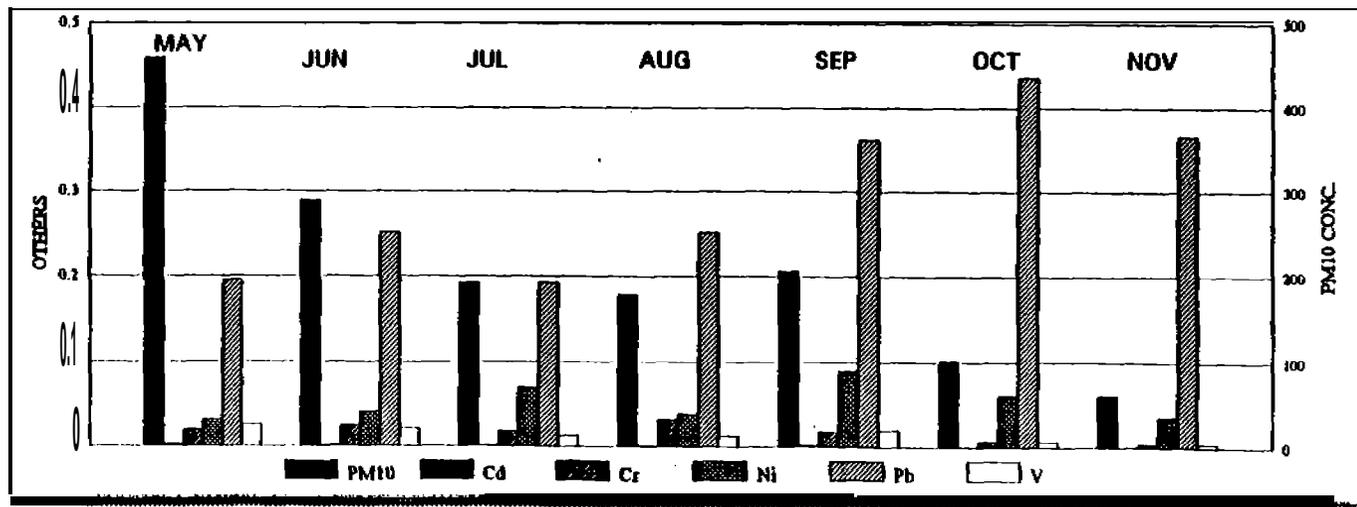
B-22

PM 10: MILITARY HOSPITAL

PM 10 AND METALS DATA (HI-VOLUME REFERENCE METHOD)
(ug/m3)

| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
|--------------------|--------|--------|--------|--------|--------|--------|--------|--------|-----------|--------|---------|--------|----------|--------|---------|--------|
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| PM 10 (Mass Conc.) | 459 | 1239 | 290 | 527 | 192 | 359 | 178 | 423 | 207 | 445 | 103 | 182 | 52.0 | 113 | 180 | 482 |
| Aluminum (Al) | NA | NA | NA | NA | NA | NA | 3.22 | 7.43 | 3.54 | 0.10 | 1.65 | 3.63 | 0.97 | 2.12 | 2.31 | 5.97 |
| Arsenic (As) | NA | NA | NA | NA | NA | NA | 0.0013 | 0.0025 | 0.0017 | 0.0040 | 0.0008 | 0.0015 | 0.0006 | 0.0017 | 0.0011 | 0.0025 |
| Beryllium (Be) | NA | NA | NA | NA | NA | NA | 0.0032 | 0.0159 | 0.0013 | 0.0081 | 0.0002 | 0.0005 | 0.0002 | 0.0002 | 0.0012 | 0.0041 |
| Calcium (Ca) | NA | NA | NA | NA | NA | NA | 20.8 | 50.1 | 18.7 | 48.3 | 5.1 | 16.8 | 5.7 | 12.0 | 13.4 | 34.2 |
| Cadmium (Cd) | 0.0040 | 0.0107 | 0.0029 | 0.0075 | 0.0024 | 0.0055 | 0.0018 | 0.0040 | 0.0022 | 0.0049 | 0.0011 | 0.0015 | 0.0010 | 0.0009 | 0.0021 | 0.0051 |
| Chromium (Cr) | 0.0189 | 0.0532 | 0.0261 | 0.0781 | 0.0184 | 0.0414 | 0.0328 | 0.0052 | 0.0185 | 0.0460 | 0.0085 | 0.0165 | 0.0044 | 0.0118 | 0.0185 | 0.0579 |
| Iron (Fe) | NA | NA | NA | NA | NA | NA | 3.58 | 5.55 | 4.05 | 11.95 | 1.80 | 4.08 | 1.20 | 2.85 | 2.86 | 0.75 |
| Magnesium (Mg) | NA | NA | NA | NA | NA | NA | 4.71 | 11.42 | 4.38 | 11.54 | 1.89 | 3.85 | 1.45 | 3.14 | 3.10 | 7.09 |
| Sodium (Na) | NA | NA | NA | NA | NA | NA | 12.62 | 17.34 | 16.27 | 27.14 | 3.58 | 8.17 | 1.38 | 2.04 | 0.24 | 29.79 |
| Nickel (Ni) | 0.0318 | 0.0872 | 0.0408 | 0.1280 | 0.0692 | 0.1600 | 0.0383 | 0.1660 | 0.0900 | 0.1748 | 0.0617 | 0.3494 | 0.0366 | 0.0668 | 0.0621 | 0.1937 |
| Lead (Pb) | 0.195 | 0.380 | 0.2620 | 0.598 | 0.182 | 0.655 | 0.252 | 0.412 | 0.362 | 0.582 | 0.438 | 0.817 | 0.355 | 0.651 | 0.301 | 0.595 |
| Vanadium (V) | 0.0263 | 0.0563 | 0.0214 | 0.0634 | 0.0135 | 0.0289 | 0.0133 | 0.0320 | 0.0202 | 0.0413 | 0.0073 | 0.0166 | 0.0048 | 0.0078 | 0.0149 | 0.0380 |
| Zinc (Zn) | 0.0540 | 0.1033 | 0.0484 | 0.0821 | 0.0282 | 0.0745 | 0.0703 | 0.2045 | 0.0553 | 0.0817 | 0.0455 | 0.0893 | 0.0358 | 0.0535 | 0.0478 | 0.1079 |

B-23



Sample collection averaging time: 12 - 30 hours
NA = no analysis performed for this analyte

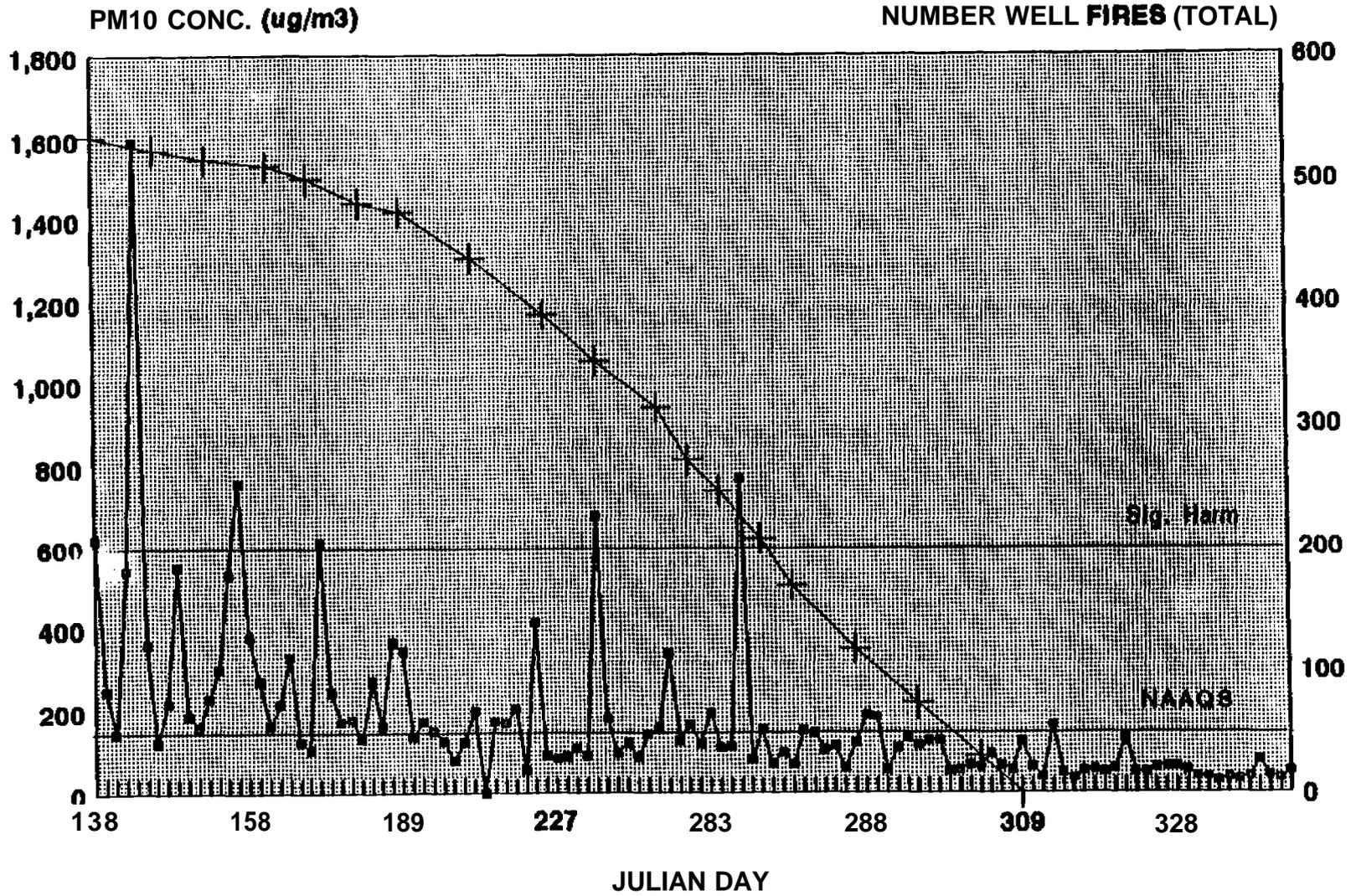
PM10 CONCENTRATION vs TIME

MILITARY HOSPITAL
(MAY - DECEMBER 1991)

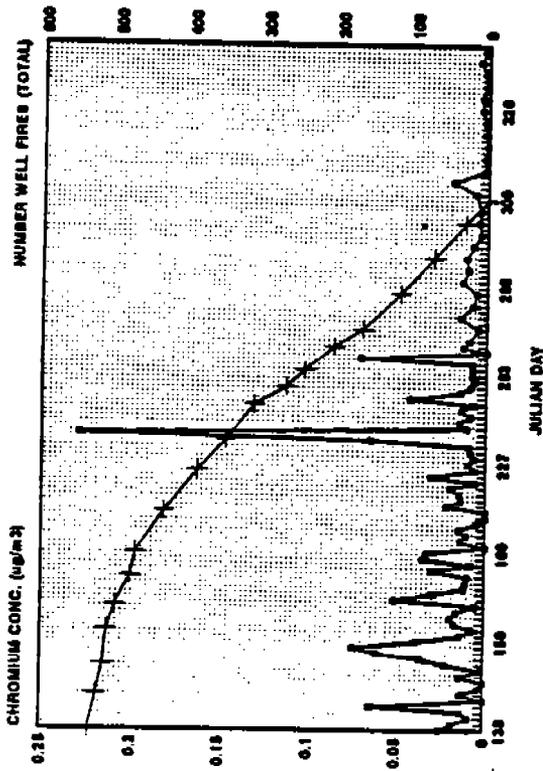
Final Rpt, Kuwait Oil Fire HRA No. 39-26-L192-81 5 May 91

Figure B-16.

B-24



TOTAL CHROMIUM vs TIME
 MILITARY HOSPITAL
 (MAY - DECEMBER 1991)

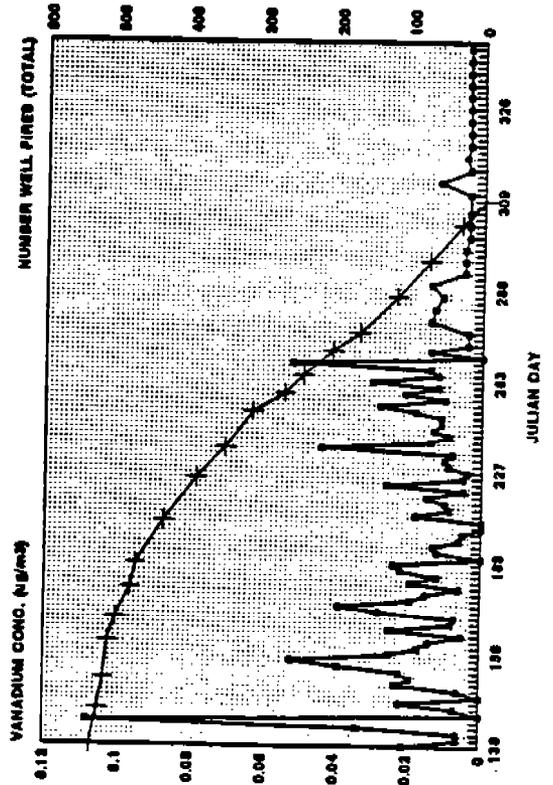


December 1993
 USAEHA/AEPD

B-25

Figure B-17.

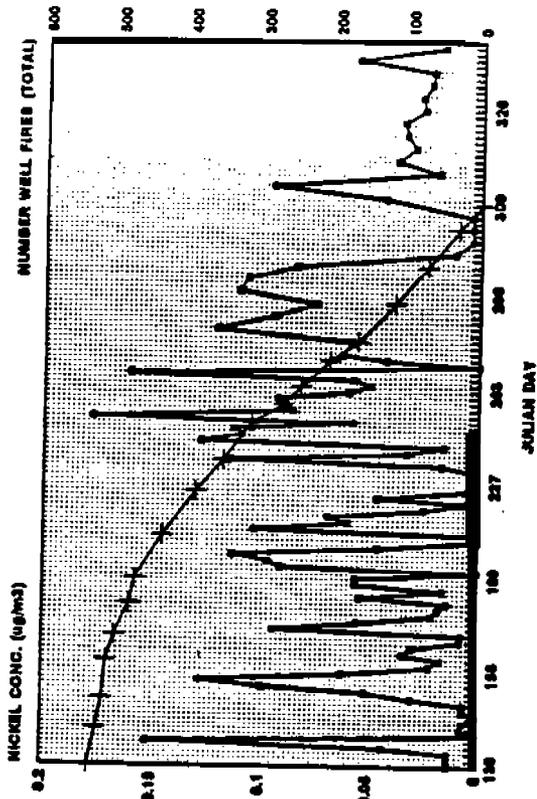
VANADIUM CONCENTRATION vs TIME
 MILITARY HOSPITAL
 (MAY - DECEMBER 1991)



December 1993
 USAEHA/AEPD

Figure B-19.

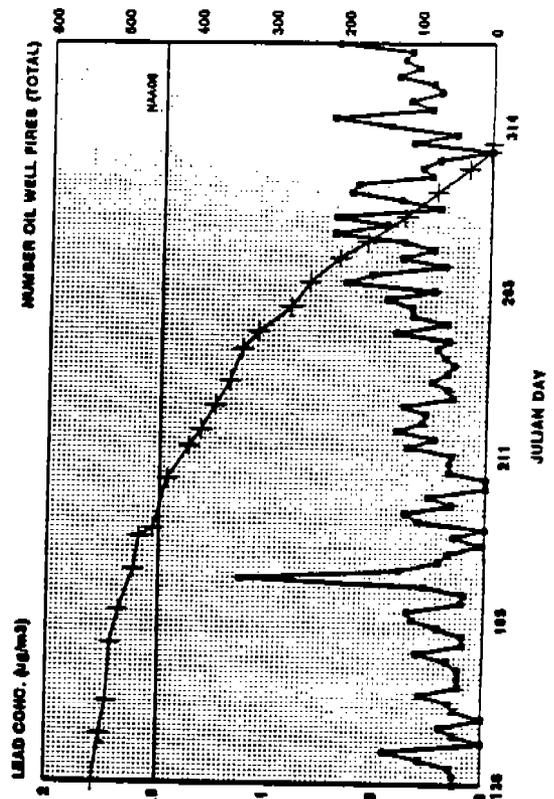
NICKEL CONCENTRATION vs TIME
 MILITARY HOSPITAL
 (MAY - DECEMBER 1991)



December 1993
 USAEHA/AEPD

Figure B-18.

LEAD CONCENTRATION vs TIME
 MILITARY HOSPITAL, KUWAIT
 (MAY - DECEMBER 1991)



December 1993
 USAEHA/AEPD

Figure B-20.

(5) Tables B-3-1 through B-5-S (Annex B-3) display the monthly and overall PM_{10} and associated metals concentration values for the remaining sampling sites to include KKMC, Riyadh, and Jubayl for the Saudi Arabia sites and Ahamdi Hospital and U.S. Embassy for the Kuwait sites. In addition, Table B-3-6 contains a listing of the maximum and minimum PM_{10} concentrations for each of the eight sampling sites.

(6) An investigation of possible relationships between windspeed and particulate concentrations in southwest Asia for 1991 was conducted (reference 51). Linear regression was performed on valid meteorological data for Dhahran, Saudi Arabia and Kuwait city, Kuwait, for overall seasonal, monthly, and wind direction sectors for individual months. Linear correlation coefficients ranged from 0.069 to 0.94. The correlation coefficients were higher for the Kuwait City meteorological data and Military Hospital particulate data. The particulate concentrations remained relatively constant through the 4 - 12 miles per hour (mph) wind speed range. Windspeeds above 12 mph displayed varying particulate levels. However, no significant conclusions were found during this investigation. Figures B-21 and B-22 display the PM_{10} versus windspeed plots for Khobar Towers, Saudi Arabia, and Military Hospital, Kuwait, respectively.

d. High Volume Particulate PAHs - The high volume PAH particulate results were ~~summarized~~ with respect to the overall sampling period statistics. There were minimal PAH pollutant detections above the respective analytical detection limit. For the Khobar Towers, Camp Thunderrock, and the Military Hospital sampling sites, Camp Thunderrock displayed the highest overall PAH particulate concentrations, while the Military Hospital site displayed the lowest PAH particulate concentrations. Tables B-12 through B-14 display the overall high volume PAH particulate concentrations for Khobar Towers, Camp Thunderrock, and the Military Hospital, respectively. Figure B-23 displays selected mean PAH particulate concentrations for each of the long-term sampling sites. Tables B-4-1 through B-4-5 (Annex B-4) contain the overall high volume PAH particulate concentrations for the remaining sampling sites which include KKMC, Riyadh, and Jubayl for the Saudi Arabia sites and Ahamdi Hospital and U.S. Embassy for the Kuwait sites. The Riyadh (Eskan Village) sampling site displayed the highest PAH particulate levels.

e. High volume EPA Method 13 PAHs. 0 - 1 3 PAH
sampling was conducted at Khobar Towers, Camp Thunderrock, and the Military Hospital from October - November 1991. A total of 33 samples were collected and were comprised of 12 samples from Khobar Towers, 11 samples from Camp Thunderrock, and 10 samples from the Military Hospital. Tables B-15 through B-20 contain the EPA Method TO-13 concentration statistics for the three sampling sites, Overall, the lower molecular weight PAH levels (to include naphthalene) were highest at the Military Hospital. For the heavier molecular weight PAHs, which include anthracene, pyrene and benzo(a)pyrene, concentration levels were highest at Khobar Towers. Figure B-24 displays selected mean PAH

PM10 vs WINDSPEED KHOBAR, SAUDI ARABIA (MAY - NOV '91)

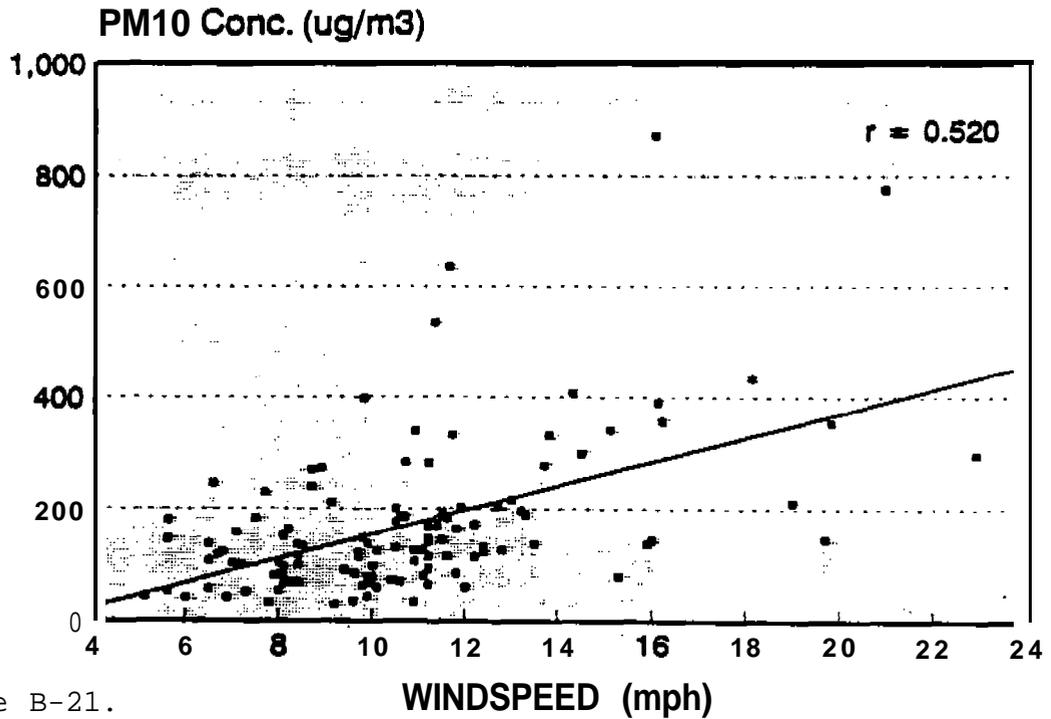


Figure B-21.

PM10 vs WINDSPEED KUWAIT (MAY - NOV 1991)

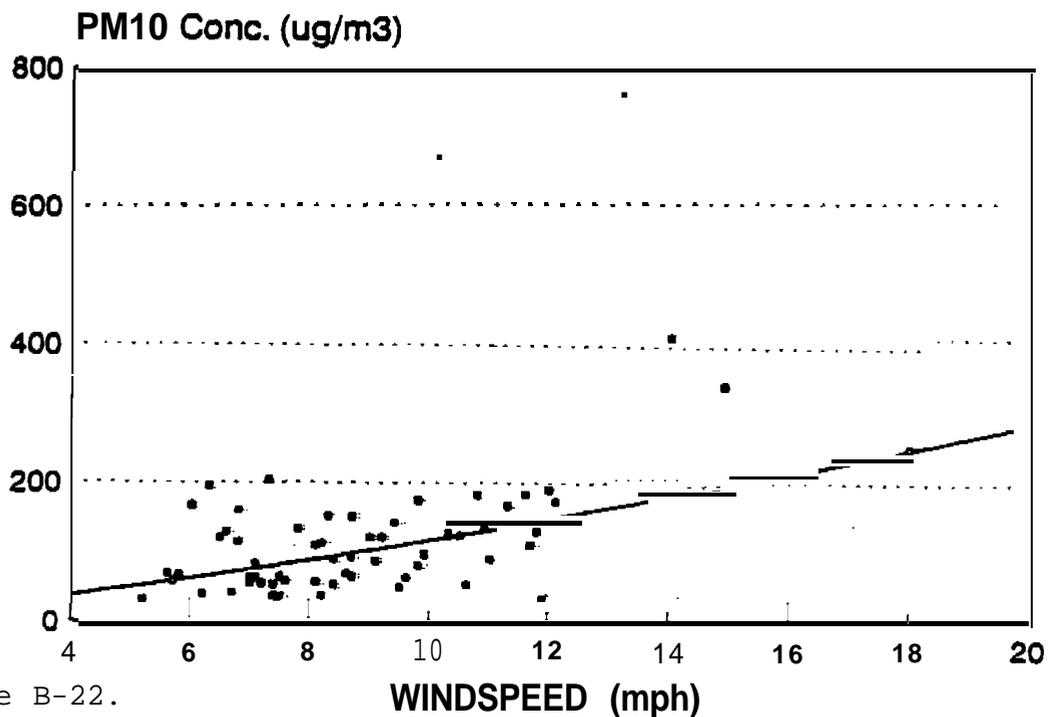


Figure B-22.

TABLE B-12.

KHOBAR TOWERS
POLYCYCLIC AROMATIC HYDROCARBONS (HI-VOL REFERENCE PM10 METHOD)
(ug/m3)

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ug/m3) | | | ANALYTICAL DETECTION LIMIT (ug) |
|------------------------|-------------------|-----|-----------------------|---------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | MAX | MIN | |
| Naphthalene | 38 | 38 | 0.00475 | BDL | BDL | 20 |
| 2-Methyl Naphthalene | 26 | 26 | 0.00489 | BDL | BDL | 20 |
| 1-Methyl Naphthalene | 26 | 26 | 0.00489 | BDL | BDL | 20 |
| Biphenyl | 27 | 27 | 0.00489 | BDL | BDL | 20 |
| Dimethyl Naphthalene | 27 | 26 | 0.00112 | 0.00491 | BDL | 4 |
| Acenaphthylene | 38 | 37 | 0.00100 | 0.00241 | BDL | 4 |
| Acenaphthene | 34 | 32 | 0.00051 | 0.00514 | BDL | 1.5 |
| Dibenzofuran | 27 | 25 | 0.00044 | 0.00560 | BDL | 1.5 |
| Fluorene | 39 | 34 | 0.00027 | 0.00319 | BDL | 1.5 |
| Phenanthrene | 39 | 30 | 0.00028 | 0.00296 | BDL | 0.5 |
| | 39 | 37 | | | | 0.5 |
| Carbazole | 39 | 27 | 0.00020 | 0.00250 | BDL | 0.5 |
| Fluoranthene | 39 | 11 | 0.00058 | 0.00307 | BDL | 0.5 |
| Pyrene | | 30 | 0.00021 | 0.00200 | BDL | 0.5 |
| Benzo(a)Anthracene | 39 | 34 | 0.00021 | 0.00155 | BDL | 0.5 |
| | 39 | 31 | | | | 0.5 |
| Benzo(b)Fluoranthene | 39 | 33 | 0.00026 | 0.00367 | BDL | 0.5 |
| Benzo(k)Fluoranthene | | 36 | 0.00027 | 0.00419 | BDL | 0.5 |
| Benzo(e)Pyrene | 27 | 26 | 0.00010 | 0.00010 | BDL | 0.5 |
| Benzo(a)Pyrene | 39 | 37 | 0.00026 | 0.00364 | BDL | 0.5 |
| Indeno(1,2,3-cd)Pyrene | 39 | 35 | 0.00028 | 0.00341 | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 39 | 37 | 0.00019 | 0.00139 | BDL | 0.5 |
| Benzo(ghi)Perylene | 39 | 37 | 0.00025 | 0.00341 | BDL | 0.5 |

BDL = below detection limit; analyte was not identified and quantified below the detection threshold

NOTE: high-volume sampler using quartz or glass fiber filter to collect particle-adsorbed PAHs

NOTE: Detection limit shown is the lowest detection limit reported by the laboratory for the individual analyte

Sampler Flow Rate: 0.7 - 2.1 m3/min

CAMP THUNDEROCK
POLYCYCLIC AROMATIC HYDROCARBONS (HI-VDL REFERENCE PM1 0 METHOD)
 (ug/m3)

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ug/m3) | | | ANALYTICAL DETECTION LIMIT (ug) |
|------------------------|-------------------|-----|-----------------------|---------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | MAX | MIN | |
| Naphthalene | 19 | 19 | 0.00496 | BDL | BDL | 20 |
| P-Methyl Naphthalene | 14 | 14 | 0.00523 | BDL | BDL | 20 |
| 1-Methyl Naphthalene | 15 | 15 | 0.00518 | BDL | BDL | 20 |
| Biphenyl | 15 | 15 | 0.60518 | BDL | BDL | 20 |
| Dimethyl Naphthalene | 15 | 15 | 0.00104 | BDL | BDL | 4 |
| Acenaphthylene | 20 | 20 | 0.00122 | BDL | BDL | 4 |
| Acenaphthene | 19 | 18 | 0.00053 | 0.00167 | BDL | 1.5 |
| Dibenzofuran | 15 | 14 | 0.00025 | 0.00110 | BDL | 1.5 |
| Fluorene | 20 | 20 | 0.00023 | BDL | BDL | 1.5 |
| Phenanthrene | 20 | 17 | 0.00031 | 0.00132 | BDL | 0.5 |
| Anthracene | 20 | 20 | 0.00023 | BDL | BDL | 0.5 |
| Carbazole | 15 | 15 | 0.00012 | BDL | BDL | 0.5 |
| Fluoranthene | 20 | 9 | 0.00050 | 0.00180 | BDL | 0.5 |
| Pyrene | 20 | 16 | 0.60027 | 0.00083 | BDL | 0.5 |
| Benzo(a)Anthracene | 19 | 19 | 0.00023 | BDL | BDL | 0.5 |
| Chrysene | 20 | 15 | 0.00035 | 0.00154 | BDL | 0.5 |
| Benzo(b)Fluoranthene | 20 | 18 | 0.00028 | 0.00099 | BDL | 0.5 |
| Benzo(k)Fluoranthene | 20 | 19 | 0.00023 | 0.00026 | BDL | 0.5 |
| Benzo(e)Pyrene | 15 | 15 | 0.00012 | BDL | BDL | 0.5 |
| Benzo(a)Pyrene | 20 | 20 | 0.00023 | BDL | BDL | 0.5 |
| Indeno(1,2,3-cd)Pyrene | 20 | 19 | 0.00025 | 0.00060 | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 20 | 20 | 0.00023 | BDL | BDL | 0.5 |
| Benzo(ghi)Perylene | 20 | 20 | 0.00023 | BDL | BDL | 0.5 |

BDL = below detection limit: **analyte** was not identified and quantified below the detection threshold
 NOTE: high-volume sampler using **quartz** or **glass fiber filter** to collect **particle-adsorbed PAHs**
 NOTE: Detection limit shown is the lowest detection **limit** reported by the laboratory for the individual analytes
 Sampler Flow Rate: 0.7 - 2.1 m3/min

MILITARY HOSPITAL
POLYCYCLIC AROMATIC HYDROCARBONS (HI-VOL REFERENCE PM10 METHOD)
 (ug/m3)

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ug/m3) | | | ANALYTICAL DETECTION LIMIT (ug) |
|------------------------|-------------------|-----|-----------------------|---------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | MAX | MIN | |
| Naphthalene | 19 | 19 | 0.00384 | BDL | BDL | 20 |
| P-Methyl Naphthalene | 10 | 10 | 0.00416 | BDL | BDL | 20 |
| 1-Methyl Naphthalene | 18 | 18 | 0.00416 | BDL | BDL | 20 |
| Biphenyl | 18 | 10 | 0.00416 | BDL | BDL | 20 |
| Dimethyl Naphthalene | 19 | 19 | 0.00083 | BDL | BDL | 4 |
| Acenaphthylene | 22 | 22 | 0.00082 | BDL | BDL | 4 |
| Acenaphthene | 19 | 21 | 0.00033 | 0.00065 | BDL | 1.5 |
| Dibenzofuran | 22 | 17 | 0.00036 | 0.00180 | BDL | 1.5 |
| Fluorene | | 20 | 0.00015 | 0.00060 | BDL | 1.5 |
| Phenanthrene | 22 | 20 | 0.00014 | 0.00048 | BDL | 0.5 |
| Anthracene | 19 | 22 | 0.00012 | BDL | BDL | 0.5 |
| Carbazole | 22 | 19 | 0.00010 | BDL | BDL | 0.5 |
| Fluoranthene | | 13 | 0.00027 | 0.00169 | BDL | 0.5 |
| Pyrene | 22 | 17 | 0.00018 | 0.00076 | BDL | 0.5 |
| Benzo(a)Anthracene | 22 | 22 | 0.00012 | BDL | BDL | 0.5 |
| Chrysene | 22 | 17 | 0.00013 | 0.00027 | BDL | 0.5 |
| Benzo(b)Fluoranthene | 22 | 18 | 0.00018 | 0.00110 | BDL | 0.5 |
| Benzo(k)Fluoranthene | | 22 | 0.00012 | BDL | BDL | 0.5 |
| Benzo(e)Pyrene | 19 | 17 | 0.00010 | 0.00010 | BDL | 0.5 |
| Benzo(a)Pyrene | 22 | 22 | 0.00012 | BDL | BDL | 0.5 |
| Indeno(1,2,3-cd)Pyrene | 22 | 21 | 0.00012 | 0.00030 | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 22 | 22 | 0.00012 | BDL | BDL | 0.5 |
| Benzo(ghi)Perylene | 22 | 19 | 0.00012 | 0.00012 | BDL | 0.5 |

NA - no analysis performed for these analytes

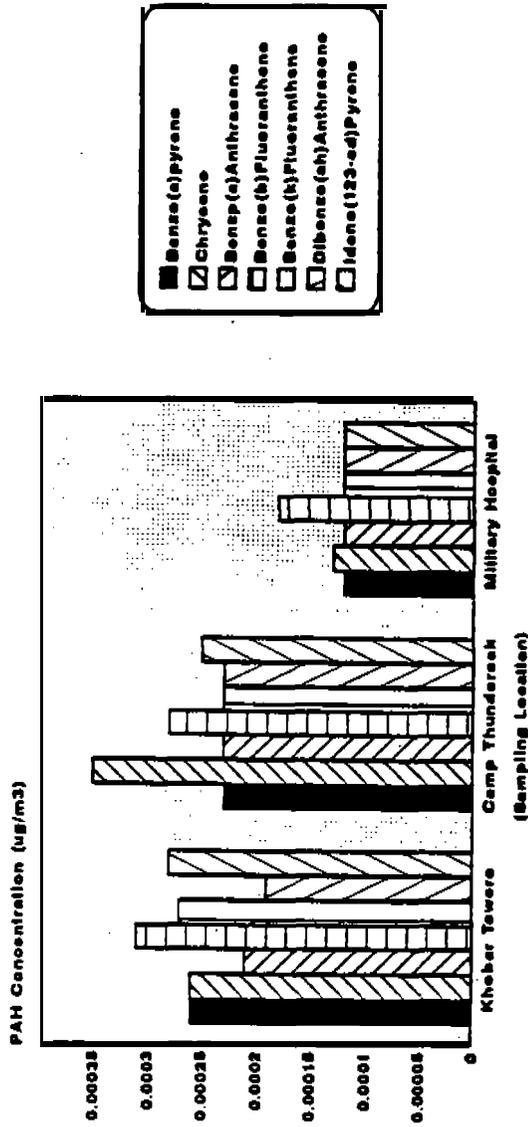
BDL = below detection limit; analyte was not identified and quantified below the detection threshold

NOTE: high-volume sampler using quartz or glass fiber filter to collect particle-adsorbed PAHs

NOTE: Detection limit shown is the lowest detection limit reported by the laboratory for the individual analytes

Sampler Flow Rate: 0.7 - 2.1 m3/min

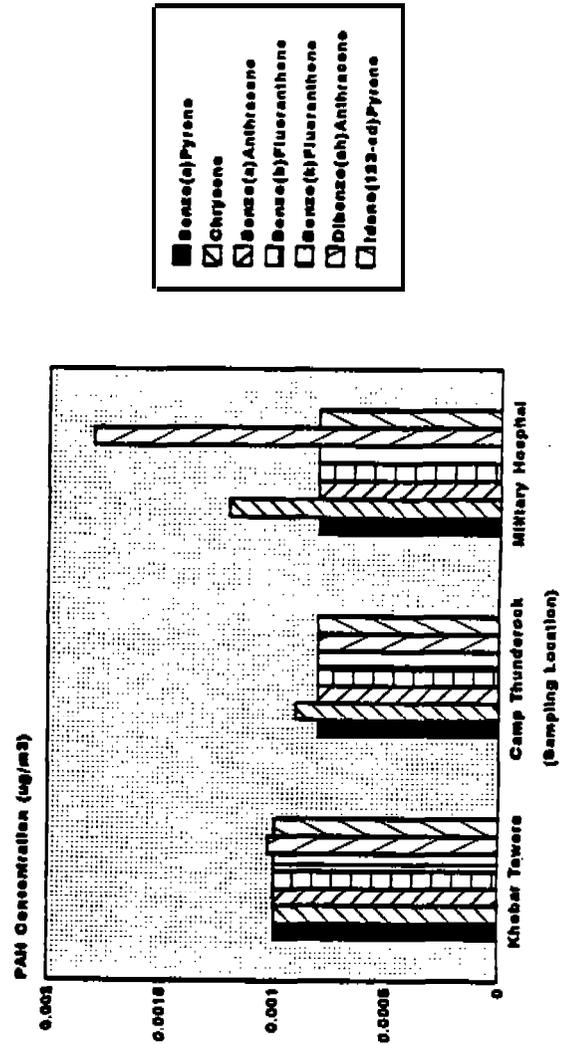
MEAN PAH PARTICULATE CONCENTRATIONS Kuwait and Saudi Arabia Locations, 1991



December 1993
USAEHA/APED

Figure B-23.

MEAN PAH TO13 CONCENTRATIONS Kuwait and Saudi Arabia Locations, 1991



December 1993
USAEHA/APED

Figure B-24.

TABLE B-15.

| ANALYTE | | SAMPLE POPULATION | | CONCENTRATION (ng/m3) | | | | ANALYTICAL DETECTION LIMIT (ug) |
|------------------------|--|-------------------|-----|-----------------------|--------|-------|-----|---------------------------------|
| | | TOTAL | BDL | MEAN | 95th | MAX | MIN | |
| Naphthalene | | 12 | 1 | 453 | 3362.5 | 1087 | BDL | 2 |
| 2-Methyl Naphthalene | | 12 | 3 | 82.1 | 359.5 | 213 | BDL | 2 |
| 1-Methyl Naphthalene | | 12 | 3 | 141 | 449.4 | 347 | BDL | 2 |
| Biphenyl | | 12 | 4 | 30.7 | 105.7 | 66.6 | BDL | 2 |
| Dimethyl Naphthalene | | 12 | 3 | 55.0 | 140.0 | 138 | BDL | 2 |
| Acenaphthylene | | 12 | 1 | 486 | 5522.5 | 954 | BDL | 2 |
| Acenaphthene | | 12 | 10 | 20.6 | 81.9 | 50.6 | BDL | 2 |
| Dibenzofuran | | 12 | 1 | 125 | 382.7 | 339 | BDL | 2 |
| Fluorene | | 12 | 4 | 18.8 | 55.6 | 46.9 | BDL | 2 |
| Phenanthrene | | 12 | 6 | 28.9 | 126.6 | 70.1 | BDL | 2 |
| Anthracene | | 12 | 10 | 18.2 | 68.8 | 43.4 | BDL | 2 |
| Carbazole | | 12 | 11 | 24.4 | 103.7 | 46.9 | BDL | 2 |
| Fluoranthene | | 12 | 4 | 40.5 | 215.3 | 281 | BDL | 0.5 |
| Pyrene | | 12 | 5 | 14.02 | 51.6 | 107.8 | BDL | 0.5 |
| Benzo(a)Anthracene | | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Chrysene | | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Benzo(b)Fluoranthene | | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Benzo(k)Fluoranthene | | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Benzo(e)Pyrene | | 12 | 12 | 0.992 | 1.2 | BDL | BDL | 0.5 |
| Benzo(a)Pyrene | | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Indeno(1,2,3-cd)Pyrene | | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Dibenzo(ah)Anthracene | | 12 | 10 | 1.02 | 1.2 | 1.20 | BDL | 0.5 |
| Benzo(ghi)Perylene | | 12 | 10 | 1.09 | 1.5 | 1.90 | BDL | 0.5 |

BDL = below detection limit: analyte was not identified and quantified below the detection threshold

NOTE: high-volume sampler using quartz or glass fiber filter to collect particle-adsorbed PAHs

NOTE: Detection limit shown is the lowest detection limit reported by the laboratory for the individual an
Sampler flow Rate: @ 300 liters/min

TABLE B-16.

CAMP THUNDEROCK

POLYCYCLIC AROMATIC HYDROCARBONS (EPA METHOD TO-13)
Lognormal (ng/m³)

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ng/m ³) | | | | ANALYTICAL DETECTION LIMIT (ug) |
|-----------------------|-------------------|-----|------------------------------------|---------|------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | 95th | MAX | MIN | |
| Naphthalens | 11 | 3 | 722 | 10029 | 2135 | BDL | 2 |
| 2-Methyl Naphthalene | 11 | 4 | 61.7 | 336.9 | 242 | BDL | 2 |
| 1 -Methyl Naphthalene | 11 | 2 | 157 | 1251 .B | 546 | BDL | 2 |
| Biphenyl | 11 | 2 | 41.4 | 147.6 | 265 | BDL | 2 |
| Dimethyl Naphthalene | 11 | 1 | 70.7 | 303.7 | 238 | BDL | 2 |
| Acenaphthylene | 11 | 0 | 1275 | 4069.6 | 3675 | 227 | 2 |
| Acenaphthene | 11 | 11 | 11.20 | 35.3 | BDL | BDL | 2 |
| Dibenzofuran | 11 | 2 | 83.4 | 480.9 | 261 | BDL | 2 |
| Fluorene | 11 | 3 | 31.9 | 135.4 | 110 | BDL | 2 |
| Phenanthrene | 11 | 4 | 11.2 | 32.9 | 37.9 | BDL | 2 |
| Anthracene | 11 | 11 | 11.00 | 35.3 | BDL | BDL | 2 |
| Carbazole | 11 | 11 | 11.20 | 35.3 | BDL | BDL | 2 |
| Fluoranthene | 11 | 4 | 7.80 | 35.9 | 24.0 | BDL | 0.5 |
| Pyrene | 11 | 1 | 5.10 | 13.8 | 13.9 | BDL | 0.5 |
| Benzo(a)Anthracene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Chrysene | 11 | 10 | 0.900 | 1.2 | 1.30 | BDL | 0.5 |
| Benzo(b)Fluoranthene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(k)Fluoranthene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(e)Pyrene | 11 | 11, | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(a)Pyrene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Ideno(1,2,3-cd)Pyrene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(ghi)Perylene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |

BDL = below detection limit; **analyte** was not identified and quantified below the detection threshold

NOTE: high-volume sampler using quam or glass fiber filter to collect particle-adsorbed PAHs

NOTE: Detection limit shown is the lowest **detection** limit reported by the laboratory for the individual an Sampler flow Rate: @ 300 liters/min

MILITARY HOSPITAL
POLYCYCLIC AROMATIC HYDROCARBONS (EPA METHOD TO-13)
Lognormal (ng/m3)

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ng/m3) | | | | ANALYTICAL DETECTION LIMIT (ug) |
|-----------------------|-------------------|-----|-----------------------|---------|--------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | 95th | MAX | MIN | |
| Naphthalens | 10 | 2 | 815 | 16561.9 | 2031.9 | BDL | 2 |
| P-Methyl Naphthalena | 10 | 2 | 69.8 | 415.7 | 189 | BDL | 2 |
| 1-Methyl Naphthalens | 10 | 2 | 175 | 1554.6 | 385 | BDL | 2 |
| Biphenvl | 10 | 2 | 24.8 | 94.2 | 62.10 | BDL | 2 |
| Dimethyl Naphthalens | 10 | 2 | 77.0 | 477.9 | 224 | BDL | 2 |
| Acenaphthylene | 10 | 1 | 1070 | 128D1.3 | 2744 | BDL | 4 |
| Acenaphthene | 10 | 10 | 12.1 | 40.4 | BDL | BDL | 2 |
| Dibenzofuran | 10 | 0 | 70.4 | 349.8 | 199 | 2.8 | 2 |
| Fluorane | 10 | 0 | 42.1 | 139.0 | 72.6 | 5.1 | 2 |
| Phenanthrene | 10 | 4 | 8.30 | 20.4 | 15.0 | BDL | 2 |
| Anthracene | 10 | 10 | 12.0 | 404.0 | BDL | BDL | 2 |
| Carbazole | 10 | 10 | 12.1 | 4D.4 | BDL | BDL | 2 |
| Fluoranthene | 10 | 5 | 6.00 | 26.3 | 12.4 | BDL | 0.5 |
| Pyrene | 10 | 3 | 4.20 | 14.0 | 11.4 | BDL | 0.5 |
| Benzo(a)Anthracene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Chrysene | 10 | 9 | 1.20 | 2.4 | 4.50 | BDL | 0.5 |
| Benzo(b)Fluoranthene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(k)Fluoranthene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(e)Pyrene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(a)Pyrene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Ideno(1,2,3-cd)Pyrene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 10 | 10 | 1.80 | 1.0 | BDL | BDL | 0.5 |
| Benzo(ghi)Perylene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |

BDL = below detection limit; **analyte** was not **identified** and **quantified** below the detection threshold
 NOTE: high-volume sampler using **quartz** or **glass fiber** filter to **collect particle-adsorbed PAHs**
 NOTE: Detection limit shown is the **lowest** detection limit **reported** by the laboratory for the individual an
 Sampler Flow Rate: @ 300 liters/min

KHOBAR TOWERS

**POLYCYCLIC AROMATIC HYDROCARBONS (EPA METHOD TO-13)
 Normal Distribution (ng/m3)**

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ng/m3) | | | | ANALYTICAL DETECTION LIMIT (ug) |
|-----------------------|-------------------|-----|-----------------------|--------|-------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | 95th | MAX | MIN | |
| Naphthalene | 12 | 1 | 453 | 1074.7 | 1087 | BDL | 2 |
| P-Methyl Naphthalsne | 12 | 3 | 02.1 | 191.6 | 213 | BDL | 2 |
| 1 -Methyl Naphthalene | 12 | 3 | 141 | 321.8 | 347 | BDL | 2 |
| Biphenyl | 12 | 4 | 30.7 | 61.5 | 66.6 | BDL | 2 |
| Dimethyl Naphthalene | 12 | 3 | 486 | 127.0 | 138 | BDL | 2 |
| Acenaphthylene | 12 | 1 | 20.6 | 1053.4 | 954 | BDL | 2 |
| Acenaphthene | 12 | 10 | | 51.2 | 50.6 | BDL | 2 |
| Dibentofuran | 12 | 1 | 125 | 202.5 | 339 | BDL | 2 |
| Fluorene | 12 | 4 | 18.8 | 42.3 | 46.9 | BDL | 2 |
| Phenanthrene | 12 | 6 | 28.9 | 67.4 | 70.1 | BDL | 2 |
| Anthracene | 12 | 10 | 18.2 | 47.1 | 43.4 | BDL | 2 |
| Carbazole | 12 | 11 | 24.4 | 54.4 | 46.9 | BDL | 2 |
| Fluoranthene | 12 | 4 | 40.5 | 171.0 | 281 | BDL | 0.5 |
| Pyrene | 12 | 5 | 14.02 | 63.3 | 107.8 | BDL | 0.5 |
| Benzo(a)Anthracene | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Chrysene | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Benzo(b)Fluoranthene | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Benzo(k)Fluoranthene | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Benzo(e)Pyrene | 12 | 12 | 0.992 | 1.2 | BDL | BDL | 0.5 |
| Benzo(a)Pyrene | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Ideno(1,2,3-cd)Pyrene | 12 | 10 | 0.992 | 1.2 | 1.20 | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 12 | 10 | 1.02 | 1.2 | 1.20 | BDL | 0.5 |
| Benzo(ghi)Perylene | 12 | 10 | 1.09 | 1.6 | 1.90 | BDL | 0.5 |

BDL = below detection limit; analyte was not identified and quantified below the detection threshold

NOTE: high-volume sampler using quam or glass fiber filter to collect particle-adsorbed PAHs

NOTE: Detection limit shown is the lowest detection limit reported by the laboratory for the individual an
 Sampler Flow Rate: @ 300 liters/min

CAMP THUNDEROCK

POLYCYCUC AROMATIC HYDROCARBONS (EPA METHOD TO-1 3)
 Normal (ng/m3)

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ng/m3) | | | | ANALYTICAL DETECTION LIMIT (ug) |
|-----------------------|-------------------|-----|-----------------------|--------|------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | 95th | MAX | MIN | |
| Naphthalane | 11 | 3 | 722 | 2170 | 2135 | BDL | 2 |
| P-Methyl Naphthalene | 11 | 4 | 61.7 | 203.1 | 242 | BDL | 2 |
| 1-Methyl Naphthalene | 11 | 2 | 157 | 432.7 | 546 | BDL | 2 |
| Biphenyl | 11 | 2 | 41.4 | 185.9 | 265 | BDL | 2 |
| Dimethyl Naphthalena | 11 | 1 | 70.7 | 179.9 | 230 | BDL | 2 |
| Acenaphthylene | 11 | 0 | 1275 | 3449.7 | 3675 | 227 | 2 |
| Acenaphthene | 11 | 11 | 11.20 | 33.0 | BDL | BDL | 2 |
| Dibenzofuran | 11 | 2 | 83.4 | 239.5 | 261 | BDL | 2 |
| fluorene | 11 | 3 | 31.9 | 99.5 | 110 | BDL | 2 |
| Phenanthrene | 11 | 4 | 11.2 | 29.2 | 37.9 | BDL | 2 |
| Anthracene | 11 | 11 | 11.00 | 33.8 | BDL | BDL | 2 |
| Carbazole | 11 | 11 | 11.20 | 33.8 | BDL | BDL | 2 |
| Fluoranthene | 11 | 4 | 7.80 | 21.7 | 24.0 | BDL | 0.5 |
| Pyrene | 11 | 1 | 5.10 | 11.2 | 13.9 | BDL | 0.5 |
| Benzo(a)Anthracene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Chrysene | 11 | 10 | 0.900 | 1.2 | 1.30 | BDL | 0.5 |
| Benzo(b)Fluoranthene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(k)Fluoranthene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(e)Pyrene | 11 | 11 | 0.800 | 1.0 | 8DL | BDL | 0.5 |
| Benzo(a)Pyrene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Ideno(1,2,3-cd)Pyrene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(ghi)Perylene | 11 | 11 | 0.800 | 1.0 | BDL | BDL | 0.5 |

BDL = below detection limit: analyte was not identified and quantified below the detection threshold

NOTE: high-volume sampler using quam or glass fiber filter to collect particle-adsorbed PAHs

NOTE: Detection limit shown is the lowest detection limit reported by the laboratory for the individual an

Sampler Flow Rate: @ 300 liters/min

MILITARY HOSPITAL
POLYCYCLIC AROMATIC HYDROCARBONS (EPA METHOD TO-13)
Normal (ng/m3)

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ng/m3) | | | | ANALYTICAL DETECTION LIMIT (ug) |
|------------------------|-------------------|-----|-----------------------|--------|--------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | 95th | MAX | MIN | |
| Naphthalene | 10 | 2 | 815 | 1806.0 | 2031.9 | BDL | 2 |
| 2-Methyl Naphthalene | 10 | 2 | 69.8 | 180.2 | 189 | BDL | 2 |
| 1-Methyl Naphthalene | 10 | 2 | 175 | 430.7 | 385 | BDL | 2 |
| Biphenyl | 10 | 2 | 24.8 | 55.0 | 62.10 | BDL | 2 |
| Dimethyl Naphthalene | 10 | 2 | 77.0 | 198.1 | 224 | BDL | 2 |
| Acenaphthylene | 10 | 1 | 1070 | 2638.3 | 2744 | BDL | 2 |
| Acenaphthene | 10 | 10 | 12.1 | 35.4 | BDL | BDL | 2 |
| Dibenzofuran | -10 | 0 | 70.4 | 180.8 | 199 | 2.8 | 2 |
| Fluorene | 10 | 0 | 42.1 | 80.2 | 72.6 | 5.1 | 2 |
| Phenanthrene | 10 | 4 | 8.30 | 15.9 | 15.0 | BDL | 2 |
| Anthracene | 10 | 10 | 12.0 | 35.4 | BDL | BDL | 2 |
| Carbazole | 10 | 10 | 12.1 | 35.4 | BDL | BDL | 2 |
| fluoranthene | 10 | 5 | 6.00 | 14.9 | 12.4 | BDL | 0.5 |
| Pyrene | 10 | 3 | 4.20 | 10.1 | 11.4 | BDL | 0.5 |
| Benzo(a)Anthracene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Chrysene | 10 | 9 | 1.0 | 3.1 | 4.50 | BDL | 0.5 |
| Benzo(b)Fluoranthene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(k)Fluoranthene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(e)Pyrene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Benzo(a)Pyrene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Indeno(1,2,3-cd)Pyrene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 10 | 10 | 1.80 | 1.0 | BDL | BDL | 0.5 |
| Benzo(ghi)Perylene | 10 | 10 | 0.800 | 1.0 | BDL | BDL | 0.5 |

BDL = below detection limit; analyte was not identified and quantified below the detection threshold
NOTE: high-volume sampler using quartz or glass fiber filter to collect particle-adsorbed PAHs
NOTE: Detection limit shown is the lowest detection limit reported by the laboratory for the individual an
Sampler Flow Bate: @ 300 liters/min

concentrations for each of the sampling sites. Using EPA Method TO-13 PAH samplers provided better collection and subsequent detection of the lower molecular weight PAHs. When the TO-13 PAH results are compared to the PAH particulate lower molecular weight results, there were more positive lower molecular weight PAH detects using the EPA Method TO-13. This was expected since the EPA Method TO-13 PAH sampling procedure is the referenced method for collection of PAHs in ambient air. For the PAH particulate data, it is postulated that the large volumes of air, which passed through the PM₁₀ filter media, stripped the lower molecular weight PAHs off the particulate matter collected on the filter. Thus, there were minimal positive detects of the lower molecular weight PAHs from the PM₁₀ filters. For both the high volume EPA Method TO-13 PAHs and high volume particulate PAHs, readers are referred to the sample population columns for each PAH pollutant to obtain the number of samples above the respective analytical detection limit.

f. ~~The results of EPA Method TO-13 PAHs~~ sampling using a low volume pump and both PUF and XAD-2[®] sorbents are presented in Tables B-5-1 and B-5-2. None of the PAHs were detected on any sample due to the high detection limit associated with the low volumes collected. Therefore, mean concentration values reported represent the concentration based on one-half of the analytical detection limit.

g. ~~Acid Gases~~ Approximately 370 acid gas samples were collected in Kuwait and Saudi Arabia during 1991. The acid gases analyzed include hydrochloric, sulfuric, nitric, acetic, and formic. The acid gas data are currently being revised and revalidated. Therefore, we will provide a complete and validated acid gas data set as an addendum to this final report. It is anticipated that the acid gas data will be forwarded by March 1994.

h. ~~Mercury~~ the mercury samples collected (approximately 160) at the Kuwait and Saudi Arabia sampling sites displayed concentrations ~~Wow~~ or just slightly above the analytical detection limit. Administrative and analytical data inspections showed the rear mercury tubes to contain a greater mass than the front tube when a positive mercury mass was detected. This fact makes the mercury data collected at the Kuwait and Saudi Arabia sampling sites suspect and subsequent data summaries were not generated.

i. Passive Dosimeter Data. Air sampling for pollution levels of nitrogen dioxide (NO₂), ozone (O₃), and sulfur dioxide (SO₂) were conducted using passive dosimeters. A description of the passive dosimeter sampling equipment is found in Appendix B of the interim report (reference SO). The passive dosimeter data were validated and summarized with respect to

* XAD-2 is a registered trademark of Rohm and Haas Corp., Philadelphia, Pennsylvania.

individual sample **concentration** levels and maximum concentration levels. **Figures B-25 through B-27 display the respective maximum NO₂, O₃, and SO₂ levels for the eight sampling sites. For comparison, the respective pollutant PSI values are depicted on the figures. The maximum passive dosimeter data collected in Kuwait and Saudi Arabia in 1991 were below the respective pollutant PSI values for all locations. Tables B-61 and B-6-2 (Annex B-6) contain the passive dosimeter statistics for each pollutant and respective sampling site.**

7. GEOGRAPHICAL INFORMATION SYSTEM PILOT PROJECT.

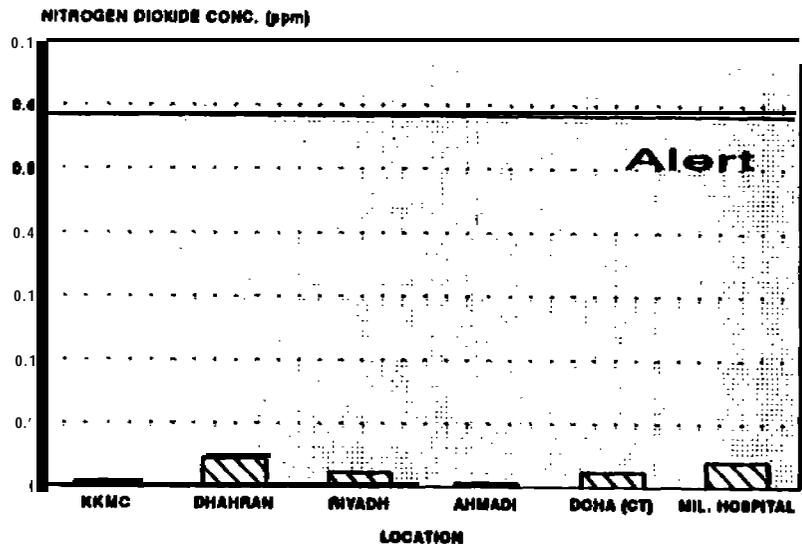
a. To support continued work efforts for the **overall Kuwait oil well fires health risk assessment**, the USAEEIA is applying a GIS to integrate all required databases for **exposure determination. It is required that all DOD military and civilian personnel who served in Operation Desert Storm be included in a medical registry which contains exposure information from the Kuwait oil well fires** (reference 52).

b. **A GIS is a computer hardware and software system which is used to input, store, retrieve, manipulate, analyze, and plot geographically referenced digital data. The GIS is a computerized database that integrates digital graphic depictions of geographic features with tabular format feature attributes. The tabular feature attribute data are attached and integrated with the graphics so that all the tabular and graphic data becomes interactive and instantly accessible. A primary operation is to perform a query on the GIS database. A query is a defined search of database records meeting specified criteria. This query enables sophisticated spatial data analysis to be performed between multiple types of graphic or map layers.**

c. The **USAEHA used a GIS on a limited geographic region of southwest Asia to demonstrate that troop unit exposure and subsequent risk can be determined. In general, the GIS pilot project database contains data types to include the air sampling data collected in Kuwait and Saudi Arabia during May 1991; modeled air concentration data for May 1991; troop unit movement data; and satellite imagery data. A workflow procedure was developed which integrates each of the above data sets. Subsequent database queries were performed which assigned risk values to specific troop units who met predefined query conditions to include king under the influence of the oil well fire plumes. Figure B-28 depicts the USAEHA GIS pilot project workflow diagram. A more detailed explanation of the USAEEIA GIS pilot project is found in Annex B-7.**

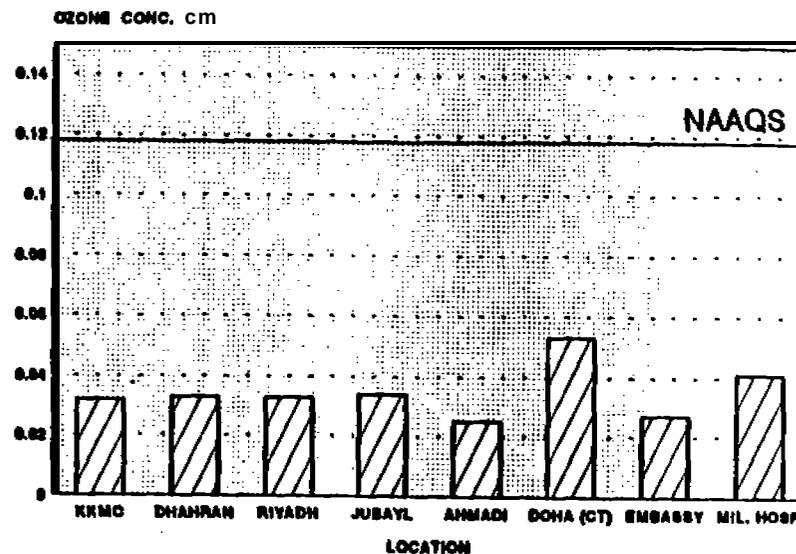
8. KUWAIT/SAUDI ARABIA NOVEMBER 1993 RETURN TRIP AIR DATA. The May - December 1991 air sampling effort was performed during or subsequent to the Kuwait oil well fires. These results reflected both contributions of the well fires and anthropogenic sources. An additional air and soil sampling effort was conducted in Kuwait and Saudi Arabia in November 1993 to provide additional information on post oil well fire ambient air

MAXIMUM NITROGEN DIOXIDE CONCENTRATIONS (ppm)
KUWAIT AND SAUDI ARABIA, 1991
 (PASSIVE DOBIMETER DATA)



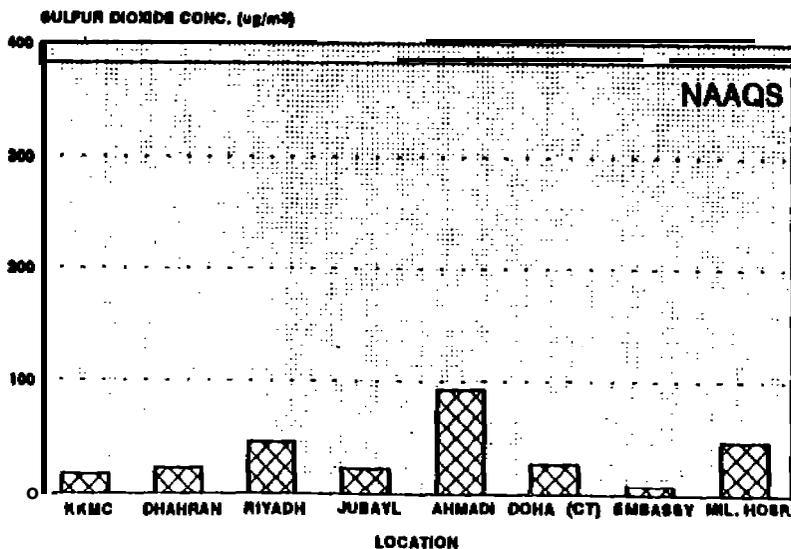
December 1993
 USAEHA/APED
 Figure B-25.

MAXIMUM OZONE CONCENTRATIONS (ppm)
KUWAIT AND SAUDI ARABIA, 1991
 (PASSIVE DOBIMETER DATA)



December 1993
 USAEHA/APED
 Figure B-26.

MAXIMUM SULFUR DIOXIDE CONCENTRATIONS (ug/m3)
KUWAIT AND SAUDI ARABIA, 1991
 (PASSIVE DOBIMETER DATA)



December 1993
 USAEHA/APED
 Figure O-27.

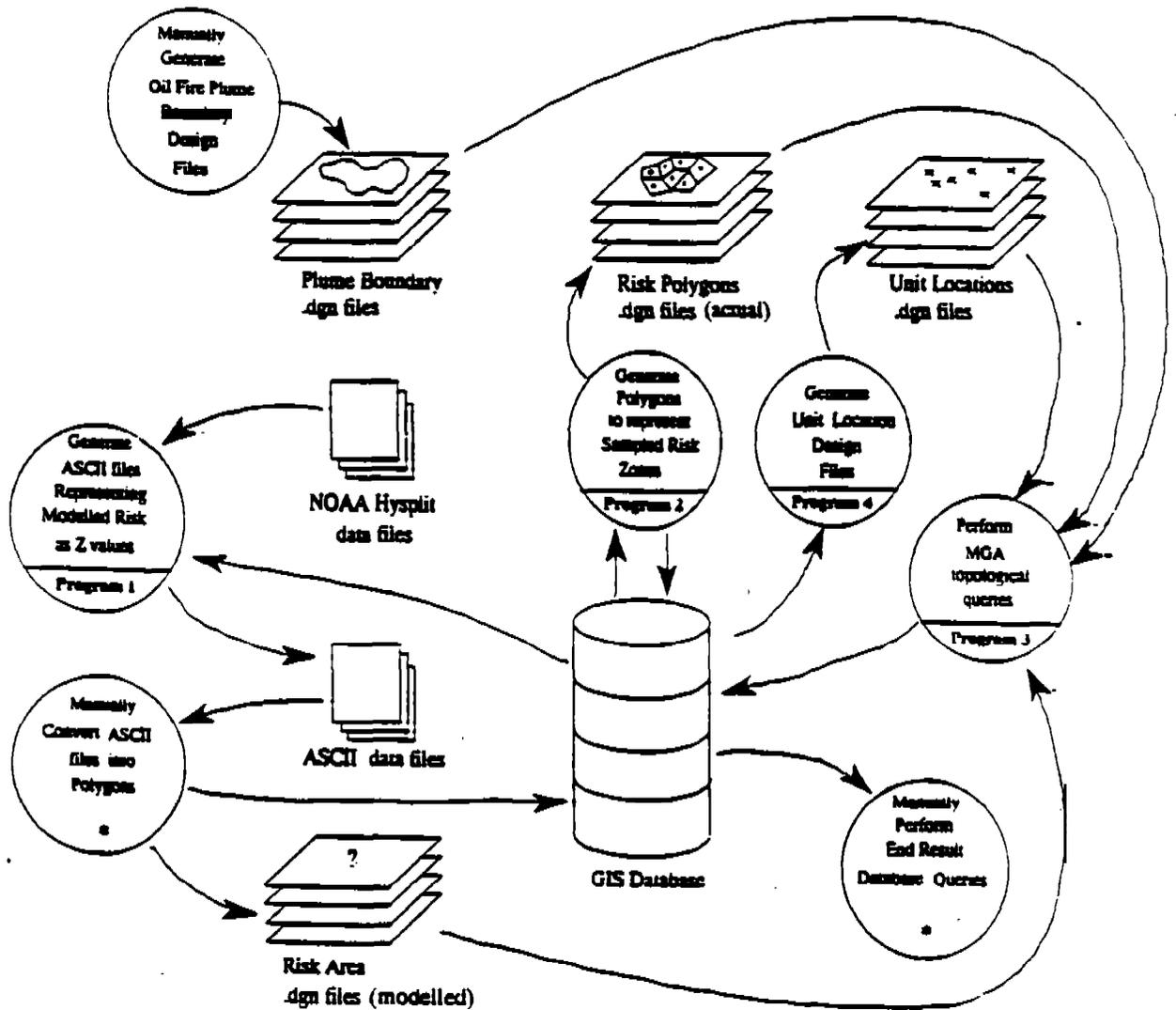


Figure B-28. GIS Pilot Project Workflow

concentrations and levels of hexavalent chromium present in both sample media. As of this writing, the **Kuwait/Saudi Arabia return trip air data** has **been** input to **applicable Lotus spreadsheets**. Validation and subsequent **summarization** of the data **will be performed during the 2nd quarter of fiscal year (FY) 1994**. The **return trip air concentration data will be provided as an addendum** by the end of March 1994. **Additional return trip air sampling information** to include **sampling dates, sampling equipment used, and number of samples collected** is found in Anna B-8.

9. RESPONSE TO **REVIEWERS' COMMENTS**. **The USAEHA asked** several agencies to review the Interim Kuwait **Health Risk Assessment report**. **These agencies** included the Departments of Navy and Air Force; **EPA**; National Institute of Standards and Technology; National **Oceanic and Atmospheric Administration**; **Department of Health and Human Services**; National **Institutes of Health**; National **Science Found&on**; Department of Veterans **Affairs**; and the National **Research Council**. **The USAEHA Air Pollution Engineering Division compiled pertinent responses to comments** which **contained air issues**. **These comments** are contained in **Appendix I** of the Final Kuwait **Health Risk Assessment** report.

10. CONCLUSIONS.

a. Ambient air sampling was conducted in Kuwait and Saudi Arabia from May through **December 1991** for various **pollutants** emitted from the **Kuwait oil well fires**. Approximately **4,000 ambient air samples were collected during this period from eight fixed sampling locations** and two **temporary sampling locations**. The **resulting ambient air concentrations for all fixed sampling sites were revised to incorporate changes in the statistical methods used to derive the 95 UCL levels and also represent the 16 September - 4 December 1991 sampling period** not covered in the interim **report**.

b. The VOC concentrations **observed in the long-term Kuwait sampling sites** of Camp **Thunderrock** and the **Military Hospital** displayed similar values. During May - August 1991 VOC concentration levels **were low as compared to the September - November 1991 period**. **The higher September - November 1991 VOC levels are probably a result of industrial activities and processes returning to Kuwait**.

c. For the Kuwait air **sampling sites**, the highest **sulfate, nitrate, and chloride concentrations** were observed at the **Ahmadi Hospital**. For **the Saudi Arabia sampling sites**, the highest **sulfate, nitrate, and chloride concentrations** were **observed at Jubayl**.

d. **The PM₁₀ concentration levels decreased** through May - November 1991 for the long-term air sampling sites. The elevated **PM₁₀ levels** are a result of **sand storms** contributing to the overall **PM₁₀ levels** and coincide with the **Shamal wind season**. A **majority** of the daily **PM₁₀ concentration levels** observed at the **sampling sites exceed** the **PM₁₀ 24-hour NAAQS**. **There were** instances when the daily **PM₁₀ concentrations exceeded** the EPA **significant harm PSI level**.

e. Nickel and vanadium ambient **air concentrations** displayed varying tendencies over time at the sampling sites. The nickel **levels** generally remain **constant**. The vanadium levels generally **decreased over time and tended to remain at levels associated with the compound's lowest analytical detection limit** after the extinguishment of the oil well **fires**.

f. For all three long-term **sampling sites**, the total chromium concentration levels generally **decreased** over time. The lead concentration levels **increased** over time at the Kuwait air sampling sites due to the return of vehicle emissions of which contain **lead** in the fuel. **The lead concentration levels remained relatively amstant** at the Saudi **Arabia sampling locations**.

g. There were minimal PAH **particulate** detections above the respective pollutant's **analytical detection limit**. **From** the three longest **running** sampling sites, Camp **Thunderrock** displayed the highest overall PAH **particulate concentrations**, while the **Military Hospital location** displayed the **lowest PAH particulate concentrations**. The PAH **data** collected from the EPA Method **TO-13** samplers provided **better** collection and subsequent detection of the lower molecular weight **PAHs** when compared to the PAH **particulate data**.

h. The acid gas data is currently being revised and revalidated. A complete and **validated acid gas data set will be provided by March 1994 as an addendum to this final report**.

i. The mercury **concentration** data displayed levels below or just slightly above the **analytical detection limit**. **This data contains numerous suspect samples and are not summarized in this final report**.

j. The maximum **NO₂, O₃, and SO₂ concentration** levels collected using passive dosimeters were **below** the **PSI values** for all sampling **locations**.

k. **As of this writing, the USAEHA GIS pilot project has been completed with the exception of validating the output risk values**. Upon completion of validation procedure, the **GIS workflow** procedures will then **be** revised in order to cover both the entire sampling

period in which the oil well fires were ablaze and the geographic regions in which troop units operated for Operation Desert Storm. It is anticipated that the final USAEHA GIS Kuwait oil well fires health risk assessment will be completed by end of CY 94.

1. The Kuwait/Saudi Arabia 1993 return trip air concentration data will be provided as an addendum by March 1994.

m. An extensive literature review of studies associated with the Kuwait oil well fires has not been completed since the interim report was published. Many peer reviewed articles have been published in scientific journals. A comprehensive review of published articles could possibly provide additional information for the GIS portion of this project and pollutant concentration comparisons to USAEHA data.

11. RECOMMENDATIONS.

a. Continue work on the final comprehensive portion of the health risk assessment using the GIS for the entire sampling period for which the oil well fires were ablaze and the geographic regions in which troop units operated for Operation Desert Storm.

b. Perform a comprehensive literature review of studies associated with the Kuwait oil well fires.

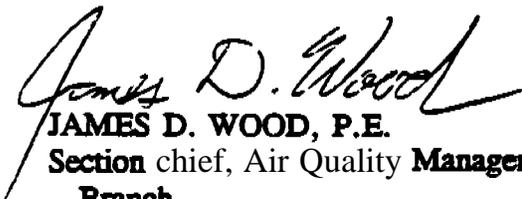


JEFFREY S. KIRKPATRICK

Meteorologist

Air Pollution Engineering Division

APPROVED:

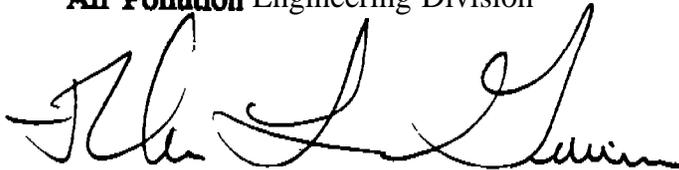


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ANNEX B-1

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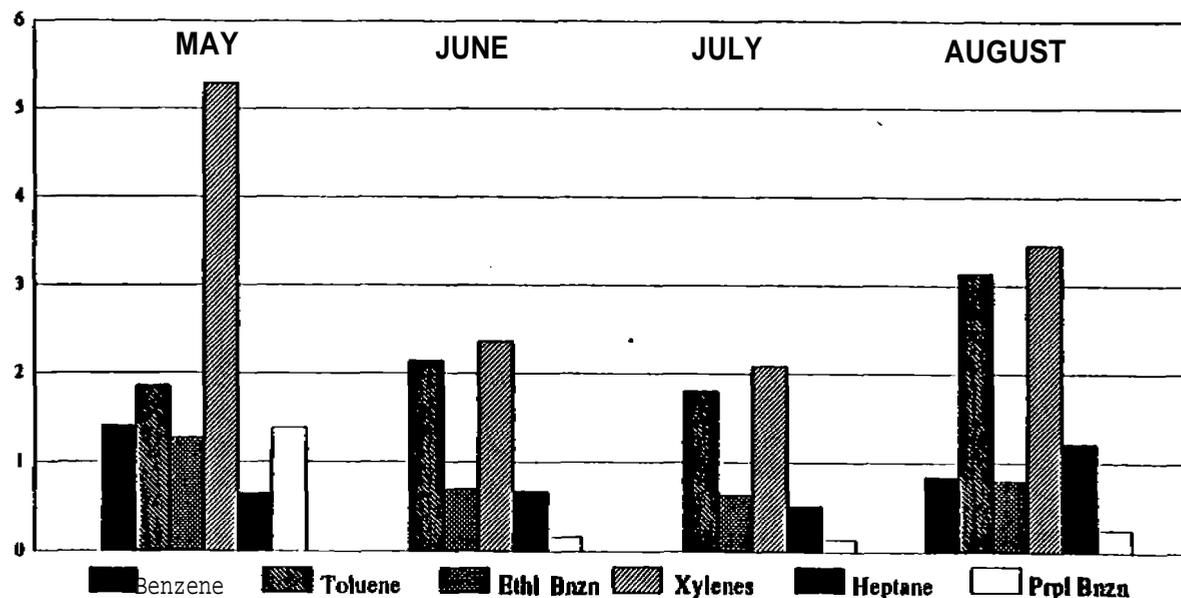
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ANNEX B-2

VOC CONCENTRATION SUMMARIES

TABLE B-2-1.

| TO-1: KKMC | | | | | | | | | | | | | | | | |
|--|-------|------|-------|-------|-------|-------|--------|------|-----------|------|---------|------|----------|------|---------|-------|
| VOLATILE ORGANIC COMPOUNDS (EPA METHOD TO-1, TENAX) (ug/m3) | | | | | | | | | | | | | | | | |
| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| Benzene | 1.42 | 3.81 | NA | NA | NA | NA | 0.660 | NA | | | | | | | 1.31 | 3.20 |
| Toluene | 1.87 | 3.12 | 2.14 | 6.64 | 1.81 | 4.63 | 3.14 | 11.2 | | | | | | | 2.18 | 1.92 |
| Ethyl Benzene | 1.27 | 10.7 | 0.703 | 1.87 | 0.830 | 1.58 | 0.800 | 2.68 | | | | | | | 0.792 | 2.51 |
| m,p-Xylene | 3.46 | 9.8 | 1.72 | 4.80 | 1.48 | 3.68 | 2.87 | 10.0 | | | | | | | 2.14 | 2.25 |
| o-Xylene | 1.44 | 6.64 | 0.866 | 1.90 | 0.697 | 1.38 | 0.800 | 2.68 | | | | | | | 0.883 | 2.30 |
| Heptane | 0.863 | 0.08 | 0.882 | 1.70 | 0.616 | 1.82 | 1.22 | 2.76 | | | | | | | 0.723 | 1.81 |
| n-Propyl Benzene | 1.39 | 6.60 | 0.164 | 0.388 | 0.133 | 0.310 | 0.242 | 0.82 | | | | | | | 0.393 | 0.82 |
| Non-target analytes | NA | NA | 15.2 | 37.20 | 12.1 | 33.6 | 18.6 | 60.8 | | | | | | | 14.8 | 40.52 |

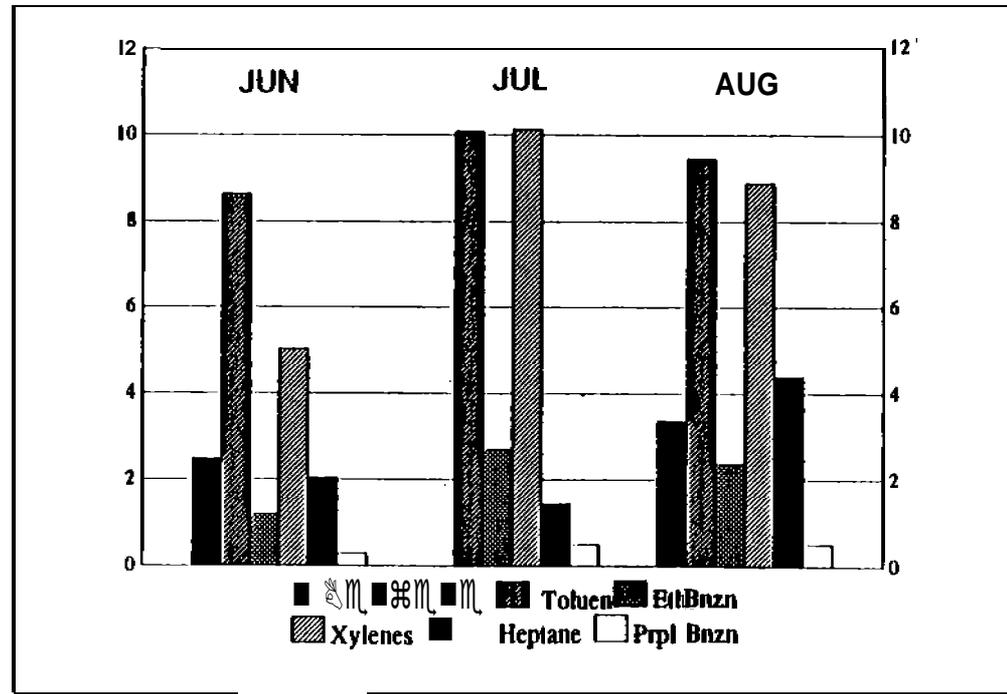


Sample collection averaging time: 12 - 30 hours
 NA = no valid samples analyzed for this compound

B-2-2

TABLE B-2-2.

| 10-1: ESKAN VILLAGE | | | | | | | | | | | | | | | | |
|---|------|------|-------|-------|-------|------|--------|------|-----------|------|---------|------|----------|------|---------|-------|
| VOLATILE ORGANIC COMPOUNDS (EPA METHOD TO-1, TENAX) | | | | | | | | | | | | | | | | |
| (ug/m3) | | | | | | | | | | | | | | | | |
| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| Benzene | | | 2.50 | NA | NA | NA | 3.39 | 6.76 | | | | | | | 3.17 | 5.10 |
| Toluene | | | 6.85 | NA | 10.1 | 22.6 | 8.45 | 17.1 | | | | | | | 9.53 | 20.0 |
| Ethyl Benzene | | | 1.18 | 2.55 | 2.72 | 4.78 | 2.38 | 5.60 | | | | | | | 2.18 | 5.15 |
| m,p-Xylene | | | 3.67 | 8.6 | 7.33 | 13.1 | 6.34 | 10.8 | | | | | | | 6.12 | 13.3 |
| o-Xylene | | | 1.35 | 2.91 | 2.81 | 4.66 | 2.56 | 6.27 | | | | | | | 2.36 | 6.10 |
| Heptane | | | 2.04 | NA | 1.43 | 3.06 | 4.39 | 13.0 | | | | | | | 3.27 | 8.1 |
| n-Propyl Benzene | | | 0.29 | 0.508 | 0.496 | 0.93 | 0.602 | 0.92 | | | | | | | 0.44 | 0.850 |
| Non-target analytes | | | 24.16 | 39.8 | 29.3 | 61.7 | 66.0 | 145 | | | | | | | 34.60 | 66.4 |



B-2-3

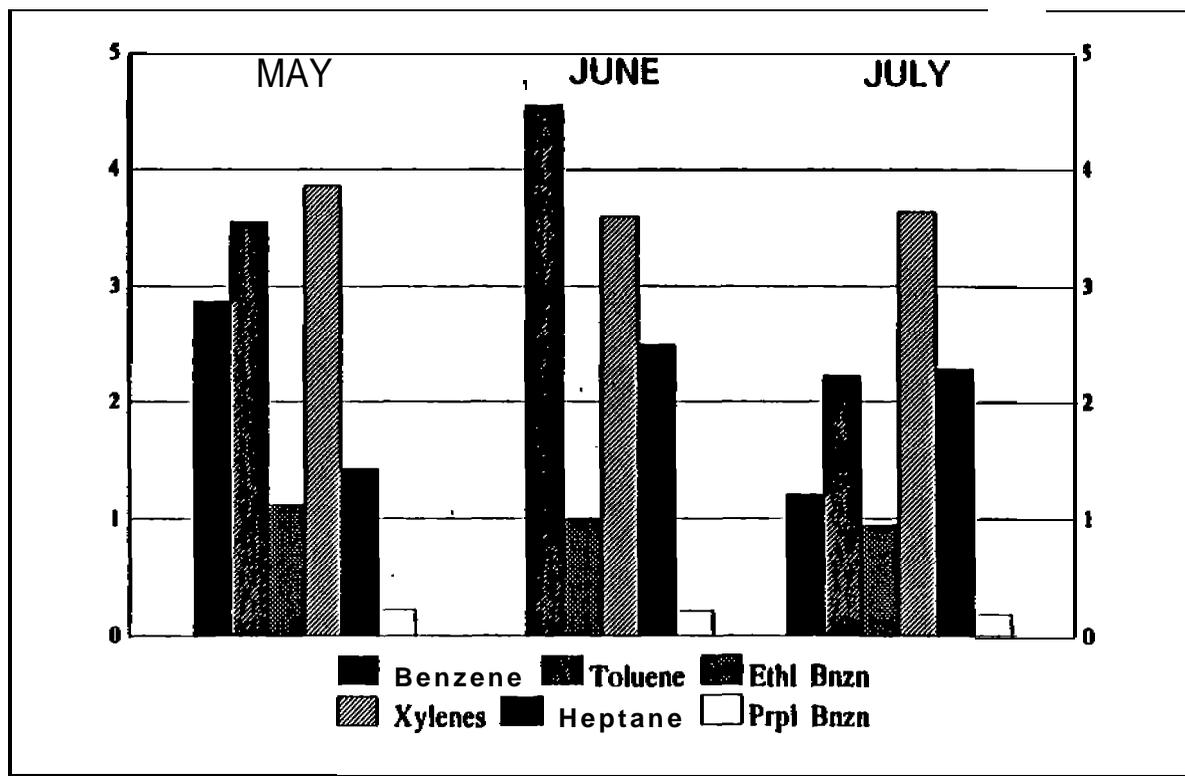
Sample collection (averaging time: 12.30 hours)
 NA = no valid samples analyzed for this compound

TABLE B-2-3.

TO-I: CAMP 1

VOLATILE ORGANIC COMPOUNDS (EPA METHOD TO-I, TENAX)
($\mu\text{g}/\text{m}^3$)

| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
|---------------------|-------|-------|-------|-------|-------|-------|--------|------|-----------|------|---------|------|----------|------|---------|-------|
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| Benzene | 2.87 | 10.04 | NA | NA | 1.21 | 1.62 | | | | | | | | | 2.60 | 7.60 |
| Toluene | 3.66 | 10.79 | 4.66 | 4.26 | 2.22 | 4.14 | | | | | | | | | 3.19 | 7.98 |
| Ethyl Benzene | 1.12 | 3.82 | 0.99 | 1.81 | 0.94 | 1.59 | | | | | | | | | 1.00 | 2.07 |
| m,p-Xylene | 2.77 | 9.27 | 2.69 | 4.90 | 2.07 | 4.74 | | | | | | | | | 2.67 | 6.11 |
| o-Xylene | 1.10 | 3.44 | 1.01 | 1.64 | 0.96 | 1.46 | | | | | | | | | 1.01 | 2.06 |
| Heptane | 1.43 | 3.69 | 2.49 | 4.06 | 2.29 | 7.20 | | | | | | | | | 1.89 | 4.96 |
| n-Propyl Benzene | 0.217 | 0.692 | 0.21 | 0.379 | 0.10 | 0.341 | | | | | | | | | 0.198 | 0.426 |
| Non-target analytes | 44.09 | 45.7 | 24.09 | 40.1 | 26.66 | 60.6 | | | | | | | | | 27.4 | 61.0 |



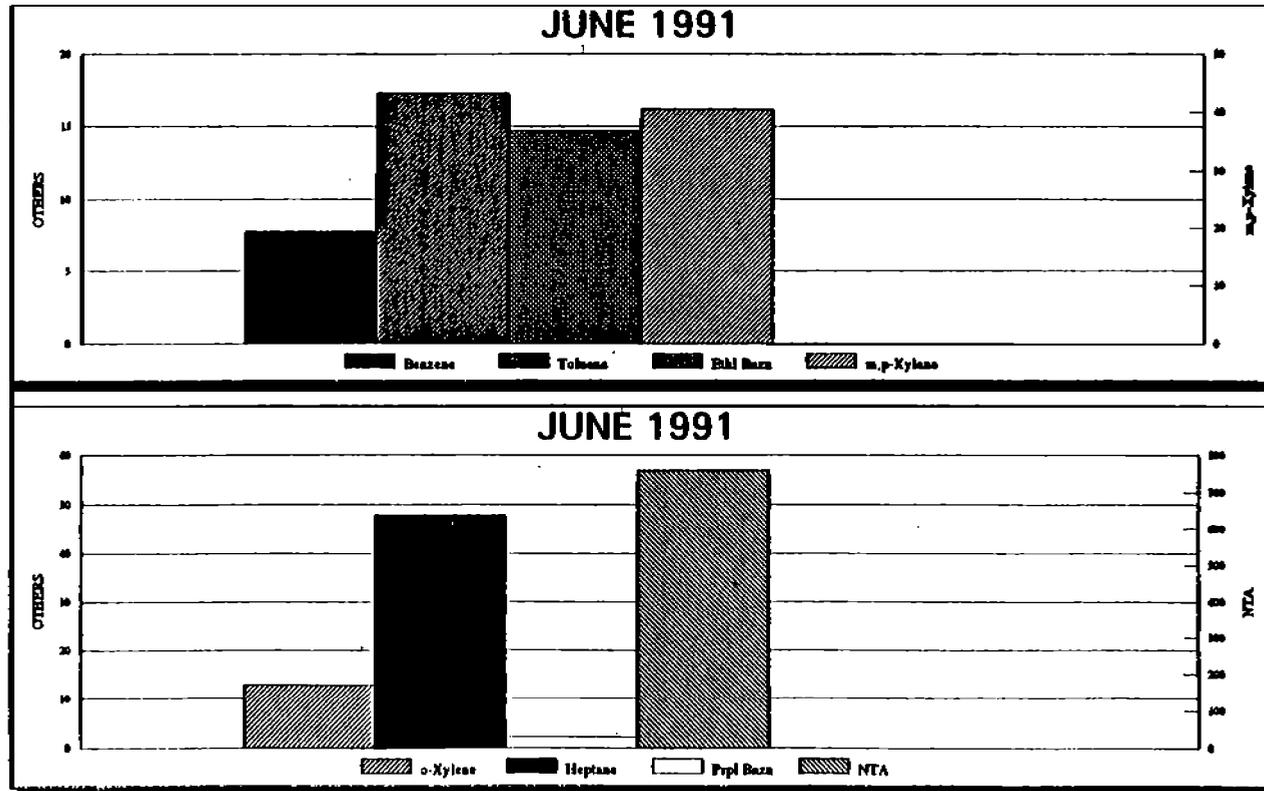
Sample collection averaging time: 12 - 30 hours
NA = no valid samples analyzed for this compound

B-2-4

TABLE B-2-4.

| TO-11: AL AHMADI HOSPITAL | | VOLATILE ORGANIC COMPOUNDS (EPA METHOD TO-1, TENAX) (ug/m3) | | | | | | | | | | | | | | |
|---------------------------|------|--|------|------|------|------|--------|------|-----------|------|---------|------|----------|------|---------|------|
| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| Benzene | | | 7.02 | 13.1 | | | | | | | | | | | 7.02 | 13.1 |
| Toluene | | | 17.3 | 30.0 | | | | | | | | | | | 17.3 | 30.0 |
| Ethyl Benzene | | | 14.7 | 41.2 | | | | | | | | | | | 14.7 | 41.2 |
| m,p-Xylene | | | 40.6 | 118 | | | | | | | | | | | 40.6 | 118 |
| o-Xylene | | | 12.8 | 30.4 | | | | | | | | | | | 12.8 | 30.4 |
| Heptane | | | 47.8 | 127 | | | | | | | | | | | 47.8 | 127 |
| n-Propyl Benzene | | | 2.18 | 4.40 | | | | | | | | | | | 2.18 | 4.40 |
| Non-target analytes | | | 760 | 1490 | | | | | | | | | | | 760 | 1490 |

B-2-5



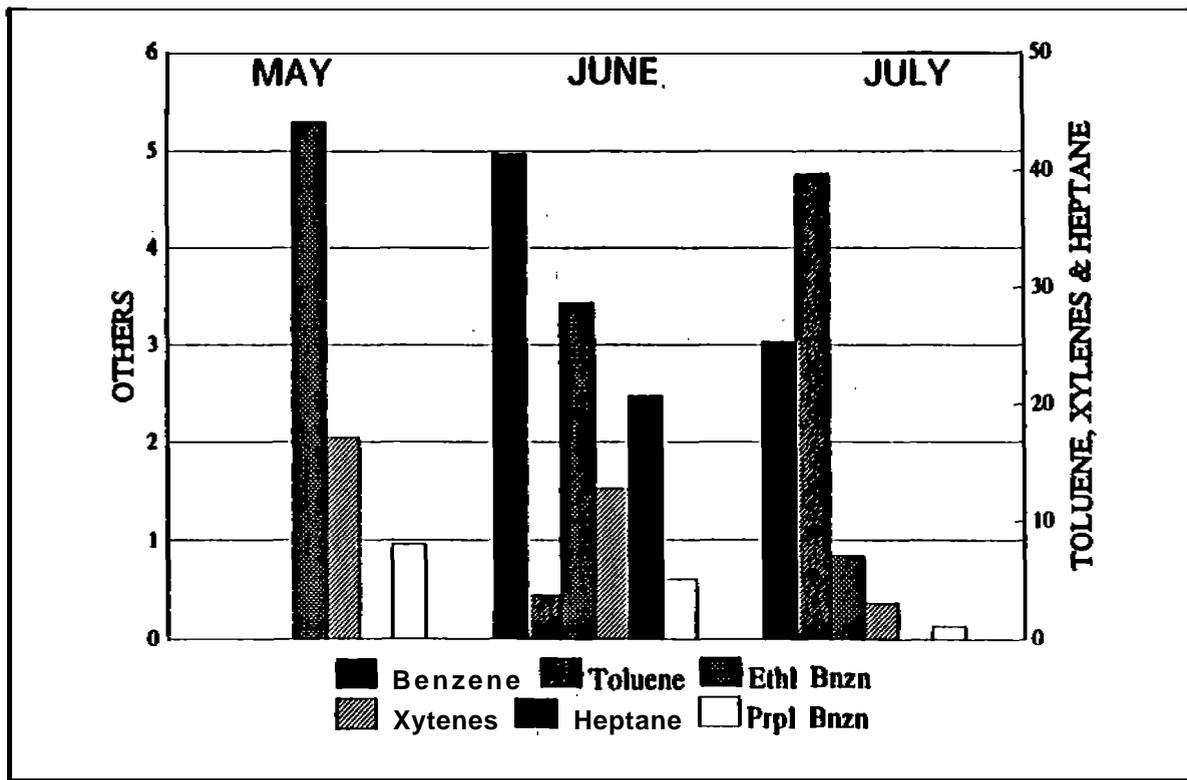
Sample collection averaging time: 12 . 30 hours
 NA = no valid samples analyzed for this compound

TABLE B-2-5.

TO-1: U.S. EMBASSY, KUWAIT

VOLATILE ORGANIC COMPOUNDS (EPA METHOD TO-1, TENAX)
[ug/m3]

| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
|------------------|-------|-------|------|------|-------|------|--------|------|-----------|------|---------|------|----------|------|---------|------|
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| Benzene | HA | NA | 4.97 | 11.8 | 3.0 | 4 NA | | | | | | | | | 4.33 | 8.7 |
| Toluene | NA | NA | 3.74 | NA | 39.0 | NA | | | | | | | | | 21.76 | 190 |
| Ethyl Benzene | 8.30 | 11.4 | 3.44 | 26.6 | 0.840 | NA | | | | | | | | | 3.66 | 15.1 |
| m,p-Xylene | 12.0 | 27.6 | 8.87 | 78 | 2.26 | NA | | | | | | | | | 8.78 | 36.9 |
| o-Xylene | 6.08 | 11.8 | 3.80 | 29.5 | 0.760 | NA | | | | | | | | | 3.76 | 16.4 |
| Heptane | NA | NA | 20.7 | NA | HA | NA | | | | | | | | | 20.73 | NA |
| n-Propyl Benzene | 0.960 | 1.93 | 0.60 | 2.01 | 0.130 | NA | | | | | | | | | 0.640 | 2.40 |
| Non-targets | 47.3 | 114.2 | 222 | 702 | NA | NA | | | | | | | | | 134.7 | 498 |

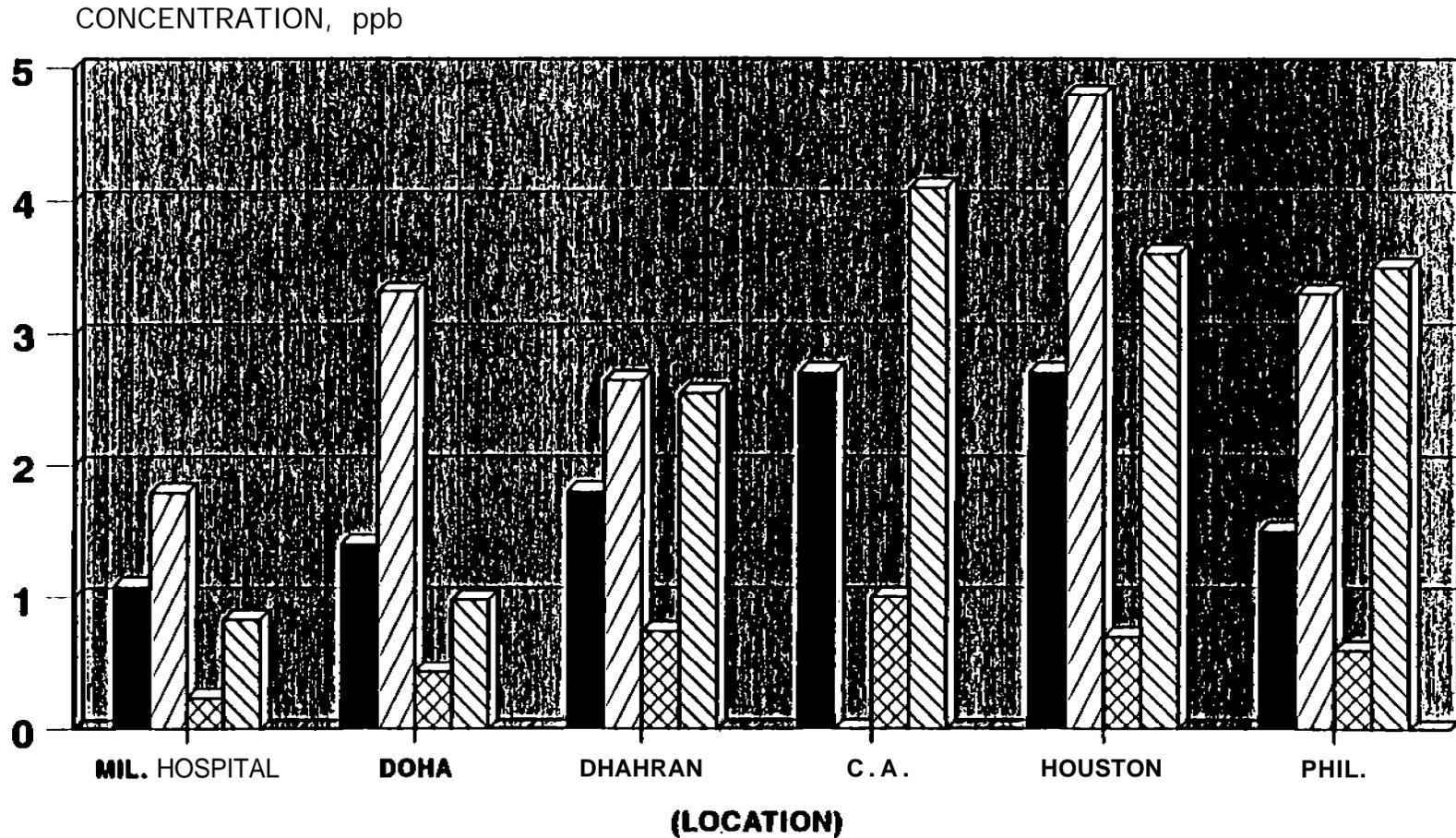


Sample collection averaging time: 12 - 30 hours
NA = no valid sample analyzed for this compound

B-2-6

MEDIAN ORGANIC CONCENTRATION COMPARISONS; KUWAIT, SAUDI ARABIA AND SELECTED U.S. CITIES

Figure B-2-1.



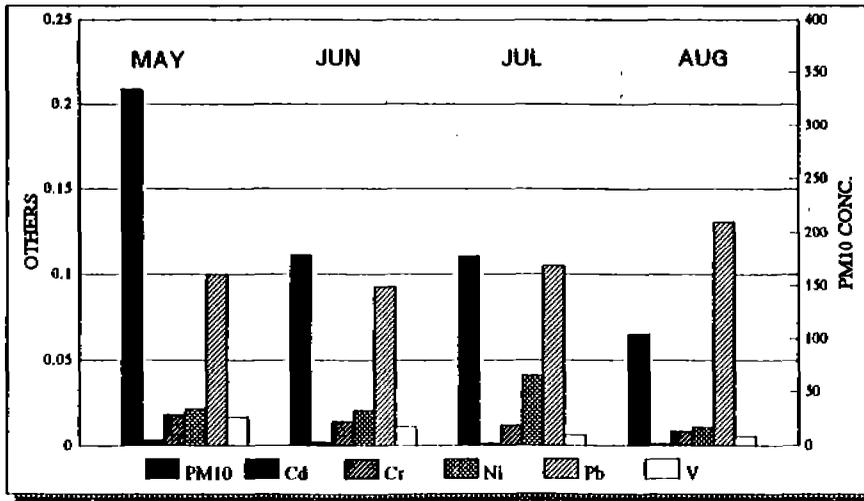
B-2-7

ANNEX B-3

PM₁₀ AND METALS CONCENTRATION SUMMARIES

TABLE B-3-1.

| PM 10 AND METALS DATA (HI-VOLUME REFERENCE METHOD) (ug/m3) | | | | | | | | | | | | | | | | |
|---|--------|--------|--------|--------|--------|--------|--------|--------|-----------|------|---------|------|----------|--------|---------|------|
| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
| | MEAN | 95TH | MEAN | 95TH | MEAN | B5TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| PM10 (Mass Conc.) | 334 | 887 | NA3 | 377 | 177 | 283 | 104 | 180 | | | | | 188 | 355 | | |
| Aluminum (Al) | NA | NA | NA | NA | NA | NA | 1.83 | 2.89 | | | | | 1.83 | 2.89 | | |
| Arsenic (As) | NA | NA | NA | NA | NA | NA | 0.0065 | 0.0014 | | | | | 0.0007 | 0.0014 | | |
| Beryllium (Be) | NA | NA | NA | NA | NA | NA | 0.0015 | 0.0030 | | | | | 0.0015 | 0.0030 | | |
| Calcium (Ca) | NA | NA | NA | NA | NA | NA | 13.8 | 21.3 | | | | | 13.8 | 21.3 | | |
| Cadmium (Cd) | 0.0034 | 0.0112 | 0.0022 | 0.0051 | 0.0018 | 0.0035 | 0.0011 | 0.0019 | | | | | 0.0020 | 0.0049 | | |
| Chromium (Cr) | 0.0177 | 0.0301 | 0.0141 | 0.0302 | 0.0117 | 0.0194 | 0.0084 | 0.0153 | | | | | 0.0130 | 0.0282 | | |
| Iron (Fe) | NA | NA | NA | NA | NA | NA | 1.65 | 3.18 | | | | | 1.65 | 3.18 | | |
| Magnesium (Mg) | NA | NA | NA | NA | NA | NA | 2.39 | 3.77 | | | | | 2.39 | 3.77 | | |
| Sodium (Na) | NA | NA | NA | NA | NA | NA | 10.88 | 14.35 | | | | | 10.88 | 14.35 | | |
| Nickel (Ni) | 0.0213 | 0.0729 | 0.0203 | 0.0540 | 0.0404 | 0.1522 | 0.0108 | 0.0280 | | | | | 0.0232 | 0.0709 | | |
| Lead (Pb) | 0.100 | 0.342 | 0.093 | 0.187 | 0.105 | 0.177 | 0.131 | 0.293 | | | | | 0.104 | 0.234 | | |
| Vanadium (V) | 0.0162 | 0.0495 | 0.0110 | 0.0291 | 0.0080 | 0.0114 | 0.0054 | 0.0095 | | | | | 0.0098 | 0.0234 | | |
| Zinc (Zn) | 0.0460 | 0.0970 | 0.0349 | 0.0559 | 0.0259 | 0.0727 | 0.0741 | 0.3190 | | | | | 0.0422 | 0.1102 | | |



Sample collection averaging time: 12-30 hours
 NA analysis performed for this analyte

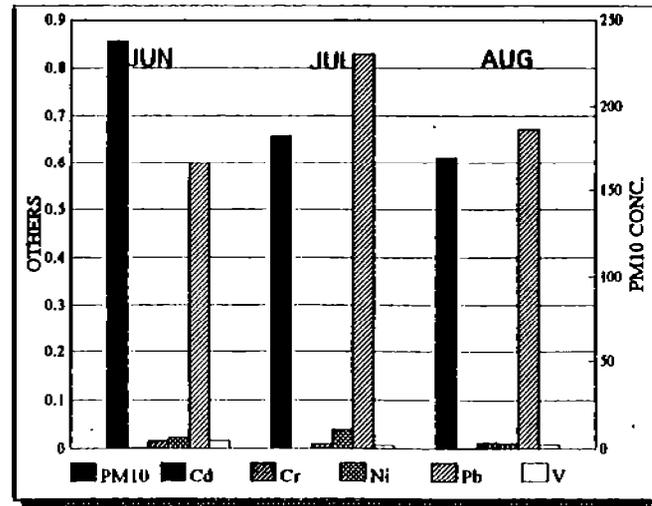
B-3-2

PM10 - WASKAN VILLAGE

PM10 AND METALS DATA (HI-VOLUME REFERENCE METHOD)
(ug/m3)

| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
|--------------------|------|------|--------|--------|--------|--------|--------|--------|-----------|------|---------|------|----------|------|---------|--------|
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| PM 10 (Mass Conc.) | | | 238 | 489 | 183 | 348 | 170 | 247 | | | | | | | 205 | 362 |
| Aluminum (Al) | | | NA | NA | NA | NA | 2.75 | 5.88 | | | | | | | 2.75 | 5.89 |
| Arsenic (As) | | | NA | HA | NA | NA | 0.0009 | 0.0024 | | | | | | | 0.0009 | 0.0024 |
| Beryllium (Be) | | | NA | NA | NA | NA | 0.0022 | 0.0043 | | | | | | | 0.0022 | 0.0043 |
| Calcium (Ca) | | | NA | NA | NA | NA | 24.5 | 38.9 | | | | | | | 24.5 | 36.9 |
| Cadmium (Cd) | | | 0.0026 | 0.0056 | 0.0012 | 0.0013 | 0.0022 | 0.0049 | | | | | | | 0.0022 | 0.0045 |
| Chromium (Cr) | | | 0.0180 | 0.0453 | 0.0100 | 0.0250 | 0.0127 | 0.0211 | | | | | | | 0.0142 | 0.0330 |
| Iron (Fe) | | | NA | NA | NA | NA | 2.32 | 4.37 | | | | | | | 2.32 | 4.37 |
| Magnesium (Mg) | | | NA | NA | NA | NA | 3.13 | 5.79 | | | | | | | 3.13 | 5.79 |
| Sodium (Na) | | | NA | NA | NA | NA | 11.49 | 18.59 | | | | | | | 11.49 | 16.59 |
| Nickel (Ni) | | | 0.0233 | 0.0566 | 0.0396 | 0.161 | 0.0110 | 0.0240 | | | | | | | 0.0236 | 0.0656 |
| Lead (Pb) | | | 0.000 | 1.598 | 0.830 | 1.588 | 0.872 | 1.016 | | | | | | | 0.075 | 1.544 |
| Vanadium (V) | | | 0.0162 | 0.0426 | 0.0089 | 0.0101 | 0.0088 | 0.0152 | | | | | | | 0.0119 | 0.0259 |
| Zinc (Zn) | | | 0.0683 | 0.1253 | 0.0420 | 0.1823 | 0.0694 | 0.2557 | | | | | | | 0.0014 | 0.2006 |

B-3



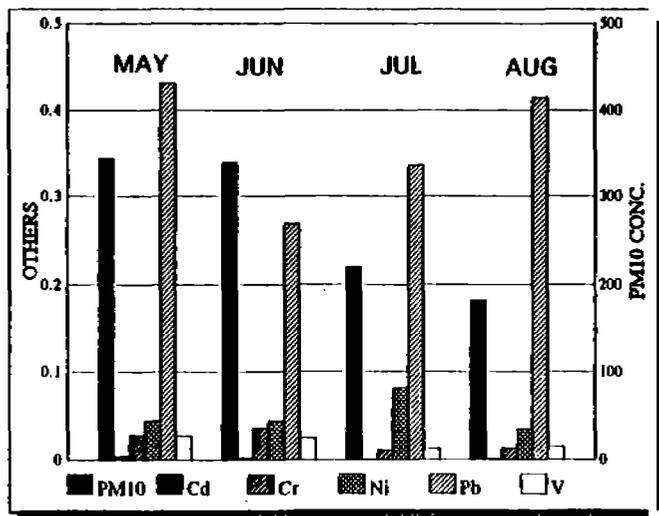
Sample collection averaging time: 12 - 30 hours

NA = no analysis performed for this analyte

NOTE: No valid PM 10 samples were collected from this site after August 1991

TABLE B-3-3.

| PM10: CAMP 1 | | | | | | | | | | | | | | | | |
|---|--------|--------|--------|--------|--------|--------|--------|--------|-----------|---|---------|------|----------|------|---------|--------|
| PM10 AND METALS DATA (HI-VOLUME REFERENCE METHOD) | | | | | | | | | | | | | | | | |
| (ug/m3) | | | | | | | | | | | | | | | | |
| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | M | E | A | N | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN |
| PM10 (Mass Conc.) | 345 | 914 | 340 | 831 | 220 | 378 | 182 | 390 | | | | | | | 300 | 585 |
| Aluminum (Al) | NA | NA | NA | NA | NA | NA | 1.78 | 4.12 | | | | | | | 1.78 | 4.12 |
| Arsenic (As) | NA | NA | NA | NA | NA | NA | 0.0008 | 0.0024 | | | | | | | 0.0008 | 0.0024 |
| Beryllium (Be) | NA | NA | NA | NA | NA | NA | 0.0017 | 0.0038 | | | | | | | 0.0017 | 0.0038 |
| Calcium (Ca) | NA | NA | NA | NA | NA | NA | 13.3 | 25.3 | | | | | | | 13.3 | 25.3 |
| Cadmium (Cd) | 0.0048 | 0.0124 | 0.0029 | 0.0078 | 0.0012 | 0.0021 | 0.0014 | 0.0027 | | | | | | | 0.0033 | 0.0088 |
| Chromium (Cr) | 0.0283 | 0.0709 | 0.0389 | 0.1384 | 0.0113 | 0.0223 | 0.0139 | 0.0374 | | | | | | | 0.0273 | 0.0758 |
| Iron (Fe) | NA | NA | NA | NA | NA | NA | 1.88 | 5.37 | | | | | | | 1.88 | 5.37 |
| Magnesium (Mg) | NA | NA | NA | NA | NA | NA | 2.58 | 4.69 | | | | | | | 2.58 | 4.69 |
| Sodium (Na) | NA | NA | NA | NA | NA | NA | 18.98 | 24.47 | | | | | | | 18.98 | 24.47 |
| Nickel (Ni) | 0.0449 | 0.1780 | 0.0448 | 0.1311 | 0.0818 | 0.1719 | 0.0349 | 0.2138 | | | | | | | 0.0502 | 0.1923 |
| Lead (Pb) | 0.431 | 0.875 | 0.269 | 0.481 | 0.337 | 0.563 | 0.415 | 0.837 | | | | | | | 0.360 | 0.693 |
| Vanadium (V) | 0.0280 | 0.0898 | 0.0257 | 0.0620 | 0.0125 | 0.0254 | 0.0150 | 0.0232 | | | | | | | 0.0237 | 0.0640 |
| Zinc (Zn) | 0.0895 | 0.1930 | 0.0662 | 0.1307 | 0.0148 | 0.0385 | 0.0535 | 0.1478 | | | | | | | 0.0667 | 0.2183 |



NA=no analysis performed for this analyte

Sample collection averaging time: 12-30 hours

NOTE: no PM10 samples were collected at this site after early August 1991

B-3-4

T B-3-4.

PM10 AMADI HOSPITAL

PM10 ANO METALS DATA (HI-VOLUME REFERENCE METHOD)
(ug/m3)

| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
|-------------------|------|------|--------|--------|--------|--------|--------|------|-----------|------|---------|------|----------|------|---------|--------|
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| PM10 (Mass Conc.) | | | 351 | 723 | 389 | 433 | | | | | | | | | 354 | 695 |
| Aluminum (Al) | | | NA | NA | NA | NA | | | | | | | | | NA | NA |
| Arsenic (As) | | | NA | NA | NA | NA | | | | | | | | | NA | NA |
| Beryllium (Be) | | | NA | NA | NA | NA | NA | | | | | | | | NA | NA |
| Calcium (Ca) | | | NA | NA | NA | NA | | | | | | | | | NA | NA |
| Cadmium (Cd) | | | 0.0031 | 0.0066 | 0.0030 | 0.0072 | | | | | | | | | 0.0031 | 0.0065 |
| Chromium (Cr) | | | 0.0152 | 0.0364 | 0.0287 | 0.0505 | | | | | | | | | 0.0173 | 0.0423 |
| Iron (Fe) | | | NA | NA | NA | NA | | | | | | | | | NA | NA |
| Magnesium (Mg) | | | NA | NA | NA | NA | | | | | | | | | NA | NA |
| Sodium (Na) | | | NA | NA | NA | NA | | | | | | | | | NA | NA |
| Nickel (Ni) | | | 0.0234 | 0.0511 | 0.0472 | 0.0983 | | | | | | | | | 0.0269 | 0.0619 |
| Lead (Pb) | | | 0.168 | 0.298 | 0.129 | 0.136 | | | | | | | | | 0.162 | 0.227 |
| Vanadium (V) | | | 0.0274 | 0.0597 | 0.0288 | 0.0398 | | | | | | | | | 0.0276 | 0.0579 |
| Zinc (Zn) | | | 0.0059 | 0.1202 | 0.0526 | 0.0657 | | | | | | | | | 0.0639 | 0.1123 |

NA = no analysis performed for this analyte
Sample collection averaging time: 12-30 hours

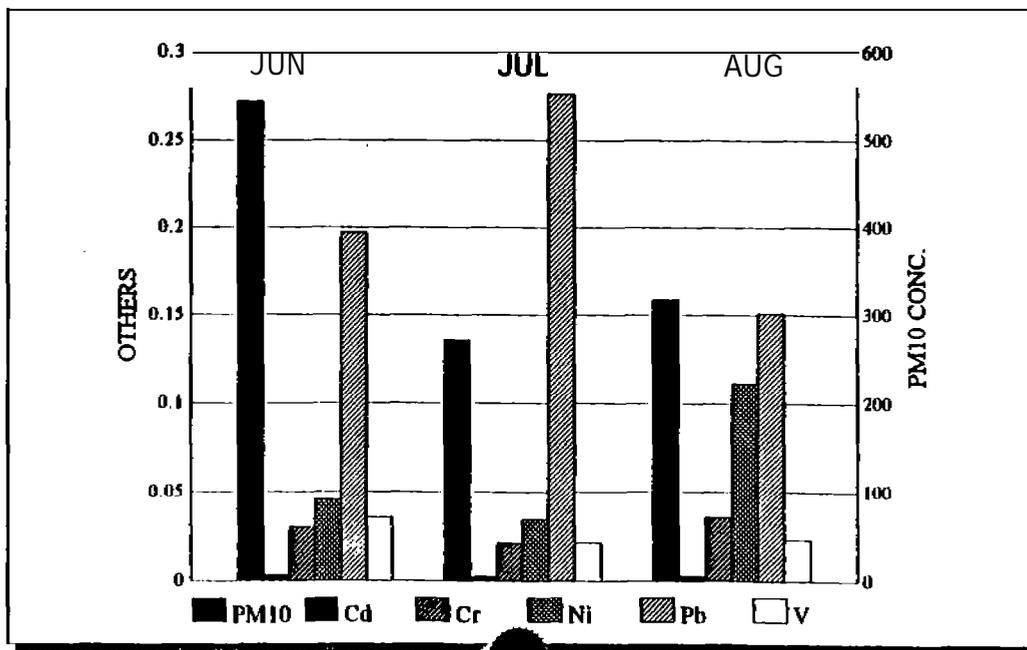
B-3-5

TABLE B-3-5.

PM10: U.S. EMBASSY

PM10 AND METALS DATA (HI-VOLUME REFERENCE METHOD)
(ug/m3)

| ANALYTE | MAY | | JUNE | | JULY | | AUGUST | | SEPTEMBER | | OCTOBER | | NOVEMBER | | OVERALL | |
|--------------------|--------|--------|--------|--------|--------|--------|--------|------|-----------|------|---------|------|----------|--------|---------|------|
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| PM 10 (Mass Conc.) | 544 | 1581 | 272 | 549 | 318 | 671 | | | | | | | | | 351 | 706 |
| Aluminum (Al) | NA | NA | NA | NA | NA | NA | | | | | | | | | NA | NA |
| Arsenic (As) | NA | NA | NA | NA | NA | NA | | | | | | | | | NA | NA |
| Beryllium (Be) | NA | NA | NA | NA | NA | NA | | | | | | | | | NA | NA |
| Calcium (Ca) | NA | NA | NA | NA | NA | NA | | | | | | | | | NA | NA |
| Cadmium (Cd) | 0.0034 | 0.0106 | 0.0028 | 0.0068 | 0.0032 | 0.0078 | | | | | | | | 0.0031 | 0.0077 | |
| Chromium (Cr) | 0.0304 | 0.0768 | 0.0217 | 0.0613 | 0.0357 | 0.0898 | | | | | | | | 0.0266 | 0.0726 | |
| Iron (Fe) | NA | NA | NA | NA | NA | NA | | | | | | | | NA | NA | |
| Magnesium (Mg) | NA | NA | NA | NA | NA | NA | | | | | | | | NA | NA | |
| Sodium (Na) | NA | NA | NA | NA | NA | NA | | | | | | | | NA | NA | |
| Nickel (Ni) | 0.0456 | 0.1594 | 0.0348 | 0.0987 | 0.1117 | 0.2672 | | | | | | | | 0.0516 | 0.1716 | |
| Lead (Pb) | 0.197 | 0.826 | 0.276 | 1.118 | 0.151 | 0.219 | | | | | | | | 0.232 | 0.855 | |
| Vanadium (V) | 0.0359 | 0.1184 | 0.0213 | 0.0510 | 0.0232 | 0.0677 | | | | | | | | 0.0256 | 0.0669 | |
| Zinc (Zn) | 0.0556 | 0.1465 | 0.0497 | 0.1075 | 0.0432 | 0.1193 | | | | | | | | 0.0495 | 0.1165 | |



NA = no sample is performed for this analyte
n averaging time: 12 - 30 hours

TABLE B-3-6. MAXIMUM AND MINIMUM PM₁₀ CONCENTRATIONS AND CORRESPONDING DATE(S) OF OCCURRENCE FOR EACH SAMPLE SITE

| PM ₁₀ CONCENTRATION (ug/m ³) | | |
|---|-----------------|----------------|
| SITE | MAXIMUM/DATE | MINIMUM/DATE |
| KKMC | 924/ 23 May 91 | 100/ 31 May 91 |
| KHOBAR | 1354/ 23 May 91 | 29/ 5 Nov 91 |
| RIYADH | 698/ 20 Jul 91 | 87/ 31 Jul 91 |
| JUBAYL | 1715/ 23 May 91 | 64/ 15 Jun 91 |
| AHMADI | 810/ 24 Jun 91 | 175/ 14 Jun 91 |
| CAMP THUNDEROCK | 1208/ 3 Oct 91 | 10/ 7 Nov 91 |
| MILITARY HOSPITAL | 1594/ 23 May 91 | 32/ 27 Nov 91 |
| EMBASSY | 1842/ 23 May 91 | 106/ 28 Jun 91 |

Final Rpt, Kuwait Oil Fire HRA No. 39-26-L192-91, 5 May - 3 Dec 91

ANNEX B-4

HIGH VOLUME PAH PARTICULATE CONCENTRATION SUMMARIES

TABLE B-4-1.

KKMC
POLYCYCLIC AROMATIC HYDROCARBONS (HI-VOL REFERENCE PM10 METHOD)
(ug/m3)

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ug/m3) | | | ANALYTICAL DETECTION LIMIT (ug) |
|-----------------------|-------------------|-----|-----------------------|---------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | MAX | MIN | |
| Naphthalene | 8 | 8 | 0.00399 | BDL | BDL | 20 |
| P-Methyl Naphthalene | 3 | 3 | 0.00376 | BDL | BDL | 20 |
| 1-Methyl Naphthalene | 2 | 2 | 0.00375 | BDL | BDL | 20 |
| Biphenyl | 3 | 3 | 0.00376 | BDL | BDL | 20 |
| Dimethyl Naphthalene | 3 | 3 | 0.00075 | BDL | BDL | 4 |
| Acenaphthylene | 8 | 8 | 0.00080 | BDL | BDL | 4 |
| Acenaphthene | 6 | 6 | 0.00030 | BDL | BDL | 1.5 |
| Dibenzofuran | 3 | 3 | 0.00023 | BDL | BDL | 1.5 |
| Fluorene | 8 | 8 | 0.00010 | BDL | BDL | 1.5 |
| Phenanthrene | 8 | 6 | 0.00023 | 0.00063 | BDL | 0.5 |
| Anthracene | 8 | 8 | 0.00017 | BDL | BDL | 0.5 |
| Carbazole | 3 | 3 | 0.00010 | BDL | BDL | 0.5 |
| Fluoranthene | 8 | 4 | 0.00083 | 0.00223 | BDL | 0.5 |
| Pyrene | 8 | 6 | 0.00018 | 0.00078 | BDL | 0.5 |
| Benzo(a)Anthracene | 8 | 7 | 0.00012 | | BDL | 0.5 |
| Chrysene | 8 | 7 | 0.00012 | 0.00029 | BDL | 0.5 |
| Benzo(b)Fluoranthene | 8 | 8 | 0.00010 | BDL | BDL | 0.5 |
| Benzo(k)Fluoranthene | 8 | 8 | 0.00010 | BDL | BDL | 0.5 |
| Benzo(e)Pyrene | 3 | 3 | 0.00010 | BDL | BDL | 0.5 |
| Benzo(a)Pyrene | 8 | 8 | 0.00010 | BDL | BDL | 0.5 |
| Ideno(1,2,3-cd)Pyrene | 8 | 7 | 0.00029 | 0.00025 | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 2 | 8 | 0.00010 | BDL | BDL | 0.5 |
| Benzo(ghi)Perylene | 8 | 2 | 0.00010 | BDL | BDL | 0.5 |

BDL = below detection limit: **analyte** was not identified and quantified below the detection threshold

NOTE: high-volume sampler using quam or glass fiber filter to collect particle-adsorbed **PAHs**

NOTE: Detection limit shown is the lowest detection limit reported by the **laboratory** for the individual **analyte**

Sampler Flow Rate: 0.7 - 2.1 m³/min

TABLE B-4-2.

ESKAN VILLAGE
POLYCYCLIC AROMATIC HYDROCARBONS (HI-VOL REFERENCE PM10 METHOD)
(ug/m³)

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ug/m ³) | | | ANALYTICAL DETECTION LIMIT (ug) |
|------------------------|-------------------|-----|------------------------------------|---------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | MAX | MIN | |
| Naphthalens | 19 | 19 | 0.00572 | BDL | BDL | 20 |
| 2-Methyl Naphthalene | 13 | 13 | 0.00622 | BDL | BDL | 20 |
| 1-Methyl Naphthalene | 13 | 13 | 0.06622 | BDL | BDL | 20 |
| Biphenyl | 13 | 12 | 0.00720 | 0.01907 | BDL | 20 |
| Dimethyl Naphthalene | 13 | 13 | 0.00125 | BDL | BDL | 4 |
| Acenaphthylene | 20 | 20 | 0.00128 | BDL | BDL | 4 |
| Acenaphthene | 19 | 17 | 0.00062 | 0.00225 | BDL | 1.5 |
| Dibenzofuran | 13 | 10 | 0.00105 | 0.00390 | BDL | 1.5 |
| Fluorene | 20 | 17 | 0.00038 | 0.00175 | BDL | 1.5 |
| Phenanthrene | 20 | 13 | 0.00043 | 0.00117 | BDL | 0.5 |
| Anthracene | 20 | 19 | 0.00029 | 0.00137 | BDL | 0.5 |
| Carbazole | 13 | 13 | 0.00018 | BDL | BDL | 0.5 |
| Fluoranthene | 20 | 7 | 0.00141 | 0.00514 | BDL | 0.5 |
| Pyrene | 20 | 16 | 0.00065 | 0.00354 | BDL | 0.5 |
| Benzo(a)Anthracene | 20 | 16 | 0.00060 | 0.00223 | BDL | 0.5 |
| Chrysene | 20 | 17 | 0.00048 | 0.00225 | BDL | 0.5 |
| Benzo(b)Fluoranthene | 20 | 19 | 0.00031 | 0.00127 | BDL | 0.5 |
| Benzo(k)Fluoranthene | 13 | 20 | 0.00026 | BDL | BDL | 0.5 |
| Benzo(e)Pyrene | 20 | 12 | 0.00018 | 0.00020 | BDL | 0.5 |
| Benzo(a)Pyrene | | 20 | 0.00026 | BDL | BDL | 0.5 |
| Indeno(1,2,3-cd)Pyrene | 20 | 20 | 0.00032 | BDL | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 20 | 20 | 0.00032 | BDL | BDL | 0.5 |
| Benzo(ghi)Perylene | 20 | 20 | 0.00032 | BDL | BDL | 0.5 |

BDL = below detection limit: analyte was not identified and quantified below the detection threshold

NOTE: high-volume sampler using quartz or glass fiber filter to collect particle-adsorbed PAHs

NOTE: Detection limit shown is the lowest detection limit reported by the laboratory for the individual analytes; Sampler Flow Rate: 0.7 - 2.1 m³/min

TABLE B-4-3.

CAMP ONE / AL JUBAIL
POLYCYCLIC AROMATIC HYDROCARBONS (HI-VOL REFERENCE PM10 METHOD)
(ug/m³)

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ug/m ³) | | | ANALYTICAL-DETECTION LIMIT (ug) |
|------------------------|-------------------|-----|------------------------------------|---------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | MAX | MIN | |
| Naphthalene | 12 | 12 | 0.00395 | BDL | BDL | 20 |
| 2-Methyl Naphthalene | 4 | 4 | 0.00511 | BDL | BDL | 20 |
| 1-Methyl Naphthalene | 5 | 5 | 0.00502 | BDL | BDL | 20 |
| Biphenyl | 5 | 5 | 0.00502 | BDL | BDL | 20 |
| Dimethyl Naphthalene | | 5 | 0.00100 | BDL | BDL | 4 |
| Acenaphthylene | 12 | 12 | 0.00089 | 0.00138 | BDL | 4 |
| Acenaphthene | 10 | 8 | 0.00050 | | BDL | 1.5 |
| Dibenzofuran | 5 | 3 | 0.00104 | 0.00270 | BDL | 1.5 |
| Fluorene | 12 | 11 | 0.00016 | 0.00026 | BDL | 1.5 |
| Phenanthrene | 12 | 8 | 0.00024 | 0.00047 | BDL | 0.5 |
| | | | | BDL | | 0.5 |
| Carbazole | 12 | 12 | 0.00016 | BDL | BDL | 0.5 |
| Fluoranthene | 12 | 6 | 0.00033 | 0.00093 | BDL | 0.5 |
| Pyrene | 12 | 7 | 0.00037 | 0.00143 | BDL | 0.5 |
| Benzo(a)Anthracene | 12 | 9 | 0.00022 | 0.00069 | BDL | 0.5 |
| Chrysene | 12 | 7 | 0.00019 | 0.00038 | BDL | 0.5 |
| Benzo(b)Fluoranthene | 12 | 10 | 0.00019 | 0.00038 | BDL | 0.5 |
| Benzo(k)Fluoranthene | 12 | 12 | 0.00015 | BDL | BDL | 0.5 |
| Benzo(e)Pyrene | 5 | 5 | 0.00010 | BDL | BDL | 0.5 |
| Benzo(a)Pyrene | 12 | 12 | 0.00015 | BDL | BDL | 0.5 |
| Indeno(1,2,3-cd)Pyrene | 12 | 12 | 0.00015 | BDL | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 12 | 12 | 0.00015 | BDL | BDL | 0.5 |
| Benzo(ghi)Perylene | 12 | 12 | 0.00015 | BDL | BDL | 0.5 |

BDL = below detection limit; **analyte** was not identified and quantified below the detection threshold

NOTE: high-volume sampler using **quartz** or glass fiber filter to **collect particle-adsorbed PAHs**

NOTE: Detection limit shown **is the lowest detection** limit reported by **the** laboratory for the individual **analyte**

Sampler Flow Rate: 0.7 - 2.1 m³/min

TABLE B-4-4.

**AL AHMADI HOSPITAL
POLYCYCLIC AROMATIC HYDROCARBONS (HI-VOL REFERENCE PM10 METHOD)
(ug/m3)**

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ug/m3) | | | ANALYTICAL DETECTION LIMIT (ug) |
|------------------------|-------------------|-----|-----------------------|---------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | MAX | MIN | |
| Naphthalens | 5 | 5 | 0.00467 | BDL | BDL | 20 |
| P-Methyl Naphthalene | 0 | 0 | N/A | N/A | N/A | 20 |
| 1 -Methyl Naphthalene | 0 | 0 | N/A | N/A | N/A | 20 |
| Biphenyl | 0 | 0 | N/A | N/A | N/A | 20 |
| Dimethyl Naphthalene | 0 | 0 | N/A | N/A | N/A | 4 |
| Acenaphthylene | 5 | 5 | 0.00155 | BDL | BDL | 4 |
| Acenaphthene | 4 | 3 | 0.00069 | 0.00025 | BDL | 1.5 |
| Dibenzofuran | 0 | 0 | N/A | N/A | N/A | 1.5 |
| Fluorene | 5 | 5 | 0.05000 | BDL | BDL | 1.5 |
| Phenanthrene | 5 | 4 | 0.00048 | 0.00184 | BDL | 0.5 |
| Anthracene | | 5 | 0.00050 | BDL | BDL | 0.5 |
| Carbazole | 0 | 0 | N/A | N/A | N/A | 0.5 |
| Fluoranthene | 5 | 2 | 0.00119 | 0.00170 | BDL | 0.5 |
| Pyrene | 5 | 5 | 0.00050 | BDL | BDL | 0.5 |
| Benzo(a)Anthracene | 5 | 5 | 0.00064 | BDL | BDL | 0.5 |
| Chrysene | 5 | 5 | 0.00064 | BDL | BDL | 0.5 |
| Benzo(b)Fluoranthene | 5 | 4 | 0.00032 | 0.01425 | BDL | 0.5 |
| Benzo(k)Fluoranthene | | 4 | 0.00321 | 0.01425 | BDL | 0.5 |
| Benzo(e)Pyrene | 0 | 0 | N/A | N/A | N/A | 0.5 |
| Benzo(a)Pyrene | 5 | 5 | 0.00064 | BDL | BDL | 0.5 |
| Indeno(1,2,3-cd)Pyrene | 5 | | 0.00093 | BDL | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 5 | 5 | 0.00093 | BDL | BDL | 0.5 |
| Benzo(ghi)Perylene | 5 | 5 | 0.00093 | BDL | BDL | 0.5 |

BDL = below detection limit: analyte was not identified and quantified below the detection threshold

NOTE: high-volume sampler using quartz or glass fiber filter to collect particle-adsorbed PAHs

NOTE: Detection limit shown is the lowest detection limit reported by the laboratory for the individual analyte

Sampler Flow Rate: 0.7 - 2.1 m3/min

TABLE B-4-5.

U.S. EMBASSY, KUWAIT CITY
 POLYCYCLIC AROMATIC HYDROCARBONS (HI-VOL REFERENCE PM10 METHOD)
 (ug/m3)

| ANALYTE | SAMPLE POPULATION | | CONCENTRATION (ug/m3) | | | ANALYTICAL DETECTION LIMIT (ug) |
|-----------------------|-------------------|-----|-----------------------|---------|-----|---------------------------------|
| | TOTAL | BDL | MEAN | MAX | MIN | |
| Naphthalene | 5 | 5 | 0.00507 | BDL | BDL | 20 |
| P-Methyl Naphthalene | NA | NA | NA | NA | NA | 20 |
| I-Methyl Naphthalene | NA | NA | NA | NA | NA | 20 |
| Biphenyl | NA | NA | NA | NA | NA | 20 |
| Dimethyl Naphthalene | NA | NA | NA | NA | NA | 4 |
| Acenaphthylene | 5 | 5 | 0.00160 | BDL | BDL | 4 |
| Acenaphthene | 4 | 4 | 0.00075 | BDL | BDL | 1.5 |
| Dibenzofuran | NA | NA | NA | NA | NA | 1.5 |
| Fluorene | 5 | 5 | 0.00049 | BDL | BDL | 1.5 |
| Phenanthrene | 5 | 3 | 0.00107 | 0.00178 | BDL | 0.5 |
| Anthracene | | 5 | 0.00049 | BDL | BDL | 0.5 |
| Carbazole | NA | NA | NA | NA | NA | 0.5 |
| Fluoranthene | 5 | 2 | 0.00137 | 0.00235 | BDL | 0.5 |
| Pyrene | 5 | 5 | 0.00049 | BDL | BDL | 0.5 |
| Benzo(a)Anthracene | 5 | 5 | 0.00061 | BDL | BDL | 0.5 |
| Chrysene | 5 | 5 | 0.00081 | BDL | BDL | 0.5 |
| Benzo(b)Fluoranthene | 5 | 5 | 0.00061 | BDL | BDL | 0.5 |
| Benzo(k)Fluoranthene | 5 | 5 | 0.00061 | BDL | BDL | 0.5 |
| Benzo(e)Pyrene | NA | NA | NA | NA | NA | 0.5 |
| Benzo(a)Pyrene | 5 | 5 | 0.00061 | BDL | BDL | 0.5 |
| Ideno(1,2,3-cd)Pyrene | 5 | 5 | 0.00086 | BDL | BDL | 0.5 |
| Dibenzo(ah)Anthracene | 5 | 5 | 0.00086 | BDL | BDL | 0.5 |
| Benzo(ghi)Perylene | 5 | 5 | 0.00086 | BDL | BDL | 0.5 |

NA - no analysis performed for these analytes

BDL = below detection limit: analyte was not identified and quantified below the detection threshold

NOTE: high-volume sampler using quartz or glass fiber filter to collect particle-adsorbed PAHs

NOTE: Detection limit shown is the lowest detection limit reported by the laboratory for the individual analytes

Sampler Flow Rate: 0.7 - 2.1 m3/min

Final Rpt, Kuwait Oil Fire HRA No. 39-26-L192-91, 5 May - 3 Dec 91

ANNEX B-5

LOW VOLUME EPA METHOD TO-13 PAH CONCENTRATION SUMMARIES

TABLE B-5-1.

| PUF | | | | | | | | | | | | | | | | |
|--|-----------------|-------|-----------------|-------|-----------------|-------|------------------|-------|-----------------|-------|-------------------|-------|-----------------|-------|-----------------|-------|
| POLYCYCLIC AROMATIC HYDROCARBONS (METHOD TO-13; LOW-VOLUME, PUF) | | | | | | | | | | | | | | | | |
| (ug/m3) | | | | | | | | | | | | | | | | |
| ANALYTE | KKMC | | KHOBAR TOWERS | | ESKAN VILLAGE | | CAMP 1 al JUBAYL | | CAMP THUNDEROCK | | MILITARY HOSPITAL | | AHMADI HOSPITAL | | U.S. EMBASSY | |
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| NAPHTHALENE | 0.182 | 0.188 | 0.182 | 0.217 | 0.248 | 0.281 | 0.175 | 0.208 | 0.212 | 0.231 | 0.228 | 0.28 | 0.22 | 0.27 | 0.234 | 0.288 |
| ACENAPHTHYLENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| ACENAPHTHALENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| FLUORENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| PHENANTHRENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| ANTHRACENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| FLUORANTHENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| PYRENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| CHRYSENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| BENZO(a)ANTHRACENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| BENZO(b)FLUORANTHENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| BENZO(k)FLUORANTHENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| BENZO(a)PYRENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| IDENO(1,2,3-cd)PYRENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| DIBENZO(a,h)ANTHRACENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| BENZO(g,h,i)PERYLENE | 0.037 | 0.04 | 0.037 | 0.042 | 0.051 | 0.058 | 0.037 | 0.041 | 0.044 | 0.047 | 0.048 | 0.058 | 0.044 | 0.052 | 0.047 | 0.056 |
| | (13) | | (14) | | (7) | | (12) | | (14) | | (8) | | (5) | | (10) | |
| | 18 May-5 Jun 81 | | 13 May-4 Jul 81 | | 31 May-4 Jul 81 | | 18 May-4 Jul 81 | | 7 Jun-4 Jul 81 | | 17 May-1 Jul 81 | | 9 Jun-28 Jul 81 | | 20 May-8 Jul 81 | |

NOTE: Samples not collected at Camp Abdaly; samples collected at Camp Freedom were appended to the data collected at the Military Hospital (1 sample)

Sample Collection Period: 20 - 28 hours

() = sample population

Dates indicate period when samples were collected

B-5-2

TABLE B-5-2.

| XAD-2 | | | | | | | | | | | | | | | | |
|--|---------------|--------------|---------------|--------------|----------------|-------------|-----------------|-------|-----------------|--------------|-------------------|--------------|-----------------|------|---------------|--------------|
| POLYCYCLIC AROMATIC HYDROCARBONS (METHOD TO-13; LOW-VOLUME, XAD-2) | | | | | | | | | | | | | | | | |
| (ug/m ³) | | | | | | | | | | | | | | | | |
| ANALYTE | KKMC | | KHOBAR TOWERS | | ESKAN VILLAGE | | CAMP 1 • JUBAYL | | CAMP THUNDEROCK | | MILITARY HOSPITAL | | AHMADI HOSPITAL | | U.S. EMBASSY | |
| | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH | MEAN | 95TH |
| NAPHTHALENE | 1.287 | 1.667 | 0.643 | 0.767 | 26.0 | 27.8 | 0.638 | 0.740 | 0.803 | 1.116 | 0.864 | 0.663 | | | 0.777 | 0.898 |
| ACENAPHTHYLENE | 1.287 | 1.507 | 0.69 | 0.76 | 26.8 | 27.8 | 0.627 | 0.762 | 0.803 | 1.116 | 0.684 | 0.661 | | | 0.777 | 0.898 |
| ACENAPHTHALENE | 0.683 | 0.707 | 0.267 | 0.333 | 12.1 | 12.6 | 0.268 | 0.333 | 0.363 | 0.509 | 0.204 | 0.368 | | | 0.347 | 0.399 |
| FLUORENE | 0.683 | 0.707 | 0.267 | 0.333 | 12.1 | 12.6 | 0.268 | 0.333 | 0.363 | 0.608 | 0.324 | 0.368 | | | 0.347 | 0.399 |
| PHENANTHRENE | 0.683 | 0.707 | 0.267 | 0.333 | 12.1 | 12.6 | 0.288 | 0.333 | 0.363 | 0.608 | 0.324 | 0.380 | | | 0.347 | 0.399 |
| ANTHRACENE | 0.683 | 0.707 | 0.267 | 0.333 | 12.1 | 12.6 | 0.268 | 0.333 | 0.363 | 0.608 | 0.324 | 0.360 | | | 0.347 | 0.300 |
| FLUORANTHENE | 0.683 | 0.707 | 0.287 | 0.333 | 12.1 | 12.8 | 0.206 | 0.333 | 0.303 | 0.609 | 0.324 | 0.319 | | | 0.347 | 0.399 |
| PYRENE | 0.603 | 0.707 | 0.267 | 0.333 | 12.1 | 12.6 | 0.266 | 0.333 | 0.383 | 0.800 | 0.324 | 0.318 | | | 0.347 | 0.399 |
| CHRYSENE | 0.603 | 0.707 | 0.267 | 0.333 | 12.1 | 12.5 | 0.268 | 0.333 | 0.363 | 0.600 | 0.324 | 0.368 | | | 0.347 | 0.399 |
| BENZO(a)ANTHRACENE | 0.683 | 0.707 | 0.267 | 0.333 | 12.1 | 12.5 | 0.260 | 0.333 | 0.313 | 0.509 | 0.324 | 0.368 | | | 0.347 | 0.399 |
| BENZO(b)FLUORANTHENE | 0.663 | 0.707 | 0.432 | 0.67 | 12.1 | 12.5 | 0.366 | 0.496 | 0.303 | 0.600 | 0.324 | 0.300 | | | 0.347 | 0.389 |
| BENZO(k)FLUORANTHENE | 0.683 | 0.707 | 0.267 | 0.333 | 12.1 | 12.5 | 0.268 | 0.333 | 0.303 | 0.608 | 0.324 | 0.309 | | | 0.347 | 0.399 |
| BENZO(a)PYRENE | 0.603 | 0.707 | 0.267 | 0.333 | 12.1 | 12.5 | 0.268 | 0.333 | 0.383 | 0.608 | 0.324 | 0.308 | | | 0.347 | 0.309 |
| IDENO(1,2,3-cd)PYRENE | 0.663 | 0.707 | 0.267 | 0.333 | 12.1 | 12.5 | 0.268 | 0.333 | 0.363 | 0.609 | 0.324 | 0.369 | | | 0.347 | 0.300 |
| DIBENZO(a,h)ANTHRACENE | 0.583 | 0.707 | 0.267 | 0.333 | 12.1 | 12.5 | 0.286 | 0.333 | 0.363 | 0.608 | 0.324 | 0.360 | | | 0.347 | 0.399 |
| BENZO(g,h,i)PERYLENE | 0.603 | 0.707 | 0.267 | 0.333 | 12.1 | 12.5 | 0.266 | 0.333 | 0.363 | 0.608 | 0.324 | 0.368 | | | 0.347 | 0.398 |
| | (3) | | (6) | | (4) | | (8) | | (3) | | (6) | | (0) | | (3) | |
| | 10 May-18 Jun | | 19 May-15 Jun | | 1 Jun-11 Jun 8 | | 19 May-15 Jun | | 7 Jun-15 Jun 8 | | 20 May-3 Jun 8 | | | | 12 May-18 Jun | |

NOTE: All concentrations above represent below detection limit values (one-half the detection threshold used for reporting purposes)

NOTE: Samples not collected at Camp Freedom, Camp Abdaly, or Ahmadi Hospital

NOTE: Very low volumes were collected at Easkan Village, resulting in high detection thresholds and thus high concentration values relative to other sites

Sample collection averaging time: 20 - 28 hours

() = sample population

Dates indicate period when samples were collected

B-5-3

ANNEX B-6

PASSIVE DOSIMETER CONCENTRATION SUMMARIES

TABLE B-6-1.

**Passive Dosimeter Results for Ozone (O₃) and Sulfur Dioxide (SO₂)
Concentrations in Micograms per Cubic Meter (ug/m³)**

| LOCATION (period of record) | O ₃ | | | SO ₂ | | |
|-----------------------------------|----------------|------|-------|-----------------|------|------|
| | Min | Mean | Max | Mtn | Mean | Max |
| KKMC (May-Jul 91) | 39.4 | 47.5 | 63.2 | 3.3 | 8.2 | 17.8 |
| KHOBAR (May-Nov 91) | 14.2 | 31.7 | 65.0 | 2.3 | 9.8 | 23.3 |
| RIY ADH (Jun-Jul 91) | 32.3 | 53.4 | 65.5 | 4.6 | 23.8 | 46.3 |
| JUBAYL (May-Jul 91) | 26.9 | 41.9 | 67.5 | 4.7 | 12.5 | 22.9 |
| AHAMDI (Jun 91) | 33.2 | N/A | 48.9 | 26.6 | N/A | 92.5 |
| CAMP THUNDEROCK (Jun-Nov 91) | 9.0 | 42.4 | 104.8 | 9.7 | 16.6 | 27.5 |
| EMBASSY (May-Jun 91) | 52.4 | N/A | 54.4 | 3.4 | N/A | 7.0 |
| MILITARY HOSPITAL (May-Nov 91) | 13.5 | 49.2 | 82.5 | 6.5 | 27.1 | 47.3 |

N/A : not available; less than three samples

Sample times approximately 4,320 minutes (3 days)

Passive Dosimeter Results for Nitrogen Dioxide (NO₂) and Nitrogen Oxide Concentrations in Micograms per Cubic Meter (ug/m³)

| LOCATION (period of record) | NO ₂ | | | NO _x | | |
|-----------------------------------|-----------------|------|------|-----------------|------|------|
| | Min | Mean | Max | Min | Mean | Max |
| KKMC (May-Jul 91) | 5.7 | 10.5 | 17.2 | 1.2 | N/A | 3.7 |
| KHOBAR (May-Nov 91) | 21.0 | 58.5 | 86.1 | 6.2 | 24.2 | 61.1 |
| RIYADH (Jun-Jul 91) | 17.2 | 32.8 | 44.0 | 5.0 | 21.6 | 56.2 |
| JUBAYL (May-Jul 91) | N/A | N/A | N/A | N/A | N/A | N/A |
| AHAMDI (Jun 91) | 13.4 | N/A | 13.4 | 12.5 | N/A | 12.5 |
| CAMP THUNDEROCK (Jun-Nov 91) | 7.7 | 23.8 | 45.9 | 6.2 | 14.1 | 23.7 |
| EMBASSY (May-Jun 91) | N/A | N/A | N/A | N/A | N/A | N/A |
| MILITARY HOSPITAL (May-Nov 91) | 7.7 | 40.6 | 76.5 | 6.2 | 19.1 | 56.2 |

N/A : not available

Sample times approximately 4,320 minutes (3 days)

ANNEX B-7

**GEOGRAPHICAL INFORMATION SYSTEM
PILOT-PROJECT SUMMARY**

KUWAIT HRA GIS PILOT PROJECT

1 BACKGROUND.

a. The USAEHA health risk assessment (HRA) effort to support Public Law 102-190 Section 734, requires a means to calculate exposure to DOD military and civilian personnel, deployed for Operation Desert Storm, from the Kuwait oil well fires. A total of 605 oil well fires, spread over eight oil well producing areas in Kuwait, were ignited by the retreating Iraqi soldiers in mid-February 1991. To accomplish this, the USAEHA combined two pollutant specific concentration data sets, troop unit movement data, and satellite imagery into a GIS. The GIS technology was selected to readily accept the dynamic nature of the data types which were required to produce a solution to the problem. The GIS portion of the Kuwait Oil Well Fires HRA is comprised of two working tasks. The first task is to apply overall workflow procedures to both a limited geographic region and timeframe in order to demonstrate the capability of the GIS. This task is termed the Kuwait HRA GIS Pilot Project. The second task is to apply the workflow procedures and methods demonstrated in the Pilot Project to the entire Desert Storm Theater of Operations for the duration of the Kuwait oil well fires. The following discussion describes the procedures used to complete the Kuwait HRA GIS Pilot Project task.

b. The first pollutant-specific concentration data set was comprised of eight fixed site sampling locations in Kuwait and Saudi Arabia. Ambient air and soil media were sampled at these sites during 15 May - 4 December 1991 and represented major geographic troop staging locations. In addition, the USAEHA coordinated with the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory (ARL) to provide 24-hour predicted unit emission concentration estimations on a 15- X 15- kilometer grid encompassing the Desert Storm Theater of Operations. The computations were performed using a Lagrangian transport and dispersion model and analyzed meteorological fields modified to account for the non-linear radiative effects of the smoke plume on the vertical mixing of the pollutants. The Lagrangian model used by the NOAA ARL is named HY-SPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectories). The reference base for the model is described by Draxler (reference 61). More information on HY-SPLIT is found in paragraph 5a. The sampling period record for the second pollutant-specific concentration data set was 3 February - 31 October 1991. This air dispersion modeling effort enables daily concentration estimations to be used in calculating troop unit exposure from the oil well fires as the troops moved within the Theater of Operations. The emphasis of the Kuwait HRA GIS Pilot Project and subsequent work for the entire Desert Storm Theater of Operations is to calculate total risk (both carcinogenic and non-carcinogenic) for troop units when they are "under" the oil well fire plume(s). Thus, the basic assumption is for exposure to be calculated when troop units are within predefined plume boundaries. The GIS Pilot Project will use both data sets to calculate exposure from the Kuwait oil well fires to troop units in the Desert Storm theater.

2. PILOT PROJECT GEOGRAPHICAL COVERAGE AND TIMEFRAME.

a. The Kuwait HRA GIS Pilot Project study area encompasses the Defense Mapping Agency Digital Chart of the World (DCW) geographic region designated as Tile RH13. This tile has geographic coordinates of 25-30 degrees north latitude and 45-50 degrees east longitude, and covers the Emirate of Kuwait, the far northeast region of the Kingdom of Saudi Arabia, the extreme south region of the Republic of Iraq, and the extreme southwest region of the Islamic Republic of Iran. The Kuwait HRA GIS Pilot Project study area is shown in Figure B-7-1.

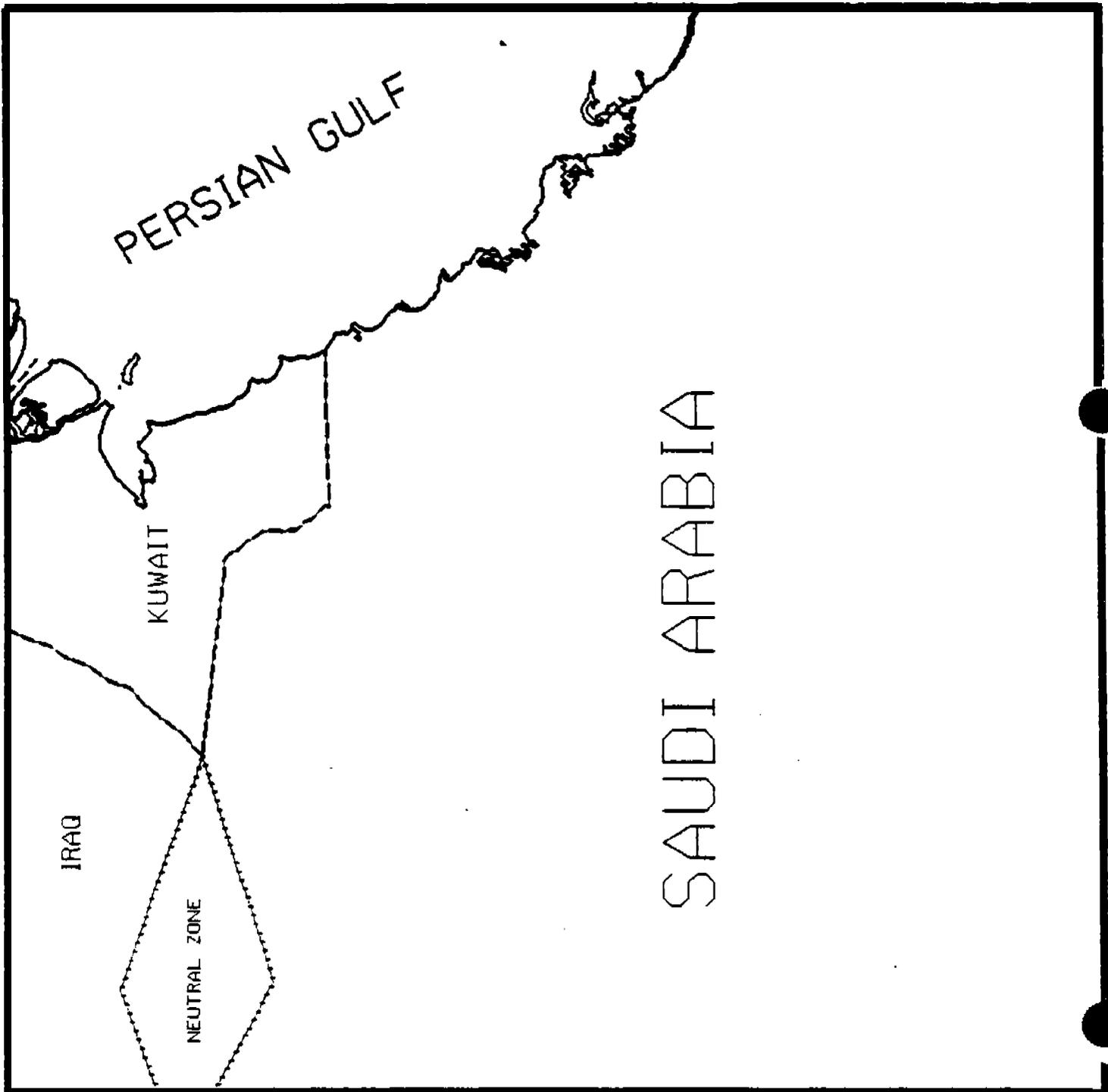
b. Kuwait HRA GIS Pilot Project Sampling Period. The chronological data analysis period for the pilot project includes the calendar year 1991 Julian day period of 138-144 (18-24 May 1991) and 15 days prior and post period (3 May - 9 June 1991). The total period of record for the pilot project is 37 days.

3. GIS SPECIFICS.

a. The USAEHA procured the GIS (both hardware and software) from the Intergraph Corporation headquartered in Huntsville, Alabama. In general, the USAEHA GIS consists of an InterPro 6455 series server; two large screen InterPro 6240 series workstations; one InterServe 6000 series workstation designated as plot server; 36-inch Versatec 8936 color electrostatic plotter; Intergraph 2217 laser printer; Epson 80 column dot-matrix printer; and a differential read/write optical media jukebox. Figure B-7-2 displays a set-up diagram of the USAEHA GIS. The Intergraph hardware was installed by a field engineer (FE) in November 1992. The Intergraph software was installed by the FE and customer engineer (CE) in December 1992.

b. The USAEHA began training on the Intergraph GIS in December 1992. Workshop I included implementing the GIS to include lessons on the modular GIS environment (MGE); database design; project inputs/outputs; production workflows; computer networking; and preliminary discussion on the Kuwait HRA GIS pilot project.

c. Workshop II included training on the Microstation 32 software package with emphasis on mapping graphic data input; graphics and text manipulation; and fundamental map design. Workshop III included training on the Microstation32, MGE/Standard Engine (MGE/SX), modular GIS applications (MGA), and relational interface system (RIS) software packages. Discussions were geared toward project planning, organization and design; database design, topology and topological construction in MGA; and the execution, display and output of analytical queries. The USAEHA received one week of training on the Informix structured query language (SQL) database management system. The USAEHA received one week of



NO P

N Figure B-7-1.

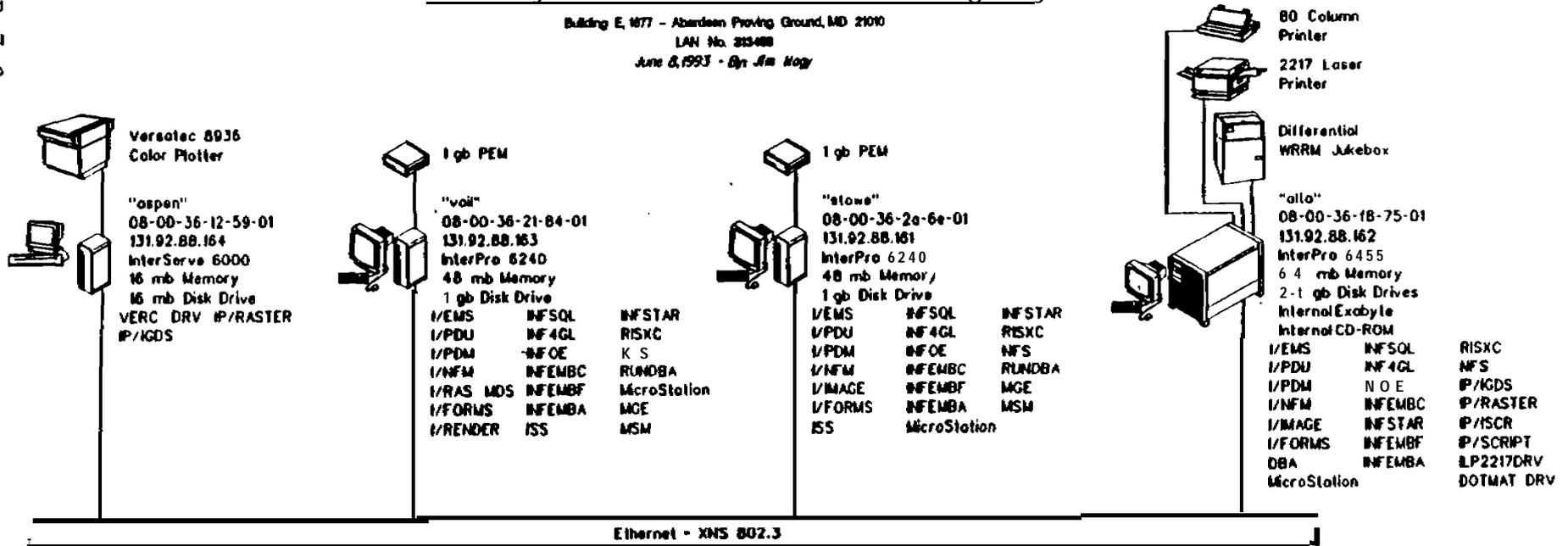
Figure B-7-2.

U.S. Army Environmental Hygiene Agency

Building E, 1677 - Aberdeen Proving Ground, MD 21010

LAN No. 313488

June 8, 1993 - Dgt Jim Nagy



R-7-5

training on Imager Station Imager (ISI-2) software to include 1-day review of remote sensing fundamentals, 2-days of ISI-2 training, and 2-days of training applications specific to interpretation of NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite images taken of the Kuwait oil well fire plumes.

4. DEVELOPMENT OF PILOT PROJECT OBJECTIVES AND MILESTONES. The USAEHA developed specific objective and milestone listings for the completion of the Kuwait HRA GIS Pilot Project. The USAEHA GIS project produces risk values from use of the site-specific data (to include the inhalation, ingestion, and dermal pathways) and the NOAA Hysplit modeled data (inhalation pathway only). Specific milestones and associated completion dates for each follow.

- a. System setup and configuration: December 1992 - June 1993.
- b. Loading of system data: May-June 93. The NOAA Hysplit data comprised approximately 3.5 gigabyte (GB) of storage space. The NOAA satellite imagery comprised approximately 9 GB of storage space.
- c. Study area defined with respect to NOAA model and satellite plume boundary features: October 1993.
- d. Calculation of daily risk values using NOAA Hysplit modeled data: November 1993.
- e. Calculation of daily risk values using site specific sampled data: November 1993.
- f. Generation of (daily) unit location files based on geographic coordinates: October - November 1993.
- g. Generation of modeled and sampled risk values assigned to troop units based on their locations for specified Julian days; and relative position to NOAA modeled grid points and sample site Thiessen polygons: November 1993.
- h. Comparison of modeled and sampled site risk values: November 1993.
- i. Generate GIS Pilot Project output and provide documentation: November - December 1993.

5. DEVELOPMENT OF PILOT PROJECT WORKFLOW PROCEDURES. For each of the above listed milestones and associated objectives, workflow procedures were developed. A brief discussion of each follows.

a. Defining NOAA Hysplit Optical Depth Area. The USAEHA received the HY-SPLIT modeled data from NOAA ARL on a series of 8 millimeter magnetic tapes. For each Julian day, four model time step files were provided to allow selection of the model time step

which coincided with the NOAA AVHRR satellite image valid time. In general, the 1500 hour local standard time step was chosen. This is a result of analysis of the NOAA AVHRR images to determine the best time for visual identification of the oil well fire plumes. Additional information is included in section 5c. The respective optical depth values (ranging from 0.01 to 4.0) for latitude/longitude coordinates within the pilot project study area were referenced to the underlying DCW vector data.

b. Creating (Digitizing) NOAA HY-SPLIT Plume Boundary from Optical Depth Parameteral depth values for each Julian day were placed into the GIS environment using a pointplacer routine. The perimeter model grid points were then digitally traced, thus creating a digitized model plume boundary feature. Figure B-7-3 shows the modeled optical depth plume grid points and boundary definition for Julian day 140 (20 May 1991).

c. Conversion, Extraction, and Color Composite Generation of NOAA AVHRR Satellite Images. The raster satellite images were obtained from the National Center for Atmospheric Research (NCAR). The AVHRR images (from the NOAA 9, NOAA 10, and NOAA 11 satellites) comprised of 5 spectral bands and through consultation with the Intergraph Corporation, spectral bands 1 through 3 were subsequently used for image interpretation. These bands cover the visible through mid infrared wavelengths of the electromagnetic spectrum. The NOAA AVHRR wavelength range (in microns, μm) for spectral bands 1 through 3 are 0.58-0.68 μm ; 0.725-1.10 μm ; and 3.55-3.93 μm , respectively. Each spectral band was then extracted from the converted file. A color composite image was then created and subsequently viewed to assess satellite plume definition. The NOAA 11 AVHRR satellite images used were taken during the afternoon satellite pass over the Persian Gulf region. This time equated to approximately 1500 hours local standard time (LST) or 1100 Greenwich Mean Time. This daytime image provided the best contrast for determining the oil well fire superplume over the Persian Gulf environs. For the pilot project, we were unable to reproduce any NOAA AVHRR images for Julian days 142 and 143.

d. Creating (Digitizing) Satellite Plume Boundary. Prior to digitizing the satellite plume boundaries, the DCW vector data for the pilot project area were referenced and then attached to the satellite images. In general, the geometric attributes are referenced to the satellite images. Next, the satellite images are individually digitized using the MGE digitizing application. The visible and near-infrared spectral bands were viewed to help in the placement of the oil field plume boundary. The color composite images were used as the primary digitizing image. Each daily satellite image plume boundary was attributed with its Julian day and linkage features.

e. Merging of Modeled and Satellite Derived Plume Boundaries. Each of the Julian day's satellite and modeled plume boundaries were area merged using the MGA area merger application. This was done to build a plume boundary feature which establishes the combined satellite and modeled plume boundaries into one complete file. After completion of this step, the merged plume boundary features were subject to generation of a

15 kilometer (km) buffer zone encompassing the merged plume boundary. This was accomplished using the feature zoner option in the MGA. The 15 km distance was chosen to extend the geographic region of troop unit risk calculation and coincides with the NOAA HY-SPLIT concentration grid spacing. Figures B-7-4 through B-7-6 display the satellite, merged, and buffer zone plume boundary features for Julian day 140.

f. Creation of Thiessen Polygons for Eight Sampled Sites assess exposure using the site-specific sampled data, a series of Thiessen polygons were constructed for the sample locations. The geographic sample location corresponded to the centroid of the Thiessen polygon. A GIS design file containing the Thiessen polygons was constructed and subsequently copied for each of the Julian days for which exposure was calculated. Figure B-7-7 displays the Thiessen polygon design file used for the pilot project work area. The sample site designations listed (i.e., 02 for KKMC; 03 for Dhahran; 04 for Riyadh; 05 for Al Jubayl; AH for Ahmadi; CT for Camp Thunderrock; MH for Military Hospital; and UN for U.S. Embassy) are the polygon centroids.

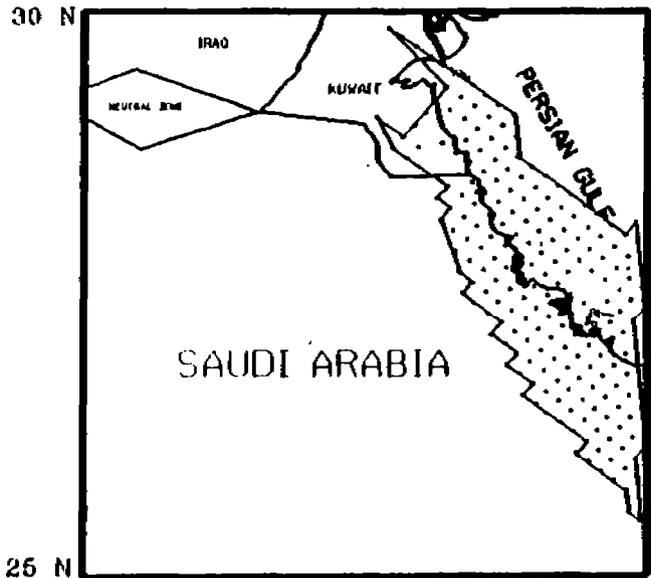
g. Troop Unit Movement Database. The U.S. Army and Joint Services Environmental Support Group (ESG) is the agency responsible for providing a database containing Desert Storm personnel and their movement in the Theater of Operations. The Defense Manpower Data Center (DMDC) developed an Operation Desert Shield/Storm database which contains personnel information for those who were deployed to the Theater of Operations. This database identifies more than 650,000 active, guard, reserve, and civilian personnel and more than 13,300 troop units. The DMDC database will serve to populate the personnel database to be used by ESG. The location of troop units in the Theater of Operations are being entered into a database at ESG. These unit locations are being gathered from unit history data archives to include daily log reports, After Action Reports, and map overlays for all military branches. In general, the ESG troop movement database will have specific fields to include unit identification codes (UICs), unit name, location name, arrival and departure Julian days, and geographic coordinates.

6. GIS PILOT PROJECT PROGRAMMING AND DATA SUPPORT. A series of compiled "C" programs were developed to support the calculation of carcinogenic and non-carcinogenic risk using both site-specific sampled data and NOAA HY-SPLIT modeled data. As previously mentioned, the site-specific sampled data will be used to generate exposure for the inhalation, ingestion, and dermal pathways. The NOAA HY-SPLIT modeled data will be used to generate exposure for only the inhalation pathway. In general, two statistical distributions have been used for representing air pollutant concentrations are the lognormal and the Weibull (references 10 and 53). Examination of the USAEHA data displayed the different media to be lognormally distributed. For both data types, the programs will generate daily risk values which are comprised of daily 31-day rolling 95 UCL log-normal concentrations for all pollutants. This 31-day rolling 95 UCL was used to continue the comparison between the interim Kuwait HRA using only the sampled data (i.e., monthly risk values were calculated) and to provide a conservative concentration estimation for the NOAA HY-SPLIT data.

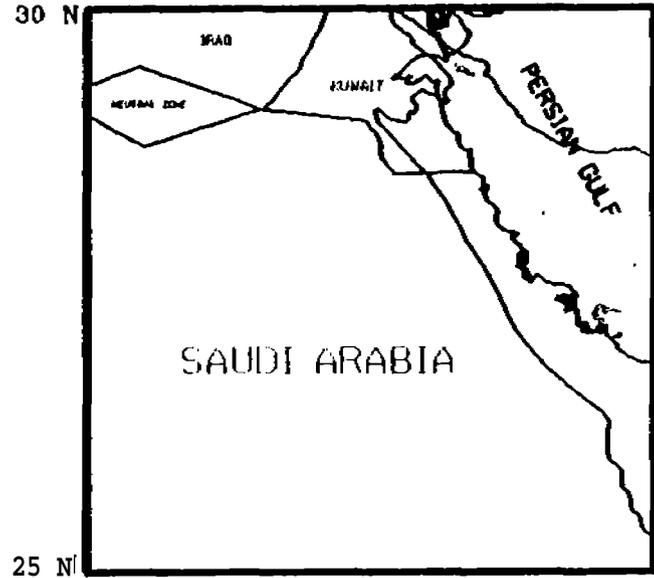
B-7-9

VB-3-5 (a)

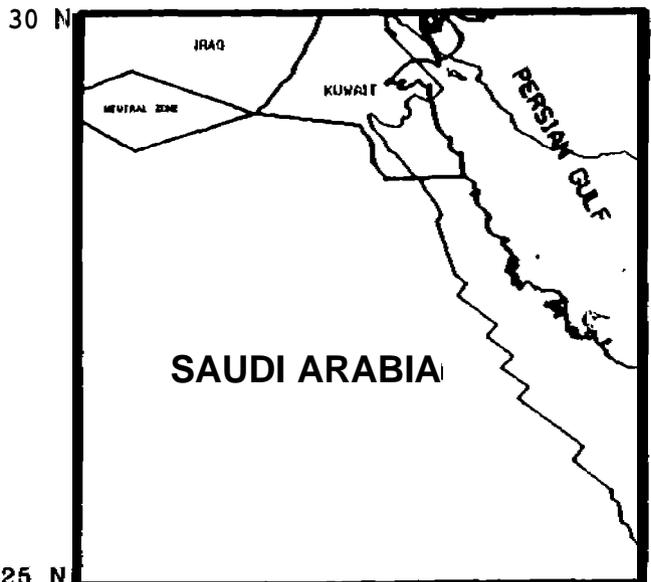
VB-3-5 (b)



45 E Figure B-7-3. 50 E



45 E Figure B-7-4. 50 E



45 E Figure B-7-5. 50 E



45 E Figure B-7-6. 50 E

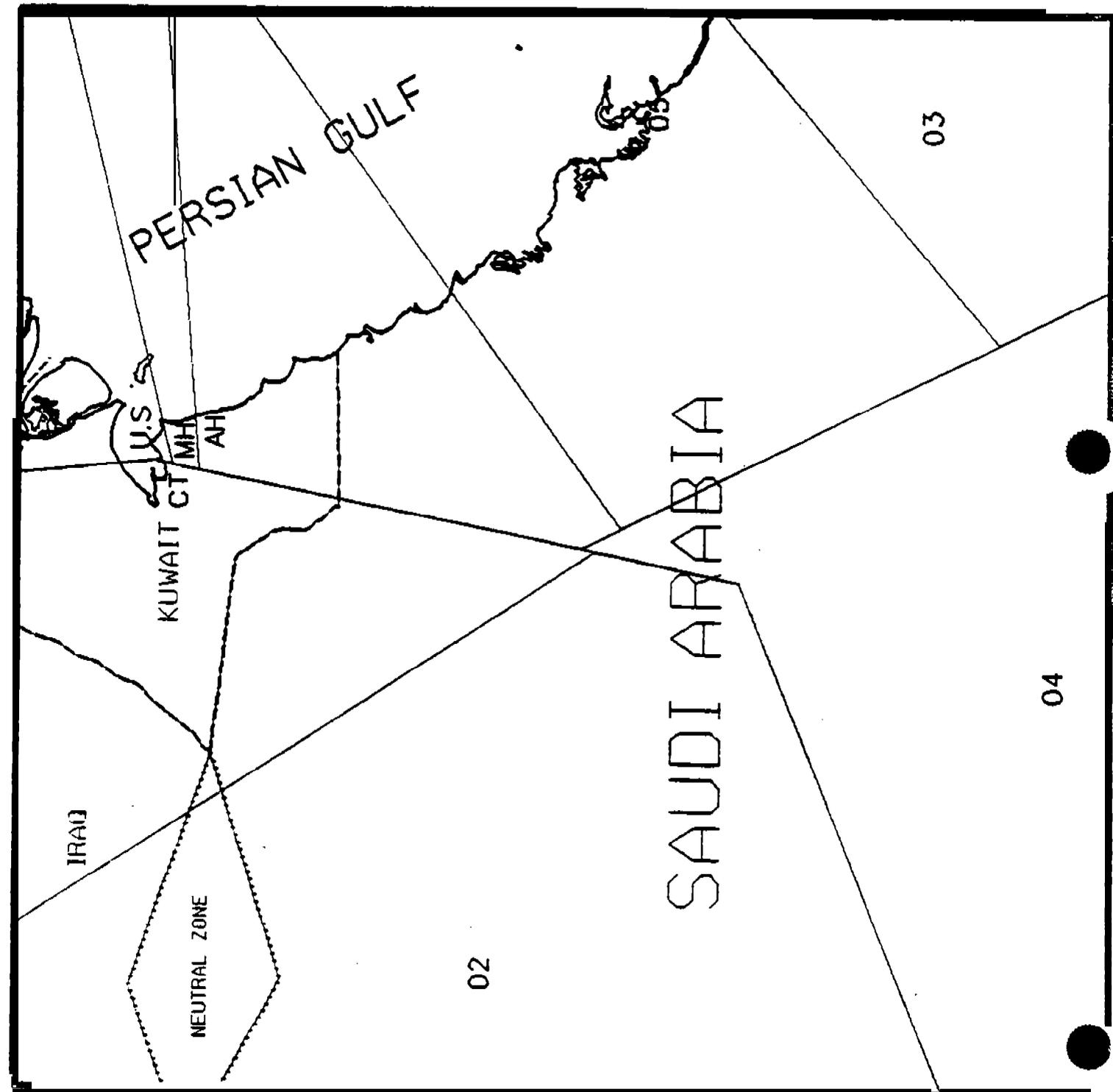


Figure B-7-7 .

30 N

26 N

a. NOAA HY-SPLIT Modeled Data. Advection and diffusion calculations are made in a Lagrangian framework, while the meteorological input information is obtained from gridded data fields output from Eulerian numerical weather prediction models. Air concentrations are calculated on a fixed three-dimensional grid by integrating all particle masses (a single pollutant particle represents the initial source which is then divided into several particles to represent the complex flow field) over the sampling time. Model computations of carbon soot smoke and sulfur dioxide air concentrations were compared with the observations from several intensive aircraft measurement campaigns as well as longer-term ground-based measurements. The measurements and model calculations were in substantial agreement when the results were averaged over several episodes. The highest normalized concentrations were always located near the coast between Kuwait and Qatar, with the peak values moving farther west and inland with each season. A rolling Julian day average was selected for generation of pollutant concentrations at the model grids. Since the HY-SPLIT model provided unit emission concentrations, a pollutant-specific emission factor table was constructed to contain oil field specific emission factors. For the GIS Pilot Project, the emission factors were arbitrarily set to a value of 100. Derivation of oil field, time dependant pollutant-specific emission factors will be conducted for the Final Kuwait Oil Fires HRA GIS Pilot Project using oil field specific assay data collected in November 1993. The program utilizing the HY-SPLIT modeled data calculates daily carcinogenic and noncarcinogenic risk values for each modeled grid point. A 201 by 201 concentration grid (or 40,401 concentration grid points) encompasses the Southwest Asia region. The number of concentration grid points contained in the GIS Pilot Project region is approximately 1,300. A plot of the project-gridded concentration receptors is displayed in Figure B-7-8.

b. Site-Specific Sampled Data. The site-specific sampled data (both administrative and concentration) collected during the May - November 1991 period was validated (with respect to sample media holding times, flow rates, and breakthrough) then loaded into the GIS database. The program utilizing the site-specific sampled data calculates daily carcinogenic and non-carcinogenic risk values for each Thiessen polygon centroid.

c. Risk Characterization. The toxicity and exposure assessments are integrated into quantitative and qualitative expressions of risk. Excess lifetime cancer risks are obtained by multiplying the intake rate at the exposure point of the contaminant by its cancer slope factor. The total cancer risk for the exposure point is determined by adding the individual cancer risks for each pollutant in pathways then summing the risk for all pathways. Noncancer hazards are obtained by dividing each pollutant's daily intake by its reference dose (RfD). The hazard quotients are summed for the various pollutants to obtain a hazard index (HI) for the pathway. The HIs for various pathways are then combined and represent the total noncancer risk for the exposure point. The exposure factors used in calculation of intake were derived from EPA Risk Assessment Guidance for Superfund (RAGS) publications (reference 64). In general, EPA default values were used along with modifications to the breathing rate, daytime and nighttime exposure hours values. The slope factor and RfD values were derived from the IRIS and HEAST database publications of 1993. The GIS database table containing these entries was developed so that as the factors are updated, the respective slope and RfD factors can also be updated.

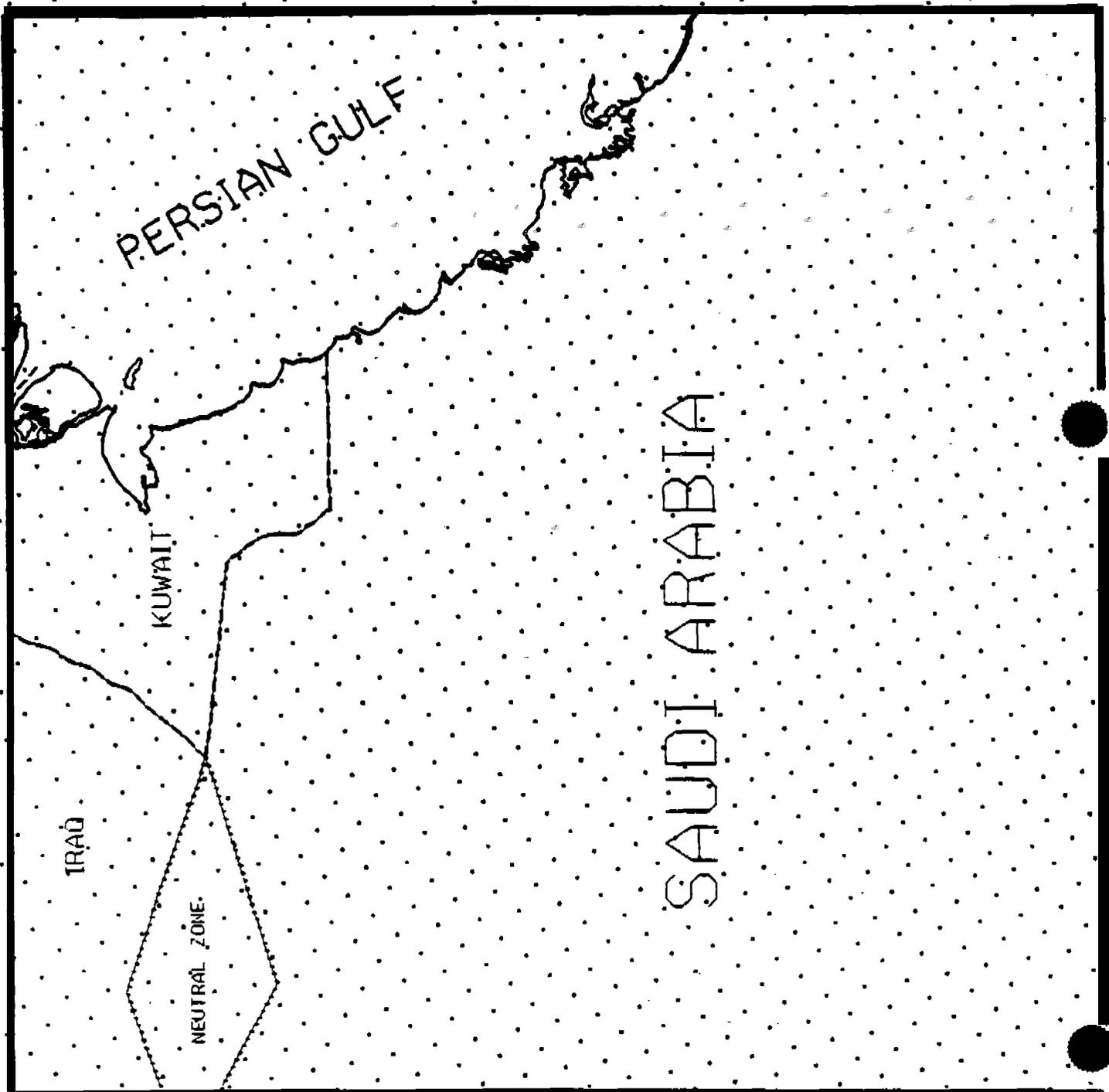


Figure B-7-8.

30 N

25 N

d. Troop Unit Data. For the GIS Pilot Project, both real-time and pseudo troop unit movement data were used. The real-time troop unit movement data contained entries for a portion of the USAEHA personnel in the Kuwait Theater of Operations during May 1991. For the most part, the USAEHA personnel remained static at the eight site-specific locations. There were instances where a portion of the USAEHA personnel moved from the Saudi Arabia locations to the Kuwait locations and vice-versa. The pseudo troop unit movement was generated using a random longitude/latitude generator.

7. EXECUTION OF PROGRAMS. All of the above information was integrated and subsequent execution of the programs to calculate both sampled-site and modeled risk for the Julian day period of record were performed. The following paragraphs provide a brief explanation of the programs. The exact execution of the programs was critical to ensure that the necessary information was available for use in the subsequent program.

a. Program 1 calculated modeled health risk values for the NOAA grid points for specified Julian days, and then generated text files to contain the calculated risk values.

b. Program 2a calculated sampled risk values for each of the eight sampled sites for specified Julian days.

c. Program 2b generated sample site design files (containing Thiessen polygons) for specified Julian days. One file is generated for each day.

d. Program 4 (GULF) generated unit location design files based on their geographic coordinates (latitude, longitude).

e. Program 3 (RAM) assigned modeled and sampled risk values to troop units based on their locations for specified Julian days and their relative position to NOAA grid points and sample site Thiessen polygons.

8. KUWAIT ERA GIS PILOT PROJECT CAPABILITY.

a. Examination of the GIS Pilot Project outputs (for Julian days 138-144) displayed results which are expected from the execution of the above programs. Program 1 generated the appropriate text files containing inhalation risk values for each model grid point. Program 2a appropriately calculated the pathway-specific risk values and populated the site risk database table with the risk values for the corresponding Julian day. Program 2b correctly copied the sample site design file (containing the sample site centroid features bounded by the Thiessen polygons) for Julian days 138-144. Program 4 generated the unit location design files for the fixed sample sites to include Khobar and Al Jubayl and random site locations within the GIS Pilot Project study area. Program 3 uniquely identified troop unit(s) that were within the plume boundary and GIS Pilot Project boundary features for the period of record and subsequently populated the unit database table with the calculated risk values. The risk values presented in this table are preliminary and have not been validated.

b. A sample output of the GIS generated risk values for the identified troop units is contained in Table B-7-1.

TABLE B-7-1. SAMPLE GIS PILOT PROJECT OUTPUT OF SAMPLED AND MODELED RISK VALUES

| DATA FIELD | UNIT/LOCATION | VALUE |
|-------------------|---------------|----------|
| ingestion hazard | Combat/05 | 4.21E01 |
| ingestion risk | Combat/05 | 6.54E-12 |
| inhalation hazard | Combat/05 | 1.15E02 |
| inhalation risk | Combat/05 | 2.79E-08 |
| dermal hazard | Combat/05 | 1.32E01 |
| dermal risk | Combat/05 | 7.53E-11 |
| modeled hazard | Combat/05 | 8.48E02 |
| modeled risk | Combat/05 | 5.10E-09 |

NOTE: The risk values presented in this table are preliminary and have not been validated

9. CONTINUED KUWAIT HRA GIS WORK. To date, the USAEHA GIS Pilot Project has been completed with the exception of validating the output risk values. We are currently revising the programs to output the associated risk values everytime a calculation is made. This will be done for a selected day within the pilot project timeframe. These values will then be analyzed and used as input to Lotus spreadsheet files to recalculate the GIS output risk. Any dissimilarities will be noted and the GIS risk calculation programs revised. Upon completion of this step, the workflow procedures will then be revised in order to cover the entire period in which the oil well fires were ablaze. All revisions will be documented. It is anticipated that the final USAEHA GIS Kuwait oil well fires HRA will be completed by end of CY 1994. This completion date is dependent upon receipt of the troop unit movement database.

10. GLOSSARY OF TERMS.

a. The ran slagrangian ach diffusion theory is based on considering the meandering of marked fluid particles in the flow.

b. Eulerian Approach. The eulerian diffusion theory is based on carrying out a material balance over an infinitesimal region fixed in space.

c. Topology. Topology is used to represent the spatial relationship between graphic data. Spatial relationships are the associations between geographic data based on their relative location to one another.

d. Optical Depth. Optical depth is defined as a mathematical expression which includes the extinction coefficient of smoke and the smoke concentration integrated over the depth of the computational domain.

e. Raster Image. A multi-dimensional matrix of spatially ordered numbers where each cell within it is called a pixel (or picture element).

f. Attributes. or characteristics in a relational database that describe geographic features.

g. Thiessen Method. A method developed from the field of hydrology for data reconstruction where adjacent stations are connected with straight lines. From each line, perpendicular bisectors are drawn forming a series of polygons.

Final Rpt, Kuwait Oil Fire HRA No. 39-26-L192-91, 5 May - 3 Dec 91

ANNEX B-8

**KUWAIT/SAUDI ARABIA 1993 RETURN TRIP
AIR DATA SUMMARY**

1. OVERVIEW. Ambient air sampling was conducted at two sites from 31 October 1993 through 10 November 1993. The Saudi-Arabian site was located in Khobar Towers on the rooftop of Building 117 (approximately 70 feet above ground). This site was within a few hundred yards of the original "Site 3" sampled during 1991. The Kuwait site was located on the roof the Directorate of Logistics, Building 25 of Camp Doha. Air sampling was conducted approximately 30 feet above ground level and within a mile of the original "Camp Thunderrock" location sampled in 1991. Table B-8-1 contains a listing of the sample locations, durations, and media collected for the return trip.

TABLE B-8-1. RETURN TRIP AIR SAMPLING SPECIFICS

| Sample Type | Site | Date Started | Date Ended | Total Samples | Total Spikes | Total Blanks |
|------------------|------|--------------|------------|---------------|--------------|--------------|
| TO-1 | CT* | 31 Oct | 8 Nov | 60 | 4 | 5 |
| | 03' | 1 Nov | 10 Nov | 64 | 4 | 4 |
| TO9 | CT | 31 Oct | 8 Nov | 12 | 7 | 4 |
| | 03 | 1 Nov | 9 Nov | 11 | 8 | 3 |
| TO-13 | CT | 31 Oct | 8 Nov | 12 | 8 | 4 |
| | 03 | 1 Nov | 9 Nov | 11 | 8 | 3 |
| PM ₁₀ | CT | 31 Oct | 8 Nov | 26 | 0 | 3 |
| | 03 | 1 Nov | 9 Nov | 20 | 0 | 1 |

- Site CT is Camp Thunderrock, Camp Doha, Kuwait
Site 03 is Khobar Towers, Dhahran, Saudi Arabia

2. SAMPLING METHODS. The air sampling comprised of: EPA Method TO-1 for VOC determination; EPA Method TO-9 for dioxin and furan determination; EPA Method TO-13 for PAH; PM₁₀ sampling for determination of particulate matter with an aerodynamic diameter of less than 10 microns; and cascade impaction for the breakdown of the particulate matter by size. Specific comments on these methods follow.

12-hour periods (comprising a total of eight Tenax tubes per day) on every other day. The remaining days were to sample for one 12-hour period using only one set of tubes. Every fourth day a matrix spike was to be collocated with this single 12-hour run.

b. EPA Method TO-9. This method used a polyurethane foam (PUF) cartridge in a high volume sampler. The method called for approximately 325 m³ of throughput in each 24-hour period. This required differential pressure (Magnehelic) readings of approximately 50 inches of water. A single PUF cartridge, together with a filter, was used for each days sampling. Most of the cartridges used had been spiked by EPA with a carbon labelled dioxin isomer. Two field blanks were used at each site in addition to one or two travel blanks. The Kuwait and Saudi Arabia TO-9 samplers were initially calibrated with a five point flow calibration. Subsequent to this, single point calibrations were performed in Kuwait and five-point calibrations were performed in Saudi Arabia. These calibrations were performed prior and subsequent to each day's run.

c. EPA Method TO-13. This method is similar to EPA Method TO-9. The difference is that the TO-13 sampling procedure uses an XAD resin cartridge. The difficulty with this sampling was that tightness of the XAD cartridge made it impossible to achieve the desired flow rates of 325 cubic meters per day. The maximum achievable rates were between 100 and 200 cubic meters per day.

d. Collocated high volume particulate samplers equipped with PM₁₀ sampling hoods were at both sites. Initially, each sampler was used for 24-hour runs. Later, one of the samplers was used for 12-hour runs while the other remained sampling for 24 hours at a time. Each PM₁₀ sampler was initially calibrated with a five-point check on Day One of sampling. Subsequent calibrations were performed only if there were major equipment modifications to include motor replacement. There were no operational, calibration or other difficulties with this sampling.

e. Cascade Impaction. Cascade impactors were run at both sites in order to determine particle size distribution. The maximum sampling time at Kuwait was 30 minutes (longer sampling periods would have put undo strain on the electrical supply), while the sampling at Khobar Towers was run for as long as 2 hours.

⊗ Tenax is a registered trademark of GC-Enka ,N.V., The Netherlands.

⊗ SKC is a registered trademark of the SKC Inc., Eighty Four, Pennsylvania.



REPLY TO
ATTENTION OF

DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010-5422



HSHB-ME-SR

FINAL REPORT
KUWAIT OIL FIRE HEALTH RISK ASSESSMENT
NO. 39-26-L192-91
5 MAY - 3 DECEMBER 1991

APPENDIX C
SOIL SAMPLING AND SOIL PATHWAY ANALYSIS

1. **PURPOSE.** As part of the multimedia environmental sampling effort to assess the health risk from oil fires to U.S. military troops and Department of Defense (DOD) civilians involved in Operation Desert Storm, soil samples were collected to determine the risk from the dermal and incidental soil ingestion routes of exposure.

2. **GENERAL.**

a. **Background.**

(1) In response to health concerns for personnel exposed to smoke and residues from the burning and gushing oil wells in Kuwait, the U.S. Army Surgeon General, as lead for the DOD Tri-Services Working Group, tasked the U.S. Army Environmental Hygiene Agency (USAEHA) to perform a health risk assessment (HRA) on the impact of the oil well fires on DOD troops and civilians.

(2) To meet this objective the following information is presented to describe the methodology for collecting soil samples which will be used to assess the dermal and ingestion routes of exposure during the HRA. The soil sampling data will be combined with the air monitoring and industrial hygiene data to perform a comprehensive HRA that will evaluate all pathways/routes of exposure.

(3) The visual impact of over 600 burning oil wells emitting smoke to the environment dramatized the air pathway/inhalation impact of the fires. Large quantities of particulate matter, both respirable and nonrespirable, were produced by the fires and subsequently deposited on the soil at varying distances from the fires. These fire-related

particulates, along with the soil, were then available for incidental ingestion and dermal contact with the resultant potential health risk. To ensure that all major routes of exposure were evaluated (inhalation, ingestion, and dermal contact) soil sampling and analysis were conducted.

b. Exposed Populations. The Kuwait Risk Assessment Team's (KRAT) mandate was to assess the exposure and subsequent health risk to DOD troops and civilians. Therefore, our sampling was concentrated at major locations where troops were stationed. To determine the exposure to troops from locations where no fixed facilities exist and no ambient air sampling was conducted, soil sampling was considered for these locations if security and logistics would allow. Unfortunately these "temporary and/or previously occupied" locations could not be sampled due to safety and transportation difficulties. Sampling locations were therefore only selected from permanent facilities where U.S. troops were or had been located. However, for the air pathway analysis modeling will be conducted to assess the impact of the inhalation route at troop sites where no air sampling activities were conducted.

c. Contaminants of Concern.

(1) Soil samples were collected to assess the impact of the particulate fall-out from the oil fires. The composition of Kuwait crude oil is extremely complex (see Table C-1). In addition, combustion, incomplete combustion and transformation products were generated by the fires and environmental reactions. The crude oil contained arsenic, vanadium, and nickel. There was also some speculation that the crude oil contained mercury. These metals were therefore selected for analysis. In addition, lead, chromium, beryllium, iron, calcium, aluminum, sodium, cadmium, zinc, and magnesium were selected for analysis based on their toxicity, potential contribution to overall risk to DOD personnel, and abundance from natural and anthropogenic sources (see Table C-2).

(2) The entire spectrum of possible organic compounds could not be analyzed; therefore, the standard EPA semivolatile organic compound (SVOC) scan (see Table C-3) was performed on the soil samples. This scan included many of the carcinogenic polynuclear aromatic hydrocarbons (PAHs) that could potentially be produced by the fires and nonvolatile compounds that are contained in the crude oil. The organics selected for analysis were again based on the composition of the crude oil and the potential to be products of combustion. Contaminants that would be expected to be associated with the air medium but not the soil, due to their physical properties [i.e., volatile organic compounds (VOCs), gases, and acid gases], were not analyzed.

TABLE C-1. SAMPLE ASSAY OF KUWAIT CRUDE OIL

Pure Components:

| | |
|-----------------------|------------------|
| Anthracene | Iso-Butane |
| 1,4-Butanediol | Pentane |
| Benzene | Propane |
| Butadiene | Propylene |
| Butane | m-Xylene |
| Butylene | Methane |
| Cumene | n-Amyl Mercaptan |
| Cyclohexane | Naphthalene |
| Cyclopentane | Nonane |
| Decahydronaphthalene | Toluene |
| Ethyl Alcohol | Nonene |
| Ethyl Benzene | o-Xylene |
| Ethylene | Octane |
| Heptane | p-Xylene |
| Hydrogen | Pentane |
| Tetrahydronaphthalene | Phenol |

Natural Occurring Hydrocarbon Mixtures:

| | |
|---------------------------|----------------------|
| Asphalt | Oil Fuel: 1 |
| Cresols | Oil Fuel: 1-D |
| Kerosine | Oil Fuel: 2 |
| Waxes: Paraffin | Oil Fuel: 2-D |
| Distillates: Flash Stocks | Oil Fuel: 4 |
| Distillates: Straight Run | Oil Fuel: 5 |
| Gas Oil: Cracked | Oil Fuel: 6 |
| Gasoline: Casinghead | Oil: Clarified |
| Gasoline: Straight Run | Oil: Crude |
| Mineral Spirits | Oil: Diesel |
| Naptha: Coal Tar | Petroleum Naptha |
| Naptha: Solvent | Straight Run Residue |
| Jet Fuels: JP-1 | Jet Fuels: JP-4 |
| Jet Fuels: JP-3 | Jet Fuels: JP-5 |

TABLE C-1. SAMPLE ASSAY OF KUWAIT CRUDE OIL (Continued)

Contaminants:

| | |
|------------------------|------------------|
| Aminoethylethanolamine | Monoethanolamine |
| Arsenic | Nickel Carbonyl |
| Benzonitrile | Nickel |
| Benzylamine | Nitrobenzene |
| Diethanolamine | Sulfur |
| Ethyl Mercaptan | Vanadium |
| Ethylenediamine | Hydrogen Sulfide |

Combustion Products:

| | |
|---------------------|--------------------|
| Nitrogen Oxides | Tetrahydrofuran |
| Allyl Alcohol | Propylene Oxide |
| Dioxane | Sulfur Dioxide |
| n-Amyl Methylketone | Nitrogen Oxides |
| Carbon Dioxide | Vanadium Pentoxide |
| Water | |

Potential Combustion By-products:

| | |
|---|------------------------|
| Acetone | Methyl Ethyl Ketone |
| Acetophenone | Acid gases |
| C ₂ -C ₄₀ compounds | Alkyls, Esters, Ethers |
| Polycyclic Aromatic | Hydrocarbons |

TABLE C-2. METALS ANALYSIS CONDUCTED ON SOIL SAMPLES

| Metal | Limit of Quantitation (mg/kg) |
|--------------|--------------------------------------|
| Aluminum | 50.0 |
| Arsenic | 0.2 |
| Beryllium | 0.2 |
| Calcium | 10 |
| Cadmium | 2.0 |
| Chromium | 4.0 |
| Iron | 10.0 |
| Mercury | 0.04 |
| Magnesium | 50.0 |
| Sodium | 20.0 |
| Nickel | 10.0 |
| Lead | 0.2 |
| Vanadium | 10.0 |
| Zinc | 4.0 |

TABLE C-3. SEMIVOLATILE ORGANIC ANALYSIS CONDUCTED ON SOIL SAMPLES

| COMPOUND | LIMIT OF QUANTITATION ($\mu\text{g}/\text{kg}$) |
|------------------------------|--|
| phenol | 330 |
| bis (2-chloroethyl) ether | 330 |
| 2-chlorphenol | 330 |
| 1,3-dichlorobenzene | 330 |
| 1,4-dichlorobenzene | 330 |
| benzyl alcohol | 330 |
| 1,2-dichlorobenzene | 330 |
| 2-methylphenol | 330 |
| bis (2-chlorisopropyl) ether | 330 |
| 4-methylphenol | 330 |
| N-nitrosodi-n-propylamine | 330 |
| hexachloroethane | 330 |
| nitrobenzene | 330 |
| isophorone | 330 |
| 2-nitrophenol | 330 |
| 2,4-dimethylphenol | 330 |
| benzoic acid | 1,700 |
| bis (2-chloroethoxy) methane | 330 |
| 2,4-dichlorophenol | 330 |
| 1,2,4-trichlorobenzene | 330 |
| naphthalene | 330 |
| 4-chloroaniline | 330 |
| hexachlorobutadiene | 330 |
| 4-chloro-3-methylphenol | 330 |
| 2-methylnaphthalene | 330 |
| hexachlorocyclopentadiene | 330 |
| 2,4,6-trichlorophenol | 330 |
| 2,4,5-trichlorophenol | 1,700 |
| 2-chloronaphthalene | 330 |
| 2-nitroaniline | 1,700 |
| dimethyl phthalate | 330 |
| acenaphthylene | 330 |

TABLE C-3. SEMIVOLATILE ORGANIC ANALYSIS CONDUCTED ON SOIL
 SAMPLES (Continued)

| COMPOUND | LIMIT OF QUANTITATION ($\mu\text{g}/\text{kg}$) |
|------------------------------|--|
| 3-nitroaniline | 1,700 |
| acenaphthene | 330 |
| 2,4-dinitrophenol | 1,700 |
| 4-nitrophenol | 1,700 |
| dibenzofuran | 330 |
| 2,4-dinitrotoluene | 330 |
| 2,6-dinitrotoluene | 330 |
| diethyl phthalate | 330 |
| 4-chlorophenyl phenyl ether | 330 |
| fluorene | 330 |
| 4-nitroaniline | 1,700 |
| 2-methyl-4,6-dinitrophenol | 1,700 |
| N-nitrosodiphenylamine | 330 |
| 4-bromophenyl phenyl ether | 330 |
| hexachlorobenzene | 330 |
| pentachlorophenol | 1,700 |
| phenanthrene | 330 |
| anthracene | 330 |
| di-n-butyl phthalate | 330 |
| fluoranthene | 330 |
| pyrene | 330 |
| butyl benzyl phthalate | 330 |
| 3,3'-dichlorobenzidine | 330 |
| benzo (a) anthracene | 330 |
| bis (2-ethylhexyl) phthalate | 330 |
| chrysene | 330 |
| di-n-octyl phthalate | 330 |
| benzo (b) fluoranthene | 330 |
| benzo (K) fluoranthene | 330 |
| benzo (a) pyrene | 330 |
| indeno (1,2,3-cd) pyrene | 330 |
| dibenz (a,h) anthracene | 330 |
| benzo (ghi) perylene | 330 |

d. Analytical Support. Samples collected in the field were sent to a central in-theater holding facility at Khobar, Saudi Arabia for any required preparation prior to shipment to the U.S. Soil samples were shipped to USAEHA for laboratory analyses (see Appendix E for a complete discussion of analytical methodology and quality assurance).

3. **SAMPLING CONCEPT.** The following paragraphs describe the approach that was used to conduct the soil sampling.

a. Sampling Occupied Areas. Samples were collected from the areas where U.S. troops were concentrated. At each selected troop location three to five soil samples were collected when the KRAT arrived. Surface composite samples were collected from 100 yard by 100 yard areas. Each composite consisted of 50 to 100 subsamples depending on the consistency of the soil and the sampling depth. This method of collection will give a better representation of the contaminants the troops were exposed to than single point discrete samples. Surface soil samples represent what troops would be exposed to by the dermal and incidental ingestion routes better than core samples. The sampling depth was the top 1 to 2 inches of soil. Soil samples were collected from the same general areas where ambient air sampling stations were located to complete the exposure assessment for all pathways. A second and sometimes a third round of soil samples were collected from the same permanent (i.e., long-term) air sampling locations and in an identical manner as the first round. This was done to try and discern if the deposition of fire-generated particulates could be measured in the soil through an increase in contaminant levels.

b. Sample Collection Methodology. The 100 yard by 100 yard sampling areas were randomly selected from within the troop areas, since the deposition of particulates should not vary substantially within the individual troop locations. Samples for organic and metals analyses were collected in pre-cleaned 1-quart glass bottles with Teflon®-lined lids. Samples were collected with disposable Teflon-coated scoops and/or spatulas to avoid organic and/or metals contamination from the sampling equipment and cross contamination between sampling sites. Each individual sub-sample was placed in a quart bottle and mixed thoroughly with the other sub-samples. In addition, the samples were mixed prior to extraction to ensure a homogeneous sample. Individual sub-sample locations within each sample site were selected at random. Sample bottles were labeled with pertinent information (i.e., identification number, sample type, date and time, location, name of collector) and placed in containers for shipment to the laboratory.

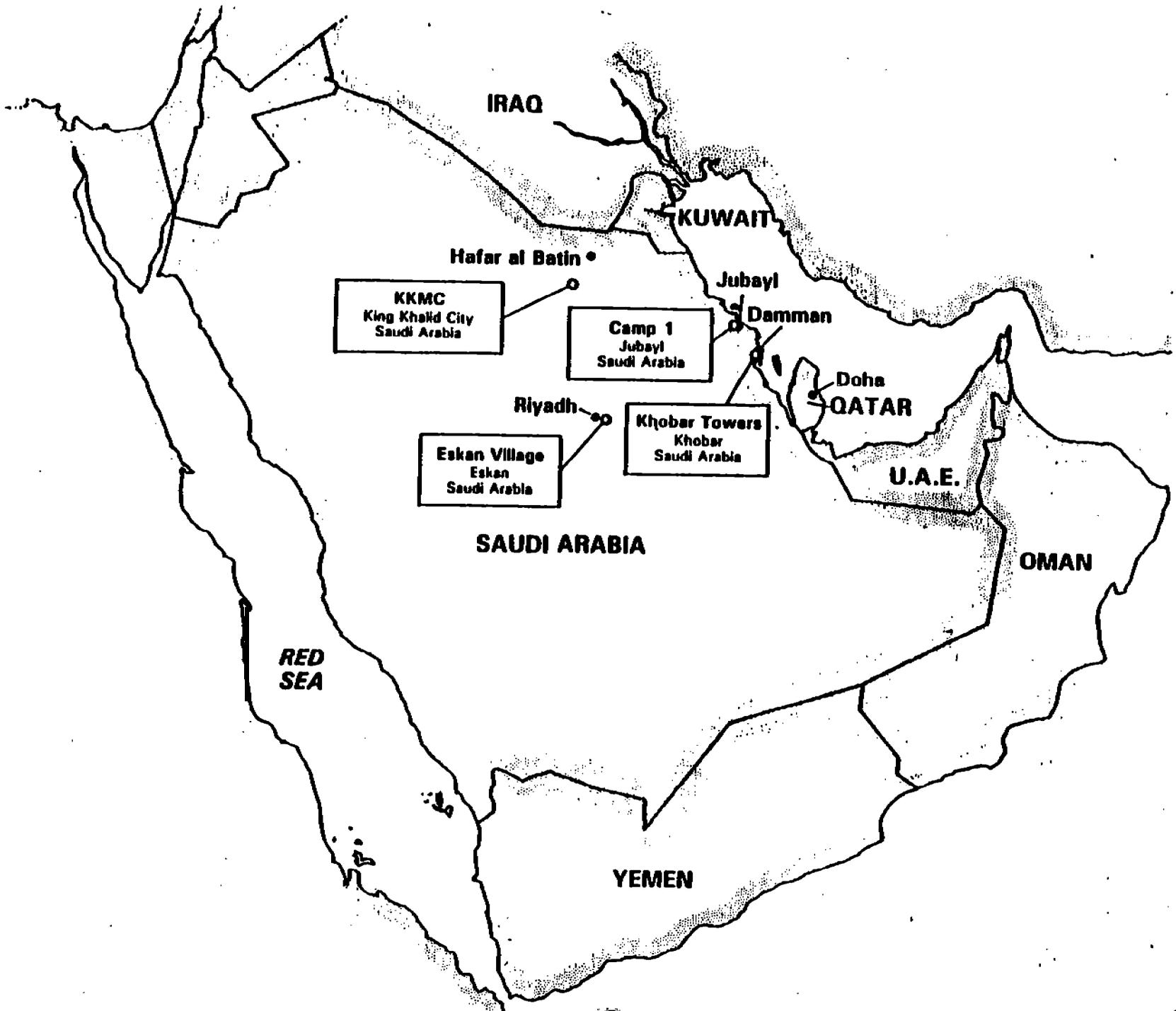
® Teflon is a registered trademark of E.I. DuPont de Nemours & Co., Inc., Wilmington, Delaware.

c. Sampling Locations. Sampling locations were selected based on their proximity to where a majority of U.S. troops and DOD civilians were located for extended periods of time during and after the war (see Figures C-1 and C-2 and Table C-4). The only exception was the Ahmadi Hospital site which was selected due to its close proximity to the fires (less than 400 meters) and its use by other agencies including the (EPA, Harvard School of Public Health and the Kuwait Environmental Protection Division). This site data can be used to compare near-source soil data with that collected from sites at varying distances from the fires. In addition to sites selected for sampling, Table C-4 also contains sampling dates and sample locations within each site. Complete descriptions of each sampling location are contained in Appendix B of the interim report. Individual sample sites are shown in Figures C-3 through C-12.

d. Quality Assurance/Quality Control (QA/QC). QA/QC measures for sampling and analysis must be followed to support any conclusions regarding risk. The standard QA/QC procedures implemented throughout this HRA included: duplicate samples (10 percent), split samples (5 percent), holding times, sample preservation, chain of custody, spiked samples in the laboratory and sample collection information.

(1) Duplicate and split sample analyses results are contained in Tables C-5 through C-11. Duplicate samples represent samples that are collected from the exact same location within a sampling site; however, the sub-samples are collected from different locations within the sampling area. Split samples are a division of the same sample that is analyzed twice in the laboratory. Randomly chosen duplicate and split samples were analyzed using the "t" test to determine the difference in the mean and variance of duplicate pairs. The threshold significance value for the 95 percent confidence level in the data (two tailed test) is 2.2. The combined duplicate and split sample data were evaluated by chemical and the "t" statistic ranged from -1.66 to 2.17. Therefore, based on the statistical evaluation that the samples are not significantly different, the soil sample data quality is considered adequate for use in the HRA.

(2) Holding Times. The holding time for semivolatile organics is 14 days. Table C-12 shows the holding times for the various sample site collections from the two rounds presented in the interim report. Holding times ranged from 13 to 40 days with a mean of 22 days. Holding times for the second round of sampling improved and had a mean of 16.5 days. The logistical difficulties associated with transporting samples within the region and back to the United States for analysis greatly contributed to the difficulties in meeting holding times. The holding time for total metals analysis (see Table C-13) is 6 months, with the exception of mercury which is 28 days. Holding times for metals ranged from 16 to 40 days with a mean of 27 days. Holding times for rounds 3 and 4 were not a problem. The samples were collected close to departure times back to the U.S., and the samples were carried on the aircraft and delivered to the USAEHA laboratory immediately upon return.



C-10

Figure C-1. Soil Sampling Sites in Saudi Arabia.

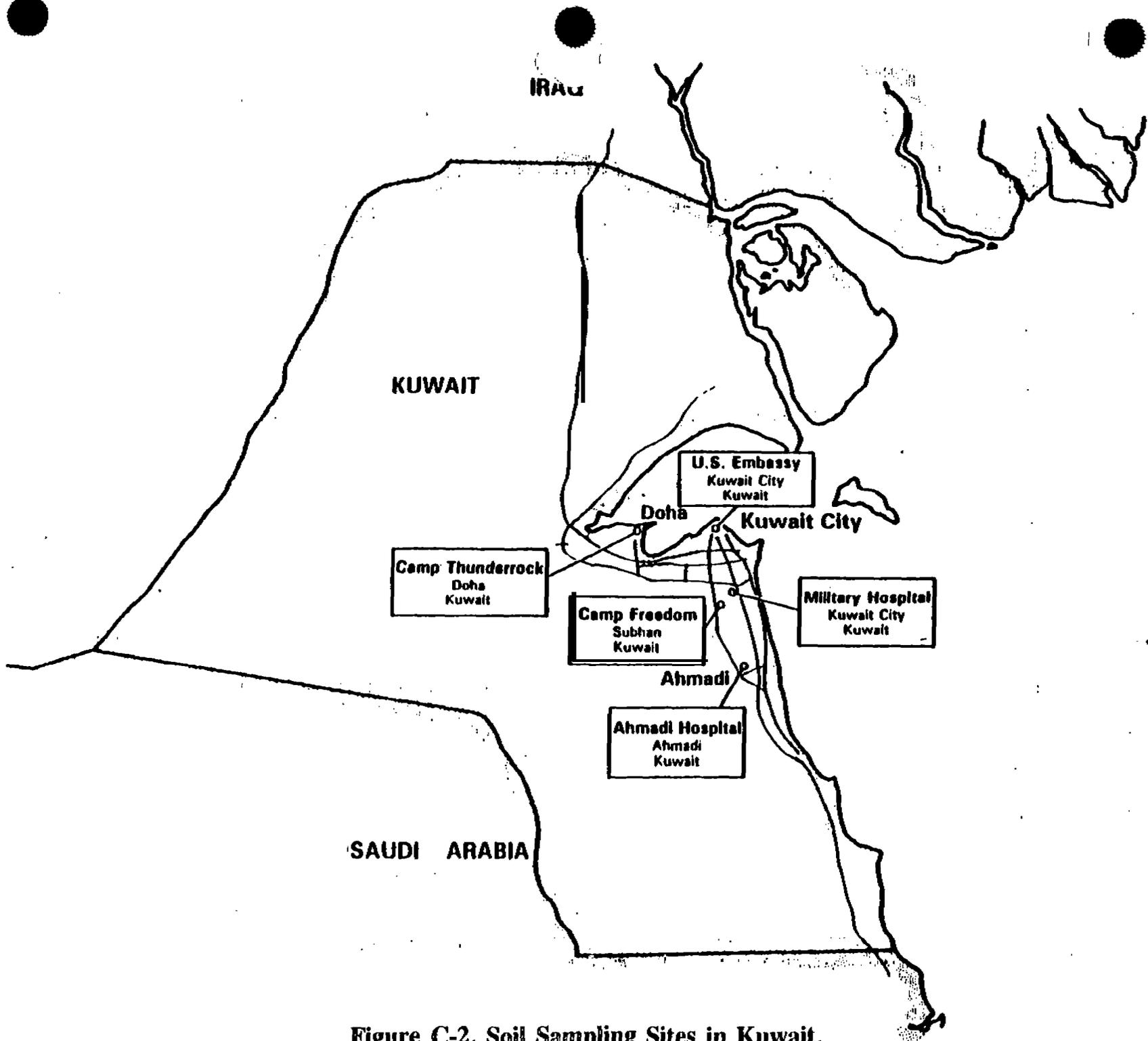


Figure C-2. Soil Sampling Sites in Kuwait.

TABLE c-4. Summary of Project Sampling Locations

| SAMPLING SITE LOCATION | SAMPLING SUB-SITE | SAMPLING DATES | |
|--------------------------------|--|--|---------------------------|
| | | ROUND 1 | ROUND 2 |
| Khobar Towers Al Khobar, SA | 600 yards southwest of main gate North and of soccer field west of Bldg. 414 Parking area closest to southwest gate (due west of Bldg. 305) Due west of Bldg. 133, east of rear gate Around Bldg. 207 | DA-1A/1B DA-2A/2B DA-3A/3B DA-4A/4B DA-5A/5B | 14 May 91 12 September 91 |
| camp 1 Al Jubayl, SA | Camp Command Post (Office 1 Complex) Around Wastewater Treatment Plant, east corner of camp Around transformers near Bldg. 910 A, on southeast side of camp Volleyball court area, south corner of camp Recreation Center 3 around Bldg. 912 A | AJ-1A/1B AJ-2A/2B AJ-3A/3B AJ-4A/4B AJ-5A/5B | 12 May 91 15 August 91 |
| Eskan Village Riyadh, SA | Army side, Bldg. B5-09, physical training area AF side, median strip area from (Army side) Bldgs. 431 and 433 AF side, median road sidewalk strip opposite Bldg. 425 Army side Wadi, near C Street gate AF side, play area by Villa 2-16 | R-1A/1B R-2A/2B R-3A/3B R-4A/4B R-5A/5B | 16 May 91 24-26 August 91 |
| KKMC SA | Field west of PM laboratory trailer (Padgett Laboratory) Hardball intersection near Hotel Panza POMCUS site at King Khalid Military City 2nd AD (F), 2nd ACR, site near 22nd SUP COM Support Center East of caterer site for 3rd AD BIVOUAC, near KKMC | KK-1A/1B KK-2A/2B KK-3A/3B KK-4A/4B KK-5A/5B | 18 May 91 24-26 August 91 |
| Camp Freedom Kuwait | Southwest side of camp, across from helipad South side of camp, near outside wall Due south of mosque Strip south of Bldg. F1006 Strip south of Bldg. 2008 | CF-1A/1B CF-2A/2B CF-3A/3B CF-4A/4B CF-5A/5B | 10 May 91 24-26 August 91 |

Footnotes. See Page C- .

TABLE C-4. Summary of Project Sampling Locations
(continued)

| SAMPLING SITE LOCATION | SAMPLING SUB-SITE | SAMPLE DESIGNATION | SAMPLING DATES | |
|----------------------------------|--|-----------------------|----------------|-----------------|
| | | | ROUND 1 | ROUND 2 |
| Military Hospital Kuwait | East of hospital, west of temporary helipad, almost directly between hospital and helipad | MH-1A/1B | 25 May 91 | 24-26 August 91 |
| | Southeast of mosque | MH-2A/2B | | |
| | South and east of permanent helipad, on west side of hospital | MH-3A/3B | | |
| Camp Thundercock Doha, Kuwait | Near road to entertainment city, east of camp, directly west of road, in line with south perimeter of camp | CT-1A/1B | 3 July 91 | 24-26 August 91 |
| | Directly east of camp, between camp and CT-1A/1B sampling location, in line with south perimeter of camp | CT-2A/2B | | |
| | East of camp, west of road to entertainment city, in line with north perimeter of camp | CT-3A/3B | | |
| | In line with old recreation area, now no storage explosion | CT-4A/4B | | |
| | In line with old recreation area, now no mans land due to storage explosion | CT-5A/5B | | |
| U. S , Embassy K.C. , Kuwait | Between volleyball court and pool building | EM-1A/1B | 23 May 91 | 24-26 August 91 |
| | Between volleyball court, playground equipment, and camp perimeter | EM-2A/2B | | |
| | Behind guard house, between guard house and Arabian Gulf St. | EM-3A/3B | | |
| | Behind Ambassadors House, between house and camp perimeter | EM-4A/4B | | |
| Al Ahmadi Hospital Kuwait | North of parking area | AH-1A/1B | | |
| | West of parking area | AH-2A/2B | | |
| | East of parking area | AH-3A/3B | | |

Footnotes.

SA = Saudi Arabia.

KKMC = King Khalid Military City.

K.C. = Kuwait City.

● = The CT-4B sampling location had to be moved to south perimeter due to live UXO in no mans land.

+ = The CT-5B sampling location had to be moved to north perimeter due to live UXO in no mans land.

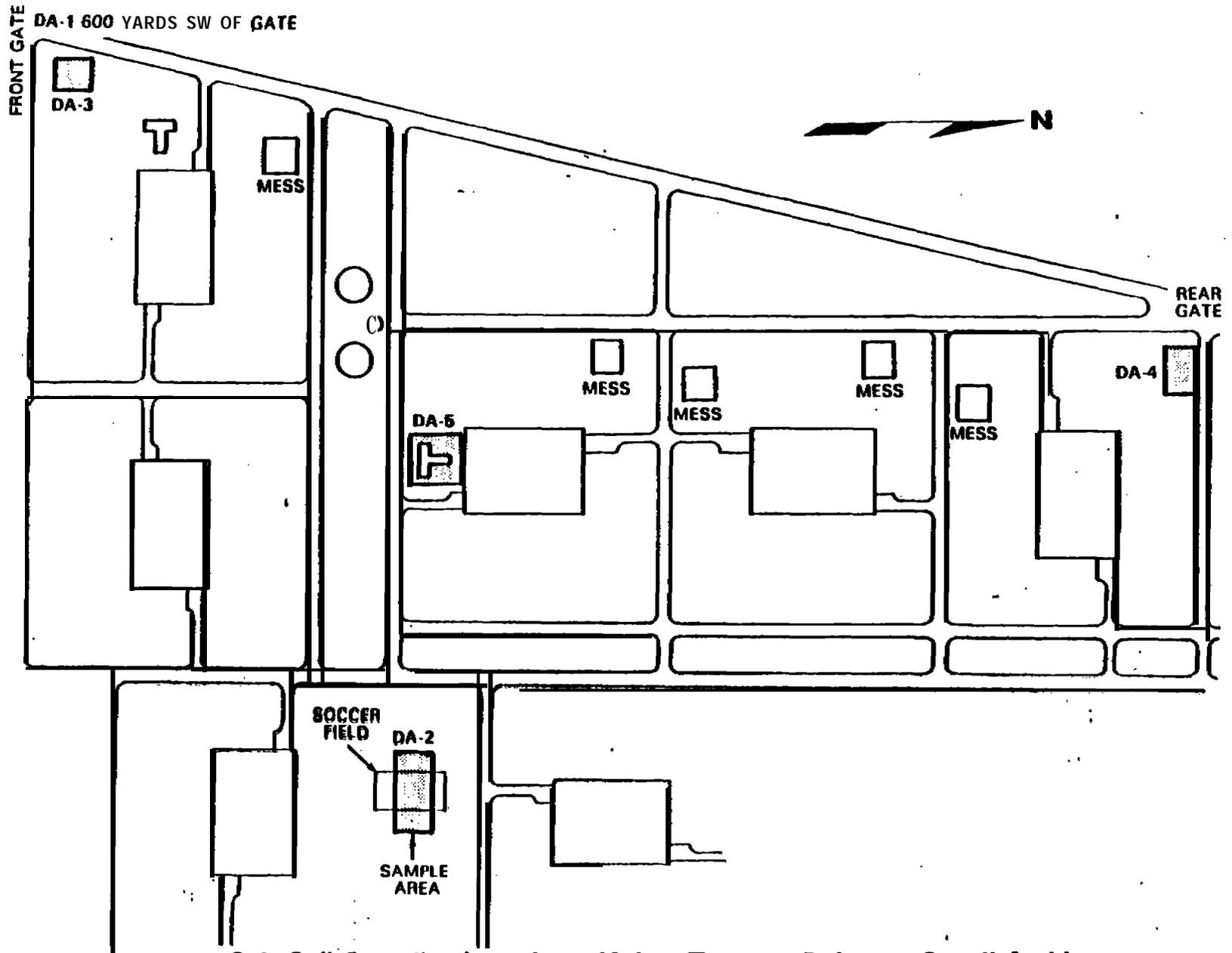


Figure C-3. Soil Sampling Locations, Kobar Towers, Daharan, Saudi Arabia.

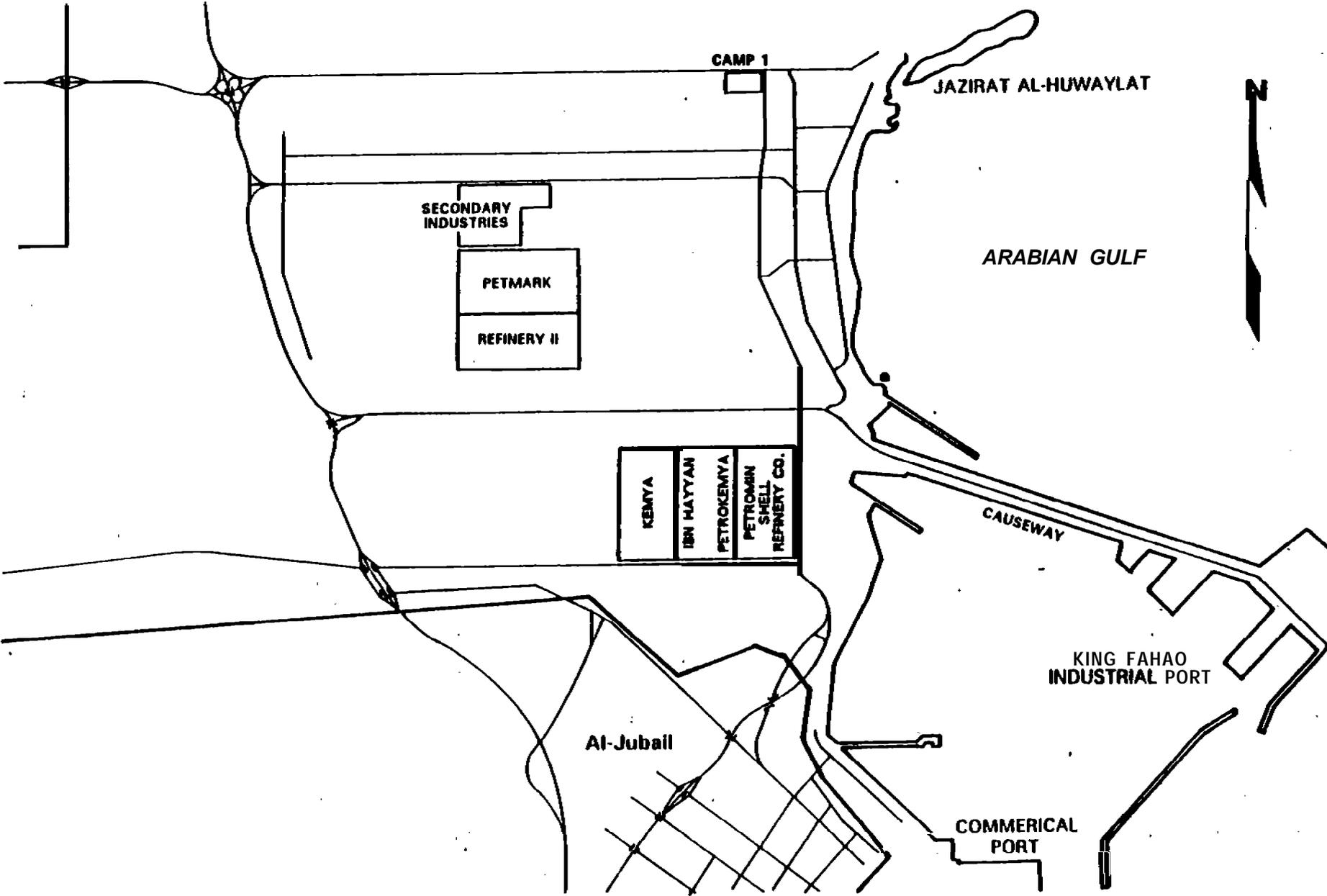


Figure C-4. Location of Camp 1, At Jubatt, Saudi Arabia.

C-15

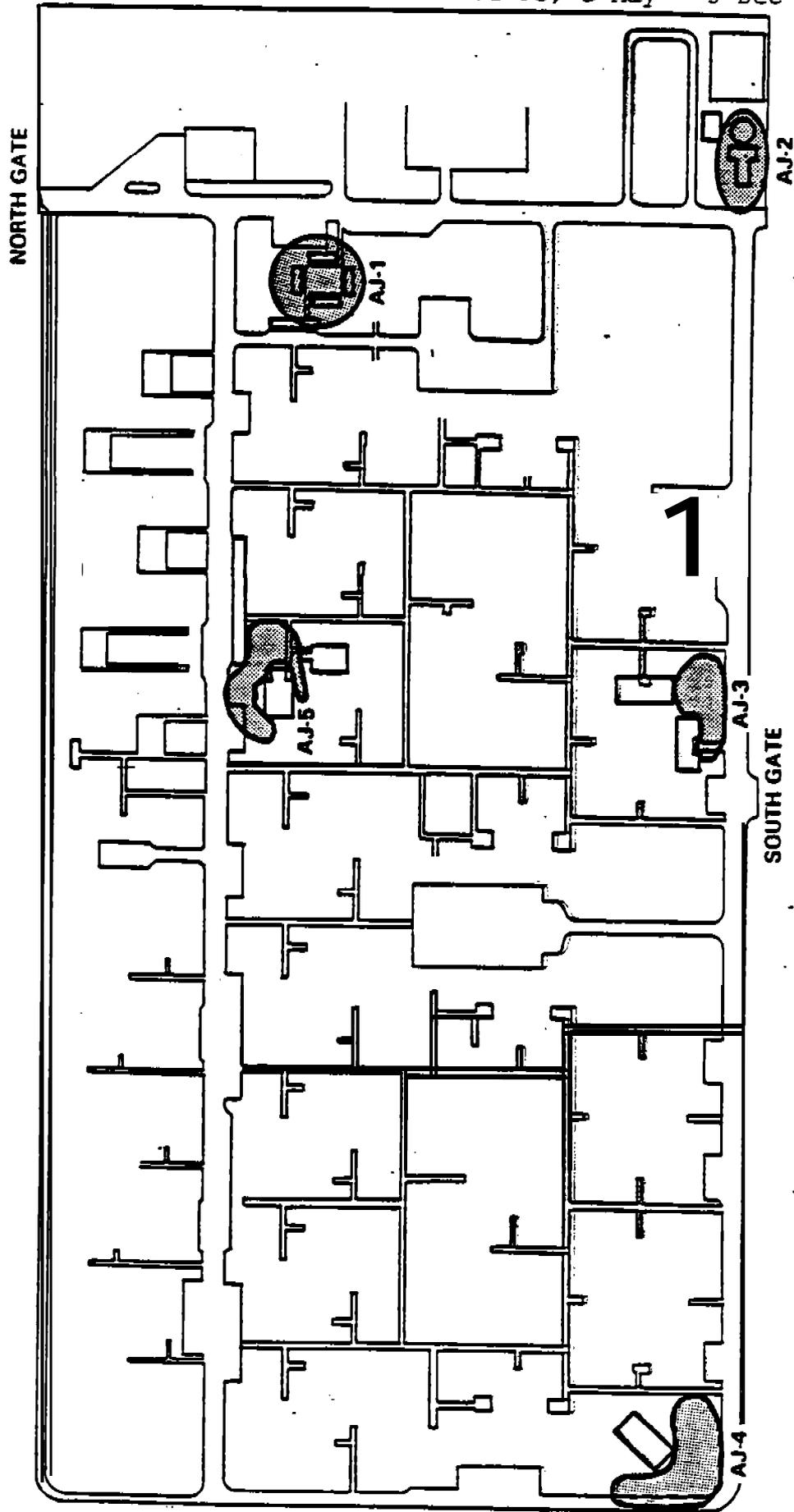


Figure C-5. Soil Sampling Locations at Camp 1, Al Jubail, Saudi Arabia.

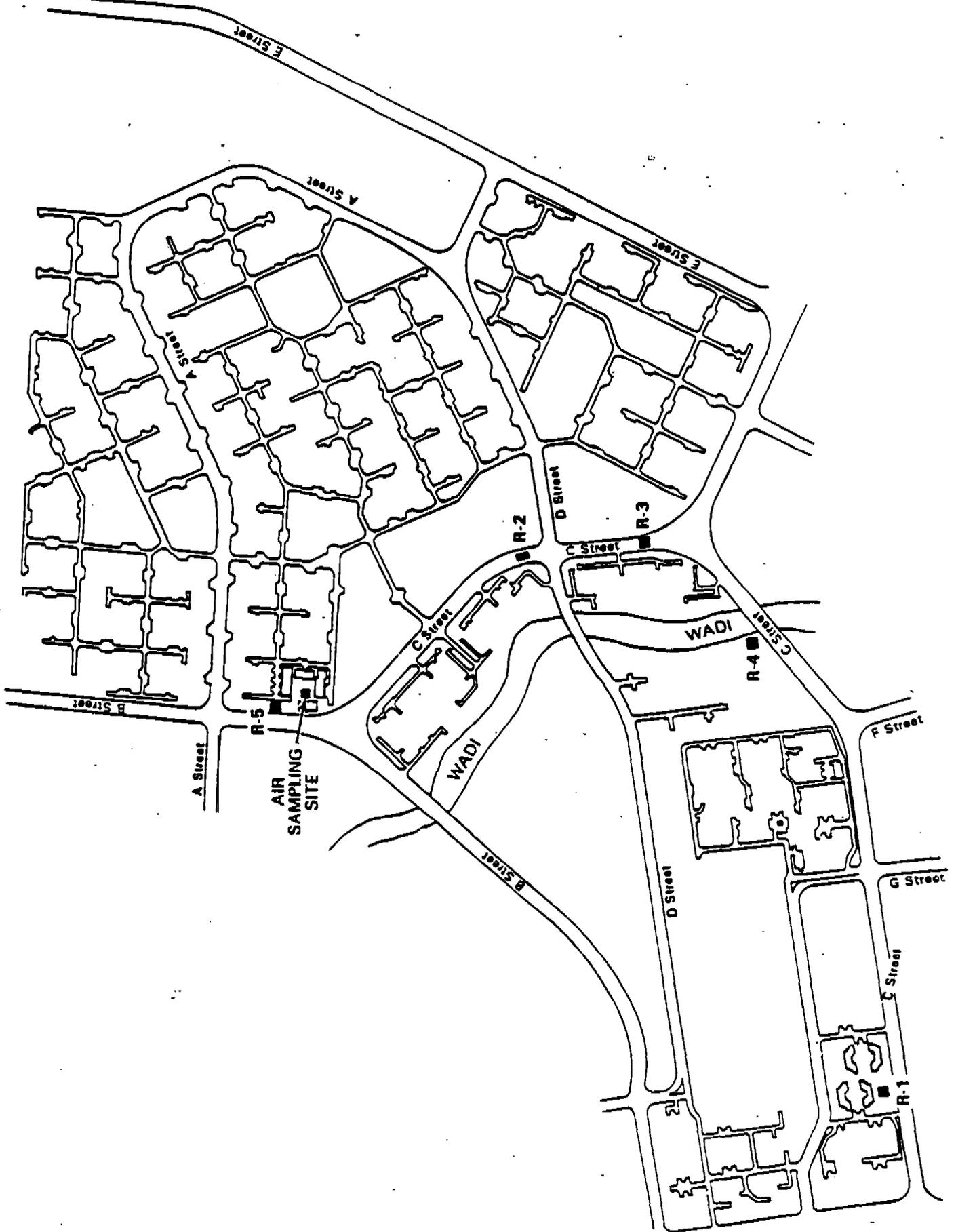


Figure C-6 Soil Sampling Locations, Eskan Villane, Riyadh, Saudi Arabia

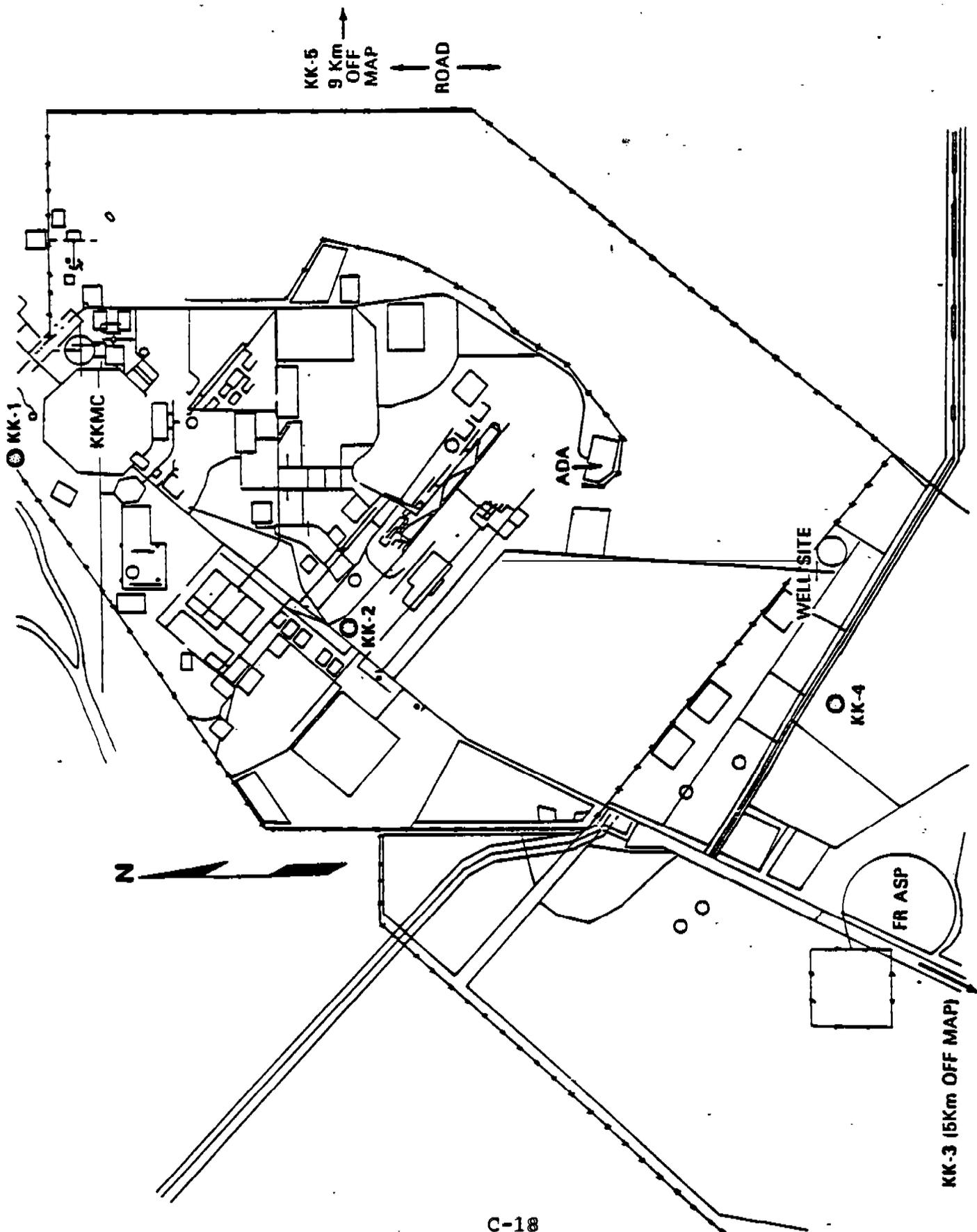


Figure C-7. Soil Sampling Locations King Fahd Military City, Saudi Arabia.

C-19

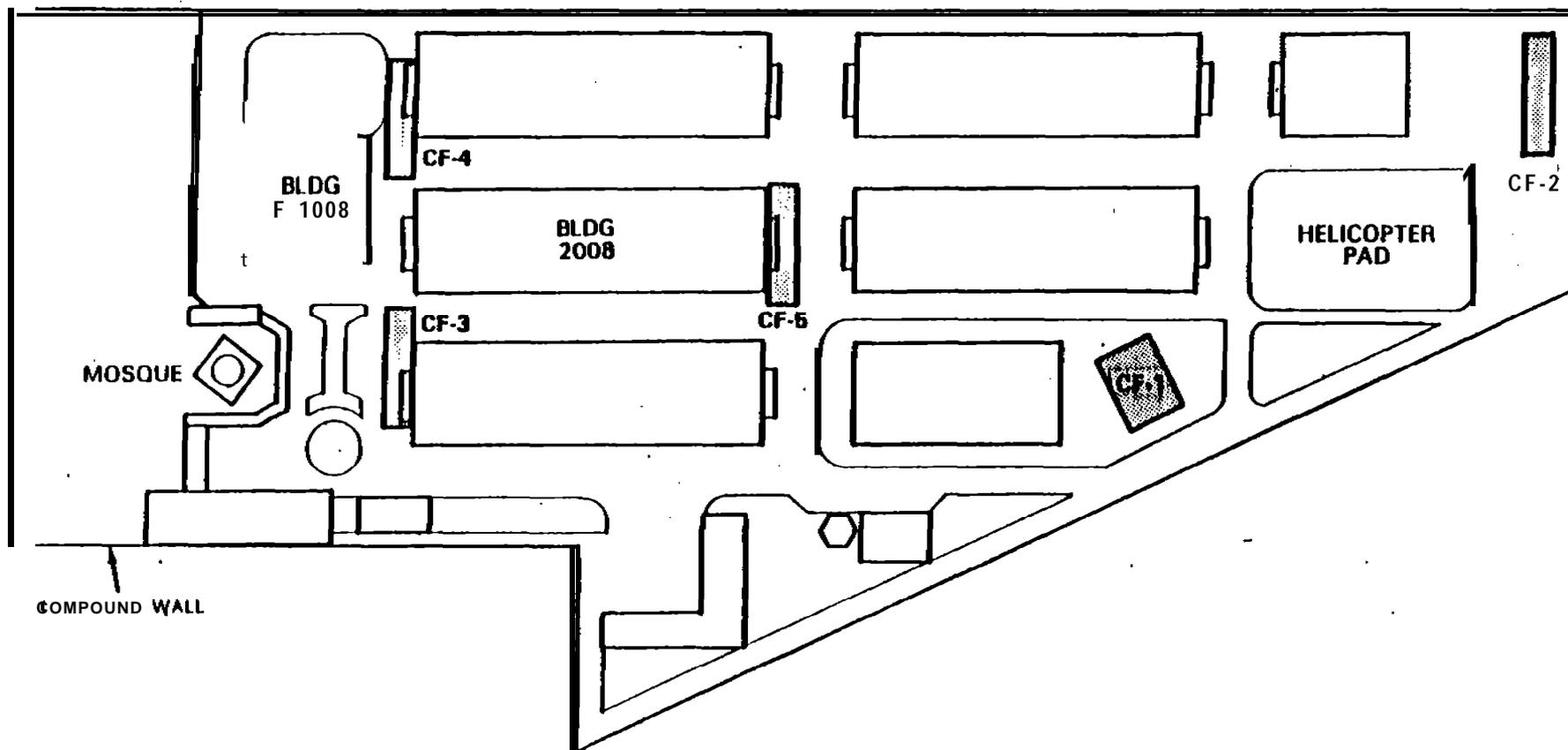
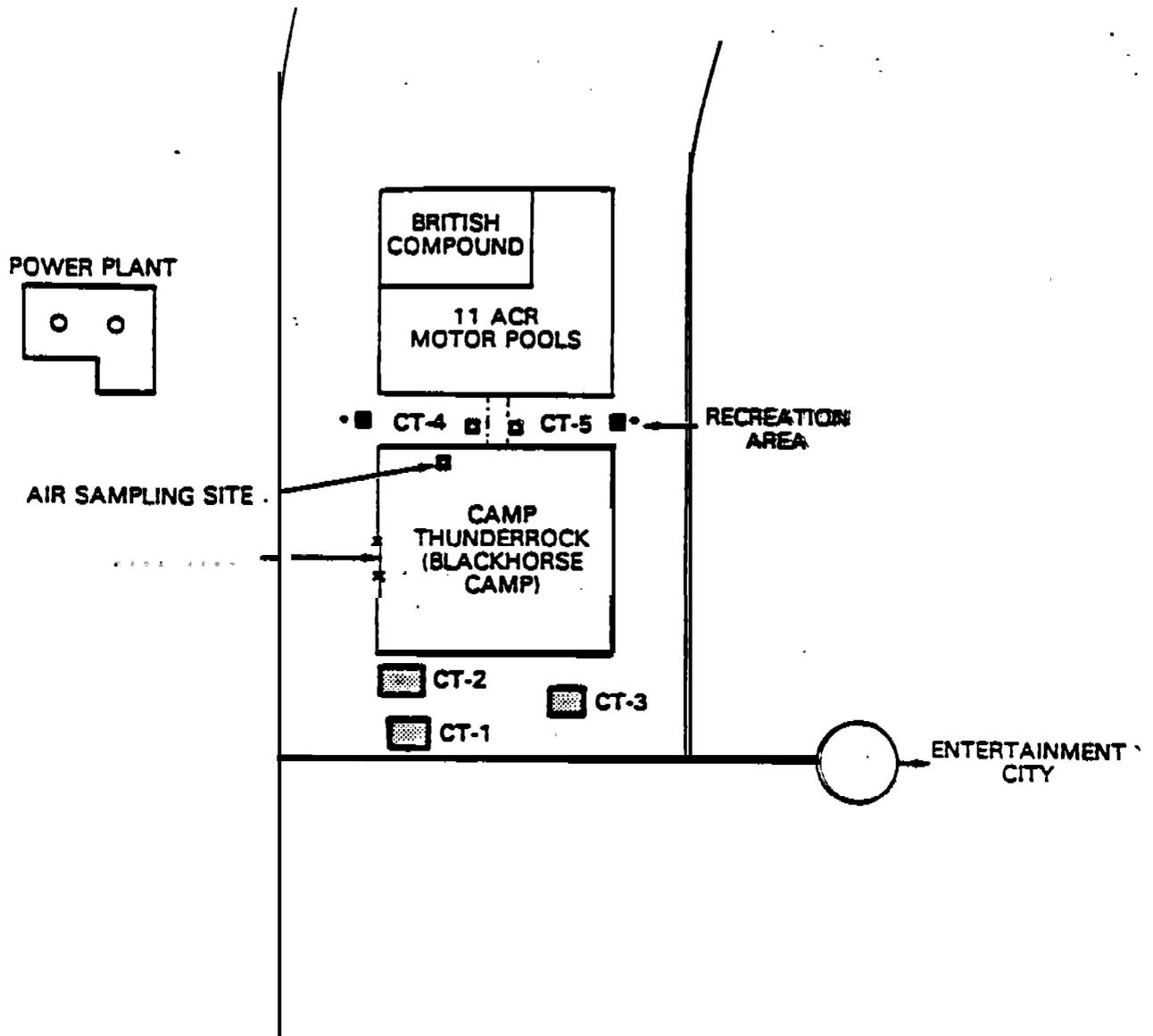


Figure C-8. Soil Sampling locations at Camp Freedom, Kuwait.



• NEW CT-4 & CT-5 SAMPLING LOCATION FOLLOWING EXPLOSION AT CAMP THUNDERROCK 22 AUG 91.

Figure C-9. Soil Sampling Locations at Camp Thunderrock, Doha, Kuwait.

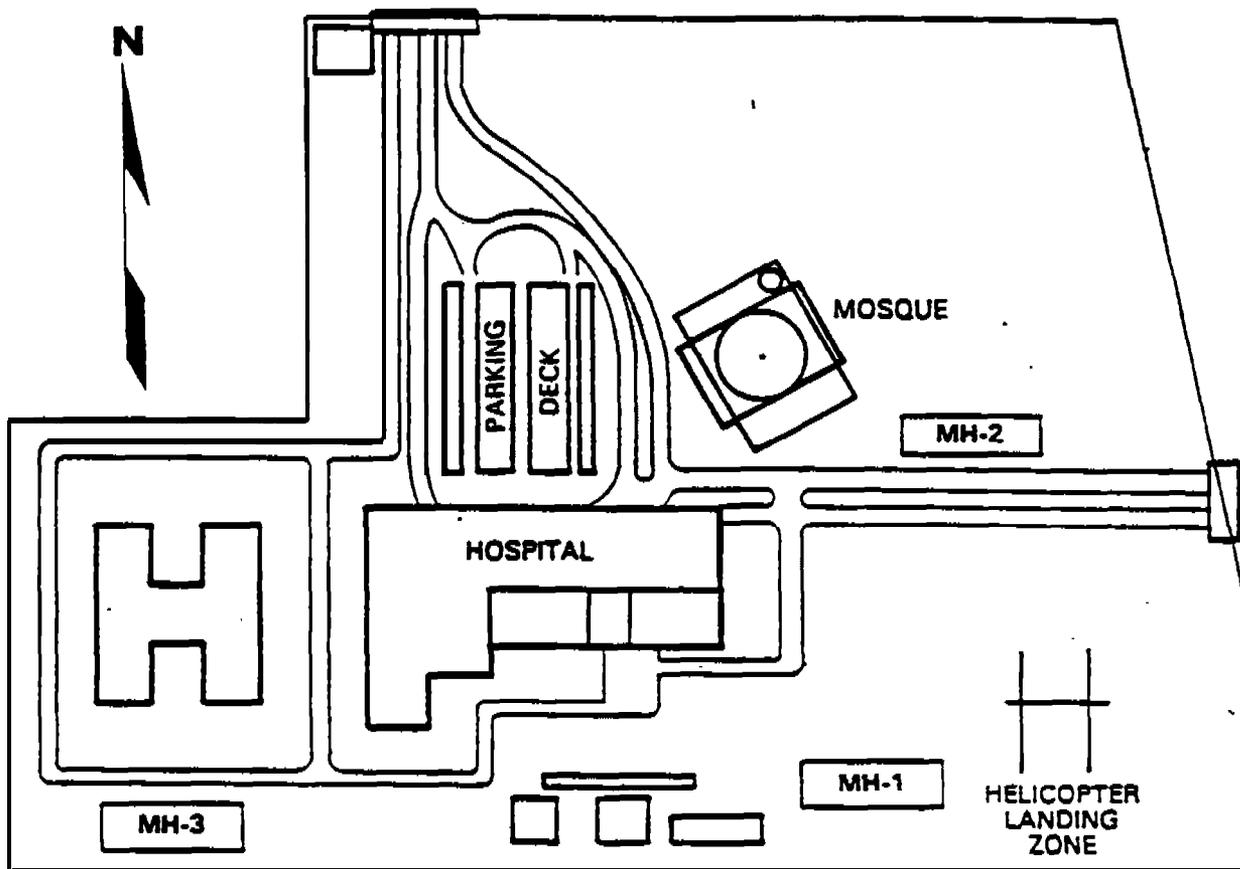


Figure C-I 0. Soil Sampling Locations at Kuwait Military Hospital.

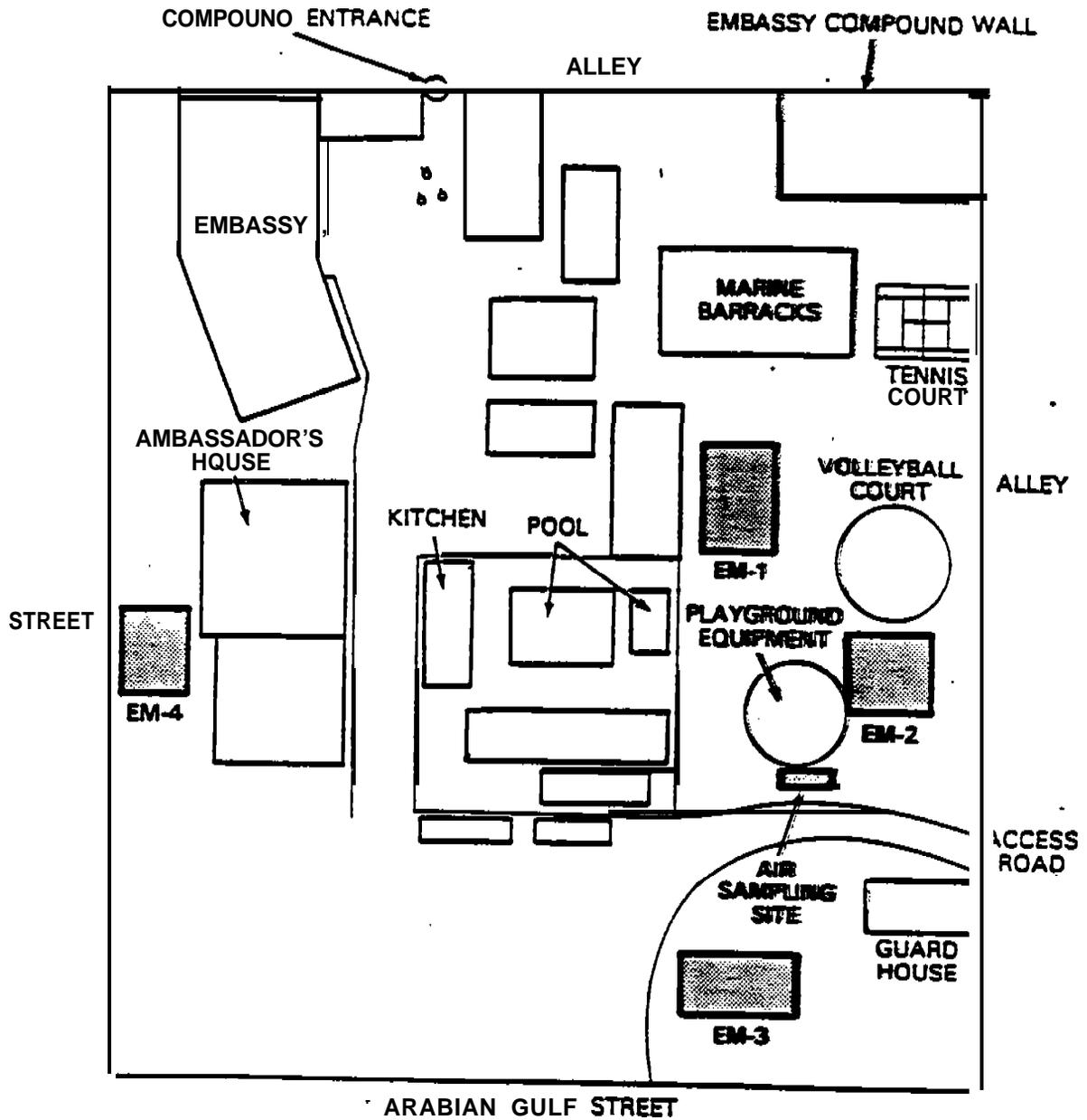
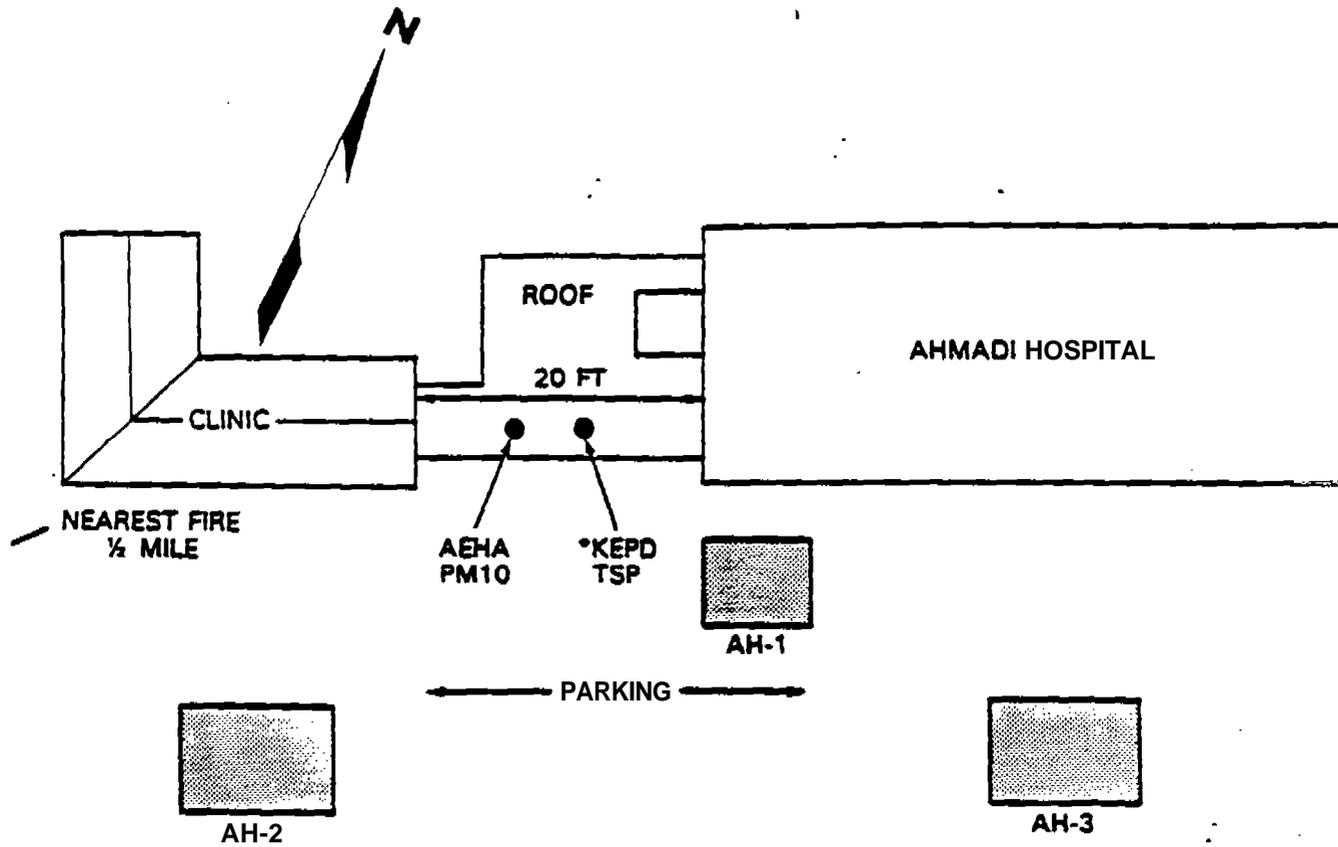


Figure C-1 1. Soil Sampling Locations at U.S. Embassy, Kuwait City.



*KUWAIT ENVIRONMENTAL PROTECTION DIVISION

Figure C-f 2. Soil Sampling Locations at Al Ahmadi Hospital, Kuwait.

TABLE c-5. Change in Total Metals Concentrations*
for Quality Assurance/Quality Control Samples
Khobar Towers, Al Khobar, Saudi Arabia

DUPLICATE SAMPLE

| METAL | DA-2B | DA-2B-D ⁺ | CHANGE +/- % |
|-----------|-------|----------------------|--------------|
| Aluminum | 3400 | 3100 | -8.82 |
| Arsenic | 1.6 | 1.3 | -18.75 |
| Beryllium | 0.085 | 0.10 | 17.65 |
| Calcium | 13000 | 10000 | -23.08 |
| Cadmium | 3.8 | 4.4 | 15.79 |
| Chromium | 16 | 15 | -6.25 |
| Iron | 3500 | 3500 | 0.00 |
| Mercury | 0.052 | 0.059 | 13.46 |
| Magnesium | 13000 | 10000 | -23.08 |
| Sodium | 6900 | 5900 | -14.49 |
| Nickel | 23 | 22 | -4.35 |
| Lead | 10 | 9.4 | -6.00 |
| Vanadium | 16 | 13 | -18.75 |
| Zinc | 46 | 67 | 45.65 |

SPLIT SAMPLE

| METAL | DA-58 | DA-58-S ⁺ | CHANGE +/- % |
|-----------|-------|----------------------|--------------|
| Aluminum | 2300 | 2600 | 13.04 |
| Arsenic | 0.92 | 0.94 | 2.17 |
| Beryllium | 0.095 | 0.095 | 0.00 |
| Calcium | 56000 | 61000 | 8.93 |
| Cadmium | 3.0 | 3.0 | 0.00 |
| Chromium | 12 | 14 | 16.67 |
| Iron | 2500 | 2900 | 16.00 |
| Mercury | 0.038 | 0.038 | 0.00 |
| Magnesium | 6700 | 6900 | 2.99 |
| Sodium | 580 | 480 | -17.24 |
| Nickel | 22 | 20 | -9.09 |
| Lead | 6.2 | 9.2 | 48.38 |
| Vanadium | 10 | 12 | 20.00 |
| Zinc | 34 | 33 | -2.94 |

Footnotes.

- = All total metals concentrations are expressed in milligrams per kilogram (mg/kg).
- + = A "D" indicates a duplicate sample: a "S" indicates a split sample.

**TABLE C-6. Change in Total Metals Concentrations*
for Quality Assurance/Quality Control Samples
Eskan Village, Riyadh, Saudi Arabia**

| DUPLICATE SAMPLE | | | |
|-------------------------|-------------|---------------------------|---------------------|
| METAL | R-28 | R-2B-D⁺ | CHANGE +/- % |
| Aluminum | 3000 | 3670 | 22.33 |
| Arsenic | 2.5 | 2.2 | -12.00 |
| Beryllium | 0.62 | 0.48 | -22.58 |
| Calcium | 140000 | 110000 | -21.43 |
| Cadmium | 2.1 | 1.0 | -52.38 |
| Chromium | 22 | 19 | -13.64 |
| Iron | 5400 | 5600 | 3.70 |
| Mercury | 0.019 | 0.020 | 5.26 |
| Magnesium | 2670 | 3310 | 23.97 |
| Sodium | 1400 | 6200 | 342.86 |
| Nickel | 14 | 19 | 35.71 |
| Lead | 11 | 10 | -9.09 |
| Vanadium | 18 | 19 | 5.56 |
| Zinc | 51 | 56 | 9.80 |

| SPLIT SAMPLE | | | |
|---------------------|----------------|----------------|---------------------|
| METAL | R - 4 8 | R-48-8' | CHANGE +/- % |
| Aluminum | 3420 | 3680 | 7.60 |
| Arsenic | 1.6 | 3.4 | 112.50 |
| Beryllium | 0.41 | 0.44 | 7.32 |
| Calcium | 130000 | 180000 | 38.46 |
| Cadmium | 2.3 | 2.5 | 8.70 |
| Chromium | 19 | 21 | 10.53 |
| Iron | 4800 | 4900 | 2.08 |
| Mercury | 0.0195 | 0.020 | 2.56 |
| Magnesium | 3120 | 3280 | 5.13 |
| Sodium | 7000 | 6900 | -0.14 |
| Nickel | 16 | 17 | 6.25 |
| Lead | 11 | 13 | 18.18 |
| Vanadium | 19 | 21 | 10.53 |
| Zinc | 32 | 37 | 15.63 |

Footnotes.

* = All total metals concentrations are expressed in milligrams per kilogram (mg/kg).

+ = A "D" indicates a duplicate sample: a "S" indicates a split sample.

TABLE C-7. Change in Total Metals Concentrations*
 for Quality Assurance/Quality Control Samples
 King Khalid Military City, Saudi Arabia

| DUPLICATE SAMPLE | | | |
|-------------------------|--------------|----------------------------|---------------------|
| METAL | KK-2B | KK-2B-D⁺ | CHANGE +/- % |
| Aluminum | 3750 | 3630 | -3.20 |
| Arsenic | 2.9 | 2.9 | 0.00 |
| Beryllium | 0.53 | 0.41 | -22.64 |
| Calcium | 96000 | 130000 | 35.42 |
| Cadmium | 2.0 | 2.4 | 20.00 |
| Chromium | 18 | 20 | 11.11 |
| Iron | 5200 | 4700 | -9.62 |
| Mercury | 0.038 | 0.039 | 2.63 |
| Magnesium | 6170 | 6830 | 10.70 |
| Sodium | 350 | 300 | -14.29 |
| Nickel | 16 | 14 | -12.50 |
| Lead | 6.4 | 4.3 | -32.81 |
| Vanadium | 20 | 20 | 0.00 |
| Zinc | 4.75 | 96 | 1921.05 |

Footnotes.

- * = All total metals concentrations are **expressed** in milligrams per kilogram (mg/kg).
- + = A "D" indicates a duplicate sample: a "S" indicates a split sample.

**TABLE C-8. Change in Total Metals Concentrations*
for Quality Assurance/Quality Control Samples
Camp Freedom, Kuwait**

| DUPLICATE SAMPLE | | | |
|-------------------------|--------------|----------------------------|---------------------|
| METAL | CF-1B | CF-1B-D⁺ | CHANGE +/- % |
| Aluminum | 4130 | 2710 | -34.28 |
| Arsenic | 1.1 | 0.67 | -39.09 |
| Beryllium | 0.43 | 0.37 | -13.95 |
| Calcium | 43000 | 26000 | -39.53 |
| Cadmium | 0.95 | 1.0 | 5.26 |
| Chromium | 14 | 8.3 | -40.71 |
| Iron | 4100 | 2800 | -31.71 |
| Mercury | 0.0195 | 0.0195 | 0.00 |
| Magnesium | 4500 | 2770 | -38.44 |
| Sodium | 210 | 180 | -14.29 |
| Nickel | 15 | 4.9 | -67.33 |
| Lead | 6.7 | 4.5 | -32.84 |
| Vanadium | 16 | 11 | -31.25 |
| Zinc | 12 | 10 | -16.67 |

SPLIT SAMPLE

| METAL | CF-2B | CF-2B-S⁺ | CHANGE +/- % |
|--------------|--------------|----------------------------|---------------------|
| Aluminum | 2320 | 3290 | 41.81 |
| Arsenic | 0.96 | 0.97 | 1.04 |
| Beryllium | 0.23 | 0.32 | 39.13 |
| Calcium | 22000 | 25000 | 13.64 |
| Cadmium | 0.95 | 0.9 | -5.26 |
| Chromium | 17 | 12 | -29.41 |
| Iron | 2700 | 3400 | 25.93 |
| Mercury | 0.019 | 0.018 | -5.26 |
| Magnesium | 3060 | 3410 | 11.44 |
| Sodium | 120 | 180 | 50.00 |
| Nickel | 16 | 13 | -18.75 |
| Lead | 7.2 | 4.8 | -33.33 |
| Vanadium | 10 | 12 | 20.00 |
| Zinc | 4.8 | 19 | 295.83 |

Footnotes.

- * = All total metals concentrations are expressed in milligrams per kilogram (mg/kg).
- + = A "D" indicates a duplicate sample; a "S" indicates a split sample.

TABLE C-9. Change in Total Metals Concentrations*
for Quality Assurance/Quality Control Sample
Military Hospital, Kuwait

| SPLIT SAMPLE | | | |
|---------------------|--------------|----------------------------|---------------------|
| METAL | MH-1B | MH-1B-S⁺ | CHANGE +/- % |
| Aluminum | 5850 | 6760 | 15.56 |
| Arsenic | 2.1 | 2.1 | 0.00 |
| Beryllium | 0.42 | 0.5 | 19.05 |
| Calcium | 34000 | 41000 | 20.59 |
| Cadmium | 0.95 | 2.8 | 194.74 |
| Chromium | 31 | 34 | 9.68 |
| Iron | 6900 | 8400 | 21.74 |
| Mercury | 0.019 | 0.020 | 5.26 |
| Magnesium | 7380 | 8810 | 19.38 |
| Sodium | 330 | 330 | 0.00 |
| Nickel | 33 | 40 | 21.21 |
| Lead | 24 | 17 | -29.17 |
| Vanadium | 25 | 29 | 16.00 |
| Zinc | 57 | 50 | -12.28 |

Footnotes,

* = All total metals concentrations are **expressed** in milligrams per kilogram (mg/kg).

+ = A "S" indicates a split sample,

TABLE C-10. Change in Total Metals Concentrations*
for Quality Assurance/Quality Control Samples
Camp Thunderrock, Doha, Kuwait

| DUPLICATE SAMPLE | | | |
|------------------|--------|----------------------|--------------|
| METAL | CT-18 | CT-1B-D ⁺ | CHANGE +/- % |
| Aluminum | 2940 | 2570 | -12.59 |
| Arsenic | 2.2 | 0.99 | -55.00 |
| Beryllium | 0.43 | 0.26 | -39.53 |
| Calcium | 160000 | 90000 | -43.75 |
| Cadmium | 3.7 | 11 | 197.30 |
| Chromium | 17 | 14 | -17.65 |
| Iron | 3200 | 2800 | -12.50 |
| Mercury | 0.019 | 0.0185 | -2.63 |
| Magnesium | 3790 | 3240 | -14.51 |
| Sodium | 1300 | 660 | -49.23 |
| Nickel | 18 | 17 | -5.56 |
| Lead | 7.3 | 5.2 | -28.77 |
| Vanadium | 20 | 14 | -30.00 |
| Zinc | 24 | 76 | 216.67 |

Footnotes.

* = All total metals concentrations are expressed in milligrams per kilogram (mg/kg).

+ = A "D" indicates a duplicate sample.'

TABLE C-11. Change in Total Metals Concentrations*
for Quality Assurance/Quality Control Samples
U.S. Embassy, Kuwait City, Kuwait

| DUPLICATE SAMPLE | | | |
|-------------------------|--------------|-----------------|---------------------|
| METAL | EM-1B | EM-1B-D* | CHANGE +/- % |
| Aluminum | 5570 | 3310 | -40.57 |
| Arsenic | 2.0 | 1.5 | -25.00 |
| Beryllium | 0.48 | 0.39 | -18.75 |
| Calcium | 94000 | 150000 | 59.57 |
| Cadmium | 2.6 | 2.6 | 0.00 |
| Chromium | 24 | 16 | -33.33 |
| Iron | 6700 | 4000 | -40.30 |
| Mercury | 0.040 | 0.0195 | -51.25 |
| Magnesium | 7390 | 5680 | -23.14 |
| Sodium | 880 | 1300 | 47.73 |
| Nickel | 35 | 22 | -37.14 |
| Lead | 20 | 13 | -35.00 |
| Vanadium | 21 | 16 | -23.81 |
| Zinc | 76 | 54 | -28.95 |

| SPLIT SAMPLE | | | |
|---------------------|--------------|-----------------|---------------------|
| METAL | EM-2B | EM-2B-S* | CHANGE +/- % |
| Aluminum | 4900 | 5480 | 11.84 |
| Arsenic | 1.6 | 1.6 | 0.00 |
| Beryllium | 0.41 | 0.48 | 17.07 |
| Calcium | 68000 | 53000 | -22.06 |
| Cadmium | 2.3 | 2.2 | -4.35 |
| Chromium | 22 | 24 | 9.09 |
| Iron | 6100 | 6800 | 11.48 |
| Mercury | 0.0195 | 0.020 | 2.56 |
| Magnesium | 7020 | 7190 | 2.42 |
| Sodium | 770 | 500 | -35.06 |
| Nickel | 32 | 38 | 18.75 |
| Lead | 26 | 25 | -3.85 |
| Vanadium | 20 | 22 | 10.00 |
| Zinc | 66 | 75 | 13.64 |

Footnotes.

* = All total metals concentrations are **expressed** in milligrams per kilogram (mg/kg).

+ = A "D" indicates a duplicate sample: a "S" indicates a split sample,

TABLE C-12. Holding Times for Samples Analyzed for Semivolatile Organic Compounds

| ROUND 1 | |
|-----------------------------------|----------------------------|
| SITE | HOLDING TIME (days) |
| Khobar Towers, Al Khobar, SA | 23 |
| Camp 1, Al Jubayl, SA | 27 |
| Eskan Village, Riyadh, SA | 23 |
| KKMC, SA | 17 |
| Camp Freedom, Kuwait | 31 |
| Military Hospital, Kuwait | 40 |
| Camp Thunderock, Doha, Kuwait | 14 |
| U.S. Embassy, Kuwait City, Kuwait | 40 |
| ROUND 2 | |
| Khobar Towers, Al Khobar, SA | 13 |
| Camp 1, Al Jubayl, SA | 21 |
| Eskan Village, Riyadh, SA | 17 |
| KKMC, SA | 16 |
| Camp Freedom, Kuwait | 16 |
| Military Hospital, Kuwait | 17 |
| Camp Thunderock, Doha, Kuwait | 17 |
| U.S. Embassy, Kuwait City, Kuwait | 16 |

Footnotes.

SA = Saudi Arabia.

KKMC = King Khalid Military City.

TABLE C-13. Holding Times for Samples Analyzed for Metals

| ROUND 1 | |
|---------------------------------------|----------------------------|
| SITE | HOLDING TIME (days) |
| Khobar Towers, Al Khobar, SA | 20 |
| Camp 1, Al Jubayl, SA | 22 |
| Eskan Village, Riyadh, SA | 18 |
| KKMC , SA | 16 |
| Camp Freedom, Kuwait | 24 |
| Military Hospital, Kuwait | 38 |
| Camp Thunderock, Doha , Kuwait | 19 |
| U.S. Embassy, Kuwait City, Kuwait | 40 |
| ROUND 2 | |
| Khobar Towers, Al Khobar, SA | 20 |
| Camp 1, Al Jubayl, SA | 23 |
| Eskan Village, Riyadh, SA | 31 |
| KKMC , SA | 31 |
| Camp Freedom, Kuwait | 31 |
| Military Hospital, Kuwait | 31 |
| Camp Thunderock; Doha , Kuwait | 31 |
| U.S. Embassy, Kuwait City, Kuwait | 31 |

Footnotes.

SA = Saudi **Arabia**.

KKMC = King Khalid Military City.

(3) **Sample Preservation.** The only sample preservation required for semivolatiles and metals in soils is cooling to 4 °C. Samples were kept cool during storage and shipment when possible. However, due to storage and transportation difficulties (i.e., length of shipment times) there were instances when samples were not kept cooled to 4 °C. Although this situation violates sample preservation requirements, as does an exceedance of holding times, the inherent stability of metals and many of the semi-volatiles causes this situation to have less of an impact on sample validity than with many less stable compounds.

(4) **Chain of Custody Procedures.** Chain of custody procedures were used to maintain sample integrity as they moved from sampling sites to the USAEHA laboratory. All personnel involved in the collection, transportation, and analyses of samples were informed of, and carried out, all appropriate chain of custody procedures.

(5) **Background Samples.** The selection of locations for background sampling was based on the extent of impact the oil fire plume was expected to have on that location. The sampling conducted at King Khalid Military City (KKMC) and Eskan Village (Riyadh), Saudi Arabia was considered background sampling with respect to expected plume impact. The use of these two sites as representative of background for the region presented several problems. The natural background level for metals may vary a great deal between sites located this far apart. In addition, the contribution from industrial sources (anthropogenic background) to metal and organic background levels at these sites will probably be different than at the other sites. The Riyadh site had a large petrochemical complex within 5 miles of the sampling areas. The KKMC site was indeed located far from contributing industrial sources; however, there was an asphalt plant and constant military traffic, (aircraft and vehicles) at the installation. Contributing and confounding factors such as these make it very difficult to determine what a true background is for the region.

e. **Sample Analysis.** Appendix E details the analytical methods used in this HRA for soil samples. Other specifics concerning analytical parameters and laboratory QA/QC are also contained in this appendix.

f. **Additional Sampling.** A return trip to Kuwait and Saudi Arabia was made in October-November 1993 to conduct additional soil sampling for chromium and other metals. Most of the field and laboratory methodology was the same as the 1991 trip, except for the chromium analysis and depth sampling. Details of the methodology are contained in Annex 1 of this appendix and Appendix I, that discusses the laboratory and field chemistry methodologies are discussed in Appendix E.

4. RESULTS AND DISCUSSION OF SOIL ANALYSES.

a. Metals Results.

(1) Tables C-14 through C-22 present the total metals analyses results for soil samples collected in Saudi Arabia and Kuwait during sampling rounds 1 and 2. These tables also give the percent change for each sample between rounds. Tables C-23 through C-24 show the mean and upper value of the 95 percent confidence interval (95 percent UCI) for these soil samples, presented by metal for each site. Tables C-25 through C-31 show the percent change in mean and 95 percent UCI for metals between sampling rounds 1 and 2 for each site. In addition to presenting the QA/QC sample results (i.e., splits and duplicates), Tables C-5 through C-11, also show the changes in values by metal for each site. All metals detected in the soil samples were considered contaminants of concern and were evaluated for potential risk to DOD personnel. To separately assess the impact of the oil fires on the soil in the region through deposition of particulates, samples from rounds 1 and 2 were compared. Sampling round 1 was considered background, containing both natural and anthropogenic levels of metals. The subsequent rounds were intended to measure any deposition of fire related particulates with an expected increase in metals levels. Table C-32 shows the metals, for each site, that had a statistically significant increase in concentration between sampling round one, representing background, and sampling rounds 1 and 2. The significance of results of this sampling effort was determined with the studentized "t" test outlined by Snedecor and Cochran in reference 12. This statistical method compares the sample means (i.e., average value) and the sample variance to calculate the "t" value. The threshold "t" value (one-tailed because only increases were evaluated) was less than 2.13. This analysis resulted in a list of chemicals that increased at each site. This increase in concentration was based on the 95 percent confidence interval of the mean which exceeds the EPA acceptable level of 90 percent.

(2) Table C-32 illustrates that there is no consistent increase in soil metals concentrations between sampling rounds 1 and 2. Three of the five sites monitored in Kuwait had no metals that increased in concentration between sampling rounds 1 and 2. The other two sites had only one or two (out of a possible 14) metals increase in concentration. These were not metals associated with Kuwait crude oil and therefore are probably not fire related. Three of the four sites in Saudi Arabia had increases in metals levels. Two sites had increases in only one metal, and these are not believed to be fire related. The other site (Khobar Towers) had an increase in five metals, two (nickel and mercury) which could possibly be fire related. A careful evaluation of the soil sampling data from rounds 1 and 2 indicates that, in all likelihood, the sporadic increases in metal concentrations at the monitoring sites are not the result of the oil fires. Other factors such as the heavy military activity in the monitoring areas, increased industrial activity following the war, or redistribution of the soil and sand by wind following breakup of the natural desert crust by military vehicles, could have caused these increases.

(3) Soil samples results from rounds 3 and 4 (see Tables C-33 through C-57), including depth profiles, were not statistically compared to rounds 1 and 2. However, even a cursory examination of the data from rounds 3 and 4, show results to be very similar to