# Air Sampling And Monitoring at the Kuwait Oil Well Fires

by

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In response to the more than 500 oil well fires in Kuwait, the Saudi Government requested U.S. technical assistance on the public health and environmental impact of the fires. The U.S. Embassy in Saudi Arabia concurred in this request, and voiced its additional concern about the health effects of the fires on troops in the region, as well as thousands of American citizens residing in the Gulf countries. Similar concerns were also expressed by the U.S. Embassy in Kuwait and the Kuwait Government. An Interagency Air Assessment Team was formed and deployed to the Persian Gulf Area.

The initial air sampling and monitoring program conducted by the U.S. Interagency Air Assessment Team in Kuwait and Saudi Arabia had the following objectives:

1. Determine if there was an acute health threat associated with the Hydrogen Sulfide (H2S) and Sulfur Dioxide (SO2) gases being emitted from the burning oil wells.

This objective was accomplished by collecting Real Time Measurements (i.e., instantaneous readings) using portable instruments for the following parameters: H2S, SO2, oxygen, and total particulate. These measurements were collected at 13 locations in Kuwait and Saudi Arabia, U.S. Embassies in Kuwait and Riyadh, MEPA Dhahran, at five oil well fields, and at various locations near the oil fields in Kuwait. The results from the March 13-20 monitoring are summarized in Table 2.

The highest readings were recorded from measurements taken in the smoke plumes in the oil fields. The results from this monitoring did not indicate an acute health threat. However, if conditions change (i.e., fires are extinguished without capping, allowing high levels of gases), an acute threat near the wells may occur.

The highest levels observed were: particulate - 5.4 mg/m3, VOCs - 2.5 ppm (adjacent to large pools of oil), H2S

Environment Canada. Arctic and Marine Oilspill Program Technical Seminar, 15th. June 10-12, 1992, Edmonton, Canada, Environment Canada, Ottawa, Ontario, 575-592 pp, 1992.

- 42 ppb, and SO2 - 2 ppm. It should be noted that the detection limit for the SO2 monitor is 1-2 ppm. A different SO2 monitor with a detection limit of 0.1 ppm did not indicate SO2. Also, the field personnel were unable to detect any sulfur odors at any of the locations. Therefore, the SO2 levels of 1-2 ppm should be used with caution.

The only elevated levels observed in the monitoring conducted in the population areas were for particulates. A reading of 480 ug/$m^3$ was obtained at MEPA in Dhahran, Saudi Arabia. Based on field observation, this reading was probably a combination of smoke from the fires and sand. Baseline particulate levels, due to blowing sand in Saudi Arabia and Kuwait, range from 200-3000 ug/$m^3$.

Further sampling and monitoring occurred from 3/24 - 3/27. These results are also attached. The results from this monitoring are similar to the previous monitoring results. In general, the particulate concentrations at ground level in the oil fields were lower than in the downwind areas outside the fields, except when in the direct path of a ground level plume. The downwind locations most heavily affected vary, depending on wind speed, temperature, humidity, and other diurnal factors.

The real time particulate readings during this phase are 15 and 20 minute averages. The highest reading occurred at the Ahmadi Hospital, with a 20 minute average reading of 0.935 mg/$m^3$ with a single highest reading of 1.16 mg/$m^3$. Other successive 20 minute averages taken at this location display the variation in particulate levels at the same location, as conditions such as wind direction change.

2. The second objective was to identify and quantify the gaseous and particulate by-products that are associated with the burning oil wells.

This objective has partially been accomplished. Samples from 10 locations have been analyzed by the Environmental Response Team (ERT) laboratory in the U.S. The air samples were collected for the following parameters at all locations: volatile organics (VOCs); polycyclic aromatic hydrocarbons (PAHs) such as naphthalene, benzo[a]pyrene; heavy metals; SO2; and inorganic acids (i.e., sulfuric, nitric, etc.). A limited number of samples were collected for H2S, formaldehyde, CO, and total nuisance dust. For specific findings relevant to these samples, see the Section entitled, "Air Sampling Results."

3. The third objective was to determine if the materials associated with the fires were affecting areas where American citizens were located.

This objective will partially be accomplished by reviewing the data from the samples taken at MEPA Dhahran,

Saudi Arabia, U.S. Embassies in Kuwait and Riyadh, Camp Freedom Kuwait, and Port Shuaybah, Kuwait; and reviewing the air monitoring data being collected by MEPA and ARAMCO in Saudi Arabia air monitoring stations and sulfur dioxide data taken at temporary hospital locations in Kuwait City.

In order to complete this objective in a sound scientific manner, sampling for $PM_{10}$ particulate (i.e., particulate less than 10 microns in size), which are the respirable particulate, and samples from the plume above ground level were taken at a later date. Also, the air monitoring network proposed by the U.S. Interagency Air Assessment Team was implemented.

**AIR SAMPLING RESULTS:**

The results from the air samples collected for sulfur dioxide, volatile organics, and inorganic acids from 3/13 - 3/20 in Kuwait and Saudi Arabia confirmed the real time measurements and sampling and analysis performed by the Kuwaitis and the Saudis. These results confirmed the conclusion of the U.S. Interagency Air Assessment Team that the primary hazards from the oil well fire is with the particulate matter.

The highest level of sulfur dioxide (0.68 ppm) was detected in the smoke plume of the Burgan Oil Field. This level is above the EPA 24 hour (0.14 ppm) and 3 hour (0.5 ppm) limit. None of the sulfur dioxide samples collected in populated areas exceeded the EPA air quality limits.

The organic vapor analysis showed that compounds associated with petroleum (i.e., benzene, toluene, and aliphatic hydrocarbons such as n-heptane (n-C7)) were detected. The highest levels (i.e., 10-20 ppb level) were detected in the smoke plume in the oil fields and a grab (SUMMA) sample collected at ground level near a pool of oil in the Sabiriyah well field. The inorganic acid analysis showed low ppb levels for both sulfuric and nitric acid. Based on this limited data, the sulfur dioxide and nitrous oxide that may be by-products from the burning of the oil are not being formed in large amounts.

The results from the particulate analysis for polycyclic aromatic hydrocarbons (PAHs) and heavy metals showed very low levels of both parameters in the samples collected in the populated areas and in the oil fields. The only metals detected were those associated with materials found in the sand particles (i.e., sodium, aluminum, magnesium, etc.).

Based on these limited number of samples, the major hazard associated with the oil well fires seems to be the particulate matter being emitted. The monitoring and sampling program discussed in the Air Monitoring Strategy

Plan should help further define the hazards associated with the particulates.

The complete results from the sampling are summarized in the attached exhibits. Only the compounds detected are listed.

**PARAMETERS:**

The air samples collected at the oil well fields, Camp Freedom, MEPA Dhahran, Saudi Arabia, and U.S. Embassies in Kuwait and Riyadh, Saudi Arabia were analyzed for the following parameters:

PAHs:

Naphthalene, 2-Methylnaphthalene, 1-Methylnapthlalene, Biphenyl, 2,6-Dimethylnaphthalene, Acenaphthylene, Acenapthene, Dibenzofuran, Fluorene, Phenanthrene, Anthracene, Carbazole, Fluoranthene, Pyrene, Benzo[a]anthracene, Chrysene, Benzo[b]fluoranthene, Benzo[k]flouranthene, Benzo[e]pyrene, Benzo[a]pyrene, Indeno(1,2,3-cd)pyrene, Dibenzo[a,h]anthracene, Benzo[g,h,i]perylene.

Inorganic Acids:

Hydrochloric, Phosphoric, Sulfuric, Nitric, Hydrofluoric.

Metals:

Platinum, Titanium, Molybdenum, Zirconium, Silver, Aluminum, Beryllium, Cadmium, Calcium, Chromium, Cobalt, Copper, Iron, Magnesium, Manganese, Sodium, Nickel, Lead, Tin, Vanadium, Zinc.

Volatile organics:

1,1,1-Trichloroethane, Cyclohexane, Carbon Tetrachloride, Benzene, Cyclohexene, n-Heptane (n-C7), 1,2-Dichlorpropane, Trichloroethane, 1,4-Dioxane, Methylcyclohexane, Methylisobutylketone, Toluene, n-Octane (n-C8), Tetrachloroethane, Chlorobenzene, Ethylbenzene, para-Xylene, Bromoform, Styrene, o-Xylene, n-Nonene, n-Nonane (n-C9), 1,1,2,2-Tetrachloroethane, Cumene, Mesitylene, Alpha-methylstyrene, 1,3-Dichlorobenzene, 1,4-Dichlorobenzene, 1,2-Dichlorobenzene, Benzyl Chloride, alpha-Terpine, D-Limonene, 4-tert-Butyltoluene, 1,2,4-Trichlorobenzene, Naphthalene, 4-Phenylcyclohexene, n-Decane (n-C10), n-Decene, n-Undecene, n-Undecane (n-C11), n-Nonanal, n-Dodecane (n-C12), n-Tridecane (n-C13), n-Tetradecane (n-C14), n-Pentane (n-C15), n-Hexadecane (n-C16).

Others:

Formaldehyde and Sulfur Dioxide.

**U.S. EMBASSY, KUWAIT**

Results for 3/16

PAHs:
none detected — detection limit: 2 - 4.6 ppb

Sulfur Dioxide:
none detected — detection limit: 0.04 mg/m3

Inorganic Acids:
none detected — detection limit: 1 - 6 ppb

VOCs:
Benzene 0.4 ppb, n-Heptane 0.13 ppb, Toluene 0.61 ppb, Ethylbenzene 0.1 ppb, para-Xylene 0.29 ppb, o-Xylene 0.12 ppb.

Metals:
Na < 1.0 ug/m3, Mg 2 ug/m3, Fe 2 ug/m3, Ca 8 ug/m3, Al 2 ug/m3.

Results for 3/17

PAHs:
Naphthalene 0.31 ppb

Sulfur Dioxide:
< 0.02 mg/m3

Inorganic Acids:
HCl 3.0 ppb, $H_2SO_4$ 1.0 ppb, $HNO_3$ 2.0 ppb

VOCs:
Cyclohexane 1.31 ppb, Benzene 4.0 ppb, n-Heptane 6.0 ppb, TCE 0.7 ppb, Methylcyclohexane 2.0 ppb, Toluene 7.7 ppb, n-Octane 3.0 ppb, Ethylbenzene 1.7 ppb, p-Xylene 5.4 ppb, Styrene 0.4 ppb, o-Xylene 2.4 ppb, n-Nonane 1.9 ppb, Cumene 0.2 ppb, Mesitylene 0.6 ppb, D-Limonene 0.1 ppb, n-Decane 1.5 ppb, n-Undecane 1.0 ppb, n-C12 0.7 ppb, n-C13 0.4 ppb.

Metals:
Na 10 ug/m3, Mg 2 ug/m3, Fe 3 ug/m3, Ca 10 ug/m3, Al 2 ug/m3.

**U.S. EMBASSY, KUWAIT, continued**

Results for 3/18

PAHs:
Naphthalene 0.16 ppb

Sulfur Dioxide:
< 0.05 mg/m3

Inorganic Acids:
HCl 6 ppb, HNO3 2 ppb, H2SO4 1.0 ppb.

VOCs:
Cyclohexane 1.2 ppb, Benzene 5.2 ppb, n-C7 8.1 ppb, Methylcyclohexane 3.0 ppb, Toluene 14.6 ppb, n-C8 4.7 ppb, Ethylbenzene 3.2 ppb, p-Xylene 9.3 ppb, o-Xylene 4.7 ppb, n-C9 2.7 ppb, Cumene 0.3 ppb, Mesitylene 1.3 ppb, Naphthalene 0.18 ppb, n-C10 1.7 ppb, n-C11 1.0 ppb, n-C12 0.7 ppb, n-C13 0.3 ppb.

Metals:
Na 5 ug/m3, Mg 1 ug/m3, Fe 1 ug/m3, Ca 7 ug/m3, Al 1 ug/m3.

**CAMP FREEDOM**

Results For 3/17

PAHs:
Naphthalene 0.09 ppb, 2-Methylnaphthalene 0.06 ppb, 1-Methylnaphthalene 0.04 ppb.

Sulfur Dioxide:
0.12 mg/m3 0.045 ppm

Inorganic Acids:
HCl 16 ppb, HF 23 ppb, H2SO4 31 ppb

VOCs:
Cyclohexane 7 ppb, Benzene 4.6 ppb, n-C7 25.6 ppb, Methylcyclohexane 9.5 ppb, Toluene 13 ppb, n-C8 18 ppb, Ethylbenzene 2.7 ppb, p-Xylene 8 ppb, o-Xylene 4.5 ppb, n-C9 10.9 ppb, Cumene 0.5 ppb, Mesitylene 1 ppb, Naphthalene 0.18 ppb, n-C10 6.3 ppb, n-C11 4.1 ppb, n-C12 2.3 ppb, n-C13 0.9 ppb, n-C14 0.5 ppb. These levels may also include emissions from vehicles in the area.

Metals:
No Data.

Results for 3/18

PAHs:
Naphthalene 0.28 ppb

Sulfur Dioxide:
<0.04 mg/m3 , < 0.015 ppm

Inorganic Acids:
HNO3 4.0 ppb, H2SO4 4 ppb.

VOCs:
Cyclohexane 2.8 ppb, Benzene 6.9 ppb, n-C7 9.7 ppb, Methylcyclohexane 3.9 ppb, Toluene 16 ppb, n-C8 5.4 ppb, Ethylbenzene 3.1 ppb, p-Xylene 9.5 ppb, Styrene 0.3 ppb, o-Xylene 4.5 ppb, n-C9 3 ppb, Cumene 0.3 ppb, Mesitylene 1.1 ppb, n-C10 1.5 ppb, n-C11 0.8 ppb, n-C14 0.2 ppb.

Metals:
Al 2 ug/m3, Ca 8 ug/m3, Fe 2 ug/m3, Mg 2 ug/m3, Na 3 ug/m3.

**MEPA DHAHRAN, SAUDI ARABIA**

Results For 3/13

PAHs:
none detected

Sulfur Dioxide:
<0.1 mg/m3, <0.037 ppm

Inorganic Acids:
H2SO4 5 ppb.

VOCs:
Benzene 0.3 ppb, Cyclohexane 0.1 ppb, Toluene 0.5 ppb, Ethylbenzene 0.1 ppb, p-Xylene 0.2 ppb, o-Xylene 0.1 ppb, Mesitylene 0.04 ppb.

Metals:
Al 2 ug/m3, Ca 5 ug/m3, Fe 2 ug/m3, Mg 2 ug/m3, Na 1 ug/m3.

Results For 3/14

PAHs:
none detected

Sulfur Dioxide:
<0.08 mg/m3 , < 30 ppb.

Inorganic Acids:
HNO3 2 ppb, H2SO4 6 ppb.

VOCs:
Cyclohexane 0.2 ppb, Benzene 0.5 ppb, n-C7 0.8 ppb, Methylcyclohexane 0.3 ppb, Toluene 0.7 ppb, n-C8 0.4 ppb, Ethylbenzene 0.1 ppb, p-Xylene 0.3 ppb, o-Xylene 0.1 ppb, n-C9 0.3 ppb.

Metals:
Al 3 ug/m3, Ca 14 ug/m3, Fe 3 ug/m3, Mg 4 ug/m3, na 8 ug/m3.

## U.S. EMBASSY RIYADH, SAUDI ARABIA

Results For 3/28

PAHs:
none detected

Sulfur Dioxide:
< 0.08 mg/m3 , < 30 ppb

Inorganic Acids:
NO3 3 ppb, H2SO4 < 2 ppb.

VOCs:
Benzene 0.3 ppb, Toluene 0.6 ppb, Ethylbenzene 1.0 ppb, p-Xylene 0.3 ppb.

Metals:
Al 2 ug/m3, Ca 4 ug/m3, Fe 1 ug/m3.

## PORT SHUAYBAH

Results For 3/17

PAHs:
no data

Sulfur Dioxide:
< 0.05 mg/m3, , 19 ppb

Inorganic Acids:
H2SO4 19 ppb.

VOCs:
Benzene 4.2 ppb, n-C7 13 ppb, Methylcyclohexane 5.3 ppb, Toluene 15 ppb, n-C8 5.6 ppb, p-Xylene 6.9 ppb, Ethylbenzene 2.2 ppb, o-Xylene 2.9 ppb, n-C9 3.8 ppb, Cumene 0.2 ppb, n-C10 2.9 ppb, n-C11 1.9 ppb, n-C12 1.4 ppb, n-C13 0.8 ppb.

Metals:
Ca 4 ug/m3, Na 7 ug/m3.

## A1 MAQUA OIL FIELD

Results for 3/15

PAHs:
no data

Sulfur Dioxide:
<0.3 mg/m3 , <0.1 ppm

Inorganic Acids:
no data

VOCs:
Cyclohexane 0.6 ppb, Benzene 1.8 ppb, n-C7 3.2 ppb, Methylcyclohexane 1.1 ppb, Toluene 2 ppb, Ethylbenzene 0.4 ppb, p-Xylene 1.4 ppb, o-Xylene 0.8 ppb, n-C9 2.8 ppb, Mestilylene 0.3 ppb, n-C10 3.3 ppb, n-C11 3.5 ppb, n-C12 3.3 ppb, n-C13 1.8 ppb, n-C16 1.1 ppb.

Metals:
Al 6 ug/m3, Ca 6 ug/m3, Fe 6 ug/m3.

**Al AHMADI OIL FIELD**

Results For 3/16

PAHs:
none detected

Sulfur Dioxide:
0.45 mg/m3 , 0.17 ppm

Inorganic Acids:
H2SO4 27 ppb, HNO3 10 ppb, HCl 9 ppb.

VOCs:
Cyclohexane 0.4 ppb, Benzene 3.9 ppb, n-C7 2.5 ppb, Methylcyclohexane 1 ppb, Toluene 2 ppb, n-C8 2.3 ppb, Ethylbenzene 0.5 ppb, p-Xylene 1.5 ppb, o-Xylene 0.9 ppb, n-C9 2.9 ppb, Mesitylene 0.4 ppb, Naphthalene 0.5 ppb, n-C10 3.4 ppb, n-C11 3.8 ppb, n-C12 4 ppb, n-C13 2.9 ppb, n-C14 2.9 ppb, n-C15 2 ppb, n-C16 1.7 ppb.

Metals:
Al 8 ug/m3, Ca 50 ug/m3, Fe 20 ug/m3.

Formaldehyde:
8 ppb.

SUMMA Data:
SO2 0.2 ppm; CO 1.9 ppm

**A1 BURGAN OIL FIELD**

Results For 3/17

PAHs:
none detected; detection limit 50 ppb

Sulfur Dioxide:
1.8 mg/m3 , 0.8 ppm

Inorganic Acids:
H2SO4 30 ppb, HNO3 32 ppb, HCl 15 ppb.

VOCs:
Benzene 8.7 ppb, n-C7 4.6 ppb, Methylcyclohexane 2.5 ppb, Toluene 4.31 ppb, n-C8 5.1 ppb, Ethylbenzene 1.3 ppb, p-Xylene 4.2 ppb, o-Xylene 2.4 ppb, n-C9 7.1 ppb, Naphthalene 1.6 ppb, n-C10 9.1 ppb, n-C11 10.4 ppb, n-C12 11.3 ppb, n-C13 7.8 ppb, n-C14 7.4 ppb, n-C15 5.4 ppb, n-C16 4.6 ppb.

Metals:
Al 20 ug/m3, Ca 120 ug/m3, Fe 20 ug/m3, Mg 30 ug/m3.

Formaldehyde:
20 ppb;

SUMMA Data:
SO2 0.23 ppm, CO 1.6 ppm, H2S none detected (0.1 ppm detection limit.)

## Al WAFRA OIL FIELD

Results for 3/19

PAHs:
no data

Sulfur Dioxide:
none detected 0.3 mg/m3 , 0.11 ppm.

Inorganic Acids:
none detected 10 ppb detection limit

VOCs:
Benzene 2.3 ppb, n-C7 0.6 ppb, Methylcyclohexane 1.6 ppb, Ethylbenzene 0.3 ppb, o-Xylene 0.4 ppb, Mesitylene 0.4 ppb

Metals:
no data

Hydrogen Sulfide:
awaiting results.

## SABIRIYAH OIL FIELD

Results For 3/17

SUMMA DATA:

Ground Level Sample:
H2S none detected (0.1 ppm); SO2 0.13 ppm; CO 1.1 ppm; NO and NO2 none detected

VOCs:
Benzene 9.8 ppb, Toluene 8.7 ppb, Ethylbenzene 10 ppb, m&p-Xylene 27.8 ppb o-Xylene 24 ppb, m-Ethyltoluene 15.8 ppb, n-C6 83 ppb, n-C7 60 ppb, n-C8 91 ppb, n-C9 91 ppb, n-C10 89 ppb, n-C11 65 ppb.

3000 ft Sample:
H2S none detected; SO2 0.08 ppm, CO none detected; NO and NO2 none detected 0.5 ppm.

1000 ft Sample:
H2S, SO2, CO, NO, and NO2 none detected.

**Table 1**
**Kuwait Oil Well Fires Real Time Monitoring**
**March 13-20, 1991**

| Site, Date, Time | Total Particulate $mg/m^3$ | Sulfur Dioxide ppm | Hydrogen Sulfide ppm | Volatile Organics ppm |
|---|---|---|---|---|
| 1) MEPA Faciltiy, Dhahran, SA 3/13 1100 hrs | .170 | 0.0 | 0.0 | 0.0 |
| MEPA Facility 3/14 1300 hrs | .480 | 0.0 | 0.0 | 0.0 |
| 2) Al Dhuba 3/15 1430 hrs | .420 | 0.0 | 0.0 | 0.0 |
| 3) Umn Al Haiman 3/15 1500 hrs | .320 | 0.0 | 0.0 | 0.0 |
| 4) Mina Abdulla 3/15 1530 hrs | .250 | 0.0 | 0.01 | 0.6 |
| 5) Near Al Maqwa Oil Field 3/15 1630 hrs | .010 | 0.0 | 0.024 | 0.8 |
| 6) In Al Maqwa Well Plume 3/15 1700 hrs | 5.4 | 0.0 | 0.006 | 0.8 |
| 7) U.S. Embassy 3/06 0900 hrs | .01 | 0.0 | 0.001 | 0.0 |
| U.S. Embassy 3/18 1230 hrs | .055 | 1.0 | 0.005 | 0.2 |
| 8) In Al Ahmadi Well Plume 3/16 1230 hrs | --- | 0.0 | 0.032 | 0.0 |
| In Al Ahmadi Oil Field 3/16 1300 hrs | .120 | 1.0 | 0.009 | 0.0 |
| 9) In Al Burgan Well Plume 3/17 1100 hrs | ___ | 1.0 | 0.015 | 0.0 |
| 10) In Sabiriyan Well Plume, Pooled Oil 3/18 1530 hrs | --- | 1.0 | 0.042 | 2.5 |
| 11) In Al Wafra Well Plume 3/19 1200 hrs | .050 | 2.0 | 0.015 | 0.0 |
| 12) Freedom City | --- | --- | --- | --- |
| 13) U.S. Embassy Riyadh, SA 3/20 1300 hrs | .032 | 0.0 | 0.0 | 0.0 |

Table 2
**Kuwait Oil Well Fires Real Time Monitoring**
**March 24-27, 1991**

| Site, Date, Time | Total Particulate $mg/m^3$ | Sulfur Dioxide ppm | Hydrogen Sulfide ppm | Volatile Organics ppm |
|---|---|---|---|---|
| 1) Al Safer Motorway and Wafra Road 3/24 1440 hrs | .825 (15 min. avg.) | 2.0 | 0.0 | 0.3 |
| 2) Al Ahmadi Gathering Center #22 3/24 1530 hrs | .359 (15 min. avg.) | 0.0 | 0.0 | 0.0 |
| 3) Al Ahmadi Hospital 3/24 1530 hrs | .222 (32 min. avg.) | 0.0 | 0.0 | 0.0 |
| 4) 1 mi. NW of Station 2 in Ahmadi Oil Field 3/24 1730 hrs | .256 (10 min. avg.) | 0.0 | 0.0 | 0.0 |
| 5) Al Maga Oil Field, .5 mi south of 7th Ring Road near oil pool 3/25 1400 hrs | .034 (17 min. avg.) | 1.0 | 0.0 | 0.6 |
| 6) Al Ahmadi Oil field (same as Station 4) 3/25 1500 hrs | .561 (13 min. avg.) | 0.0 | 0.003 | 0.6 |
| 7) Al Ahmadi Hospital (same as Station 3) 3/25 1545 hrs | .295 (15 min. avg. | 0.0 | 0.0 | 0.0 |
| 8) Al Safer and Wafra Road 3/25 1615 hrs | .065 (16 min. avg.) | 0.0 | 0.002 | 0.0 |
| 9) Al Ahmadi Hospital (same as Station 3 and 7) 3/27 1020 hrs | .935 (20 min. avg.) | 0.0 | 0.0 | 0.2 |
| 10) Al Ahmadi Hospital (same as Stations 3, 7, and 9) 3/27 1040 hrs | .457 (20 min. avg.) | --- | --- | --- |
| 11) Al Ahmadi Hospital (same as Stations 3, 7, 9, and 10) 3/27 1100 hrs | .457 (20 min. avg.) | --- | --- | --- |
| 12) Shuaiba Port 3/27 1215 hrs | .468 (15 min. avg.) | 0.0 | 0.0 | 0.0 |

| | | | | |
|---|---|---|---|---|
| 13) Al Safer Motorway and Wafra Road 3/27 1300 hrs | .119 (12 min. avg.) | 0.0 | 0.0 | 0.0 |
| 14) 16 Kilo-meters SE of Al Safer and Wafra Roads 3/27 1330 hrs | .257 (12 min. avg.) | 0.0 | 0.0 | 0.0 |
| 15) 27 Kilo-meters SE of Al Safer and Wafra Roads 3/27 1350 hrs | .227 (15 min. avg.) | --- | --- | --- |
| 16) 5 Kilometers South of Khafji, Saudi Arabia 3/27 1510 hrs | .072 (14 min. avg.) | --- | --- | --- |

**Table 3**
**Sulfur Dioxide Bubbler Measurements**
**(Acidimetric Method)**
**Temporary Hospital Locations in Kuwait City**
**March 13-24**

| Hospital | Date | Concentration (ug/m$^3$) |
|---|---|---|
| Adan | 3/14/91 | 40.31 |
| | 3/17/91 | 43.88 |
| | 3/18/91 | 39.34 |
| | 3/19/91 | 26.18 |
| | 3/20/91 | 27.68 |
| | 3/23/91 | 28.16 |
| | 3/24/91 | 15.99 |
| Mubarek Al Kabeer | 3/13/91 | 193.66 |
| | 3/18/91 | 56.48 |
| | 3/19/91 | 58.11 |
| | 3/20/91 | 42.34 |
| | 3/23/91 | 43.43 |
| | 3/24/91 | 23.72 |
| Al Farwaniya | 3/13/91 | 81.32 |
| | 3/16/91 | 19.21 |
| | 3/17/91 | 29.56 |
| | 3/18/91 | 134.81 |
| | 3/19/91 | 218.65 |
| | 3/20/91 | 27.57 |
| | 3/23/91 | 26.66 |
| | 3/24/91 | 10.54 |
| Al Jahra | 3/16/91 | 32.03 |
| | 3/18/91 | 66.59 |
| | 3/19/91 | 32.54 |
| | 3/23/91 | 13.92 |
| | 3/24/91 | 9.90 |