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Abdul Aziz R Al Nuaimi

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MANAGEMENT OF EMISSIONS AT ABU DHABI GAS LIQUEFACTION COMPANY

A Thesis Submitted in Partial Fulfillment for the
Degree of M.Sc. in Environmental Science

By

Abdul Aziz Ali R. Al Nuaimi

Faculty of Science

United Arab Emirates University

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SUPERVISORS

Professor Essam Abdul Hafiz
Head of Civil Engineering Department
College of Engineering
United Arab Emirates University

Dr. Munjed Maraqa
Assistant Professor
Civil Engineering Department
College of Engineering
United Arab Emirates University

Dr. Mohamed Hassan Al Marzouqi
Assistant Professor
Chemical and Petroleum Engineering Department
College of Engineering
United Arab Emirates University

The Thesis of Abdul Aziz Ali Rashed AlNuaimi for the degree of Master of Science in Environmental Sciences is approved .

A. Hafiz

Chair of Committee, Prof. Essam Abdul Hafiz

Examining Committee Member, Dr. Mahmoud Fathy Abd-Rabbo

Examining Committee Member, Dr. Reyadh Al Mehaideb

A. S. ALSHARHAN

Dean of The Faculty of Science,

United Arab Emirates University

ABSTRACT

Gas industries in the United Arab Emirates are vastly growing in order to mainly cope with the increasing demand for energy productions as well as for the wise utilization of gas associate with the crude oil. Environmental problems coupled with gas employment necessitates the development of a management techniques that can lead to better control of emissions from gas processing companies since some of these emissions are unavoidable for safety reasons.

This study suggests a framework to be used to control emissions from Abu Dhabi Gas Liquefaction Company (ADGAS) in Das Island, which represents a typical major gas processing company in the region, through investigations of the impact of introducing a modification scheme, within the unit processes, on the quality of the surrounding atmosphere.

A baseline study for current emissions and ground level concentrations of four pollutants (sulphur dioxide, nitrogen oxides, carbon monoxide and particulates) was established.A computer model was then used to simulate the proposed modifications in order to reduce ground level concentrations that exceed regulatory standards.

Two main approaches were considered to minimize ground level concentrations. First, reducing flow of gas into the flares by adding compressors to recover any excess gas from going into the flares during operations. Second, upgrading sulphur recovery units to a higher efficiency and some other reduction can also be accomplished through sweetening of fuel gas directed to utilities.

The study concluded that the rates of emitted gas at ADGAS Liquefied Natural Gas Plant are exceeding the exposure limits under all emergency and current normal operation conditions. Gas turbines and boilers were proved to be the major sources for nitrogen oxides and carbon monoxide, while both sulphur recovery units and gas turbines are contributing to the emission of sulphur dioxide. In the meantime, upgrading of the sulphur recovery units to 97.5% resulted in 30% decrease in sulphur dioxide concentration. A significant decrease in nitrogen oxides and carbon monoxide as well as particulate concentrations resulted from adding a third boil-off-gas compressor.

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LIST OF ABBREVIATIONS

ADGAS	Abu Dhabi Gas Liquefaction Company Limited.
ADIA	Abu Dhabi International Airport.
ADMA-OPCO	Abu Dhabi Marine Operating Company.
ADNOC	Abu Dhabi National Oil Company.
BOG	Boil off Gas.
CH_4	Methane.
CO_2	Carbon dioxide.
CO	Carbon monoxide.
DEA	Diethanolamine.
DGA	Diglycolamine.
EPA	Environmental Protection Agency.
HC	Hydrocarbons.
H_2S	Hydrogen sulphide.
ISC3	Industrial Source Complex Model Version 3.0.
K_2CO_3	Potassium Carbonates.
LNG	Liquefied Natural Gas.
LPG	Liquefied Petroleum Gas.
MCR	Multi-Component Refrigerant.

MEA	Monoethanolamine.
M.Wt	Molecular Weight.
NO	Nitric oxide.
N_2O	Nitrous oxide.
NOx	Nitrogen oxide.
PM	Particulate matter.
SO_2	Sulphur dioxide.
SRUs	Sulphur Recovery Units.
VOCs	Volatile Organic Compounds.
WHO	World Health Organization.

LIST OF SYMBOLS

C	Concentration (μ g/m^3).
d	Top inside stack diameter (m).
F_b	Buoyancy flux (m^4/s^3).
F_m	Momentum flux (m^4/s^3).
g	Acceleration of gravity (9.8m/s^2).
h	Stack height (m).
h_e	Effective stack height (m).
Δh	Plume rise (m).
P	Factor or exponent.
Q	Rate of pollutant from a continuous source (g/s).
s	Stability parameter.
ΔT	Temperature difference between stack emission temperature (T_o) and ambient air temperature (T) in K.
$\partial T/\partial z$	Actual temperature gradient (K/m).
$\partial\theta/\partial z$	Potential temperature gradient ($\partial T/\partial z + \Gamma$) (K/m).
Γ	Adiabatic lapse rate (0.01 K/m for dry air).
θ	Potential temperature (K).
u	Wind speed at the stack height (m/s).
u_m	Wind speed at 10 m elevation reference (m/s).

V	Vertical term of the Gaussian plume equation (dimensionless).
v	Stack emission exit velocity (m/s).
x	Downwind distance from the emission source (m).
σ_y	Standard deviation of the horizontal pollutant distribution (m).
σ_z	Standard deviation of the vertical pollutant distribution (m).
y	Crosswind locations from the emission source (m).
z	Vertical locations from the emission source (m).
Z	Vertical distance at stack height (m).
Z_m	Vertical distance at reference level height (m).

CHAPTER 1

INTRODUCTION

1.1 GENERAL

The economic growth in the United Arab Emirates (UAE) induces physical expansion, and construction and operation of new industrial facilities. These facilities commonly generate pollutants that affect, directly or indirectly, the air quality, the aquatic resources, and the terrestrial environment. Construction and operation of industrial facilities also require people whom themselves may contribute to the problems through their needs for living space, transportation, food and water, utilities, and disposal of their waste. Thus the environmental problems accumulate, sometimes continuous, sometimes through interaction of different factors in a manner that their combined effect is greater than the sum of individual effects. Solutions to these problems require a balance of many values including short-term socioeconomic growth versus long term economic stability; industrial expansion versus environmental protection.

The economy of the UAE is greatly dependent on oil and gas industry. In the past, gas associated with the crude oil production was burned off. This was a waste of an income source and a contribution to local environmental problems. Over the past years, gas produced by oil and gas industries has been increasingly used to operate the production facilities, and to generate electricity. In addition, a major portion of this processed gas has been exported. Nowadays, gas industries in UAE are actively developing further markets for gas utilization and will thus reduce gas emission and waste gas flaring. However, flaring in the oil industry will continue for safety reasons. The question is how to reduce these emissions in such a way that the quality of the surrounding atmosphere does not exceed the specified regulatory limits (Ecology and Environment Incorporated,1978).

1.2 OBJECTIVES

Several compounds are emitted, through flares, stacks, and turbines, during gas processing stages. The effect of these emissions on air quality is dependent on many factors including the concentration of each compound, and the exposure time-scale at the receptor. The main objective of this study is to propose a management technique that can lead to a better control of emission level from gas processing companies in UAE. Abu Dhabi Gas Liquefaction company (ADGAS) located in Das Island has been selected for this purpose as it represents a typical major gas processing company in the region. Investigations of the impact of introducing a modification scheme within the unit processes on the quality of the surrounding atmosphere will be undertaken through the followings strategy:

1. Estimations of emission rates and ground level concentration for pollutants resulting from waste gas emissions under current situation by considering both normal operating and emergency conditions.
2. Determination of ground level concentration for each proposed modification scheme under normal operating conditions.
3. Comparison of ground concentration for each pollutant before and after modification.

1.3 MANAGEMENT FRAMEWORK

The importance of this study stems from a perspective that visualizes production capacity in parallel with emission reduction as the core concerns of gas industry. Achievement of healthier environment, compliance with environmental legislation, in addition to recovery of wastefully burnt gas will be accomplished through the application of emission management framework that fits with the conditions and interventions proposed. The designed management framework is shown in Fig 1.1.

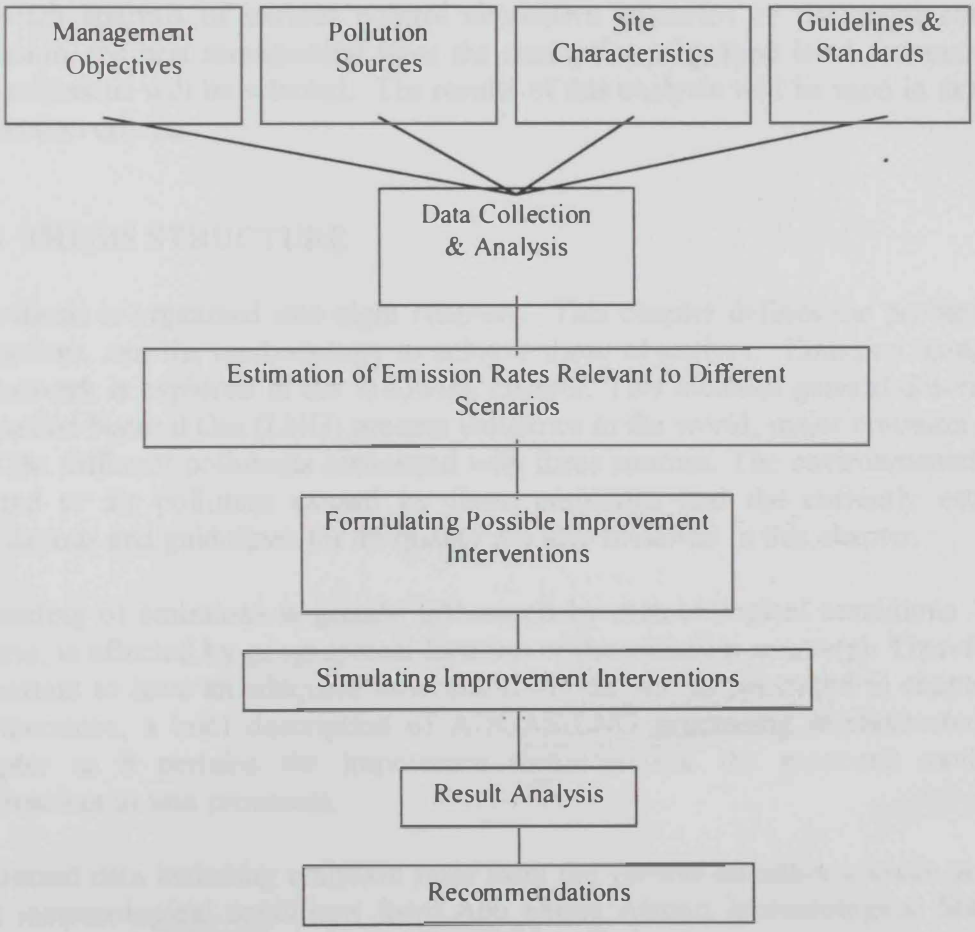

Fig 1.1 Emission Management Framework

1.4 APPROACH

To achieve the above objectives, field data collected will be utilized. These data include: emission discharge rates, coordinates of sources and receptors, time-scale for normal operation and maintenance and emergency shutdowns, meteorological data, and physical conditions.

The necessary input parameters for the air dispersion model will be obtained in order to determine ground level concentration of the target pollutants under current conditions before consideration of any proposed modification scheme. Three emission scenarios will be considered under current gas processing conditions: normal operation, maintenance, and emergency shutdown. The ground level concentration will be predicted for a variety of averaging times (1hr, 24hr, annual). Hot zones, where predicted ground concentration exceeds regulatory limits, will be identified. Similar simulations will be conducted for modified case scenarios after incorporating the estimated reduction in emission discharge rates that results from adopting a certain modified scheme.

Through analysis of various control alternative scenarios of the major sources of emission, the best arrangement from the standpoint of ground level concentration of gas emissions will be selected. The results of this analysis will be used in developing protection criteria.

1.5 THESIS STRUCTURE

The thesis is organized into eight chapters. This chapter defines the problem, study objectives, and the methodology to achieve those objectives. Emission management framework is explored in the following chapter. This includes general description of Liquefied Natural Gas (LNG) process industries in the world, major emission sources, and the different pollutants associated with these sources. The environmental aspects related to air pollution caused by these emissions and the currently established regulations and guidelines for air quality are also reviewed in this chapter.

Spreading of emissions is greatly influenced by meteorological conditions. This, of course, is affected by geographical location of the emission source(s). Therefore, it is important to have an adequate description of the site as presented in chapter three. Furthermore, a brief description of ADGAS-LNG processing is preseneted in this chapter as it pertains the importance to understand the proposed modification alternatives to unit processes.

Collected data including emission rates from the various emission sources on the site and meteorological conditions from Abu Dhabi Airport Meteorological Station are presented and analyzed in chapter four. Original raw data are listed in the appendix. The theory of air dispersion along with the different models currently available is explored in chapter five. Among these models, the Industrial Source Complex (ISC3) code developed by the United States Environmental Protection Agency (US EPA) has been selected to run simulation of ground concentration. Model verification has been also presented in chapter five.

Simulations of ground concentration for several emitted pollutants are presented in chapter six and seven. Emissions under current situation for normal and emergency cases are the focus of chapter six while those under modified case scenarios are illustrated in chapter seven. Finally, chapter eight concluded this study and suggested some recommendations for future investigations.

CHAPTER 2

EMISSION MANAGEMENT FRAMEWORK

2.1 INTRODUCTION

Natural gas is found both in onshore and offshore as independent deposits, or mixed with crude oil as associated gas. This associated gas has to be separated before crude oil is exported and refined. In the past, oil producing countries wasted this gas by burning it off in the atmosphere. But later some of these countries started utilizing the gas as fuel for their industrial plants and other domestic purposes. The surplus that exceeded their local requirements was exported to neighboring countries, through special pipelines.

The sixties witnessed a dire and pressing need to find a solution that would help oil producing countries utilize the gas, stop flaring it away and subsequently protect the environment and, at the same time, make it easily available for the importers. Transportation was the major problem. Gas in its form represents a huge volume and transporting it would undoubtedly require exorbitant expenses.

The solution was found: liquefaction of gas by cooling it down to -160 °C, thus reducing its volume by a 600 folds. It could then be easily transported, involving much reasonable expenses, to the importers, who in turn will store it in its liquefied form under the same temperature. It could later be regasified, whenever required, for use as fuel. It was here that gas liquefaction plants and LNG tankers came into existence. Nowadays, the world is producing over 100 millions tonnes of LNG annually (Table 2.1).

Table 2.1 Survey of liquefied natural gas production world wide[1]

Country	Production of LNG (million tonnes/year)
USA	1
Libya	3
UAE	6
Qatar	7
Brunei	7
Australia	8
Malaysia	16
Algeria	23
Indonesia	31

[1] Gas Engineering Training Center, Paris 1990

2.2 GENERAL DESCRIPTION OF LIQUEFIED NATURAL GAS PROCESSING

Knowledge of LNG processing is essential for better management of gas emissions resulting from gas processing plants. Production of liquefied natural gas undergoes several processes including separation, sweetening, dehydration, and liquefaction. These processes are described in some detail below (Gas Engineering Training Center, 1993).

Occasionally, the feed gas contains entrained liquids and solids. These entrained substances are not desirable during gas processing. Installing separators large enough to handle the most demanding conditions of feed gas insures proper protection of process units from liquid carry over. Another installation of solids separators such as oil bath scrubbers, centrifugal separators, or cylindrical gas filters insures adequate dust removal. Often, liquid and solid removal is combined in separators achieving both liquid and solid separation. These devices are generally installed ahead of the liquefaction plant in the metering units where pressure control of the feed gas is performed.

Sweetening refers to reomval of acid gas from a feed stream. Acid gas limits must be set to avoid freeze-out during subsequent liquefaction. As carbon dioxide is more difficult to remove compared to hydrogen sulphide, the limit in the effluent gas is generally set by the former. Usual limits for CO_2 and H_2S are 50 and 4 ppm, respectively.

Chemical absorption, physical absorption, or molecular sieving can accomplish acid gas removal. Chemical absorption employs a solvent in an aqueous solution, which reacts with the acid gas components to form complexes. When the temperature is increased and the pressure is reduced, the complexes are decomposed and the acid gases are released. Among the most commonly used solvents are monoethanolamine (MEA), diethanolamine (DEA), and diglycolamine (DGA). This chemical absorption can also be accomplished using a 25 to 35 % by weight of a hot (95-120 °C) K_2CO_3 solution.

Removal of acid gases may also be carried out by physical absorption, without forming complexes, using a medium such as Selexol, Purisol, Rectisol,..etc. Physical absorpion is not commonly used in the liquefaction field due to the affinity of the sorbent for heavy hydrocarbons and their expensive costs.

Molecular sieves can simultaneously remove water and acid gases from the feed gas. However, with regards to water removal where regeneration gas can be recycled, as acid gas cannot be condensed, regeneration gas has to be vented to the fuel gas system. If the acid gas content is not very small, this stream can exceed the fuel gas requirements of the plant.

Moisture content of natural gas must be reduced to a low limit (about 1ppm by volume) before liquefaction to avoid freezeout. Natural gas contains naturally water vapor, but becomes saturated upon removal of acid gas using aqueous solutions. A great part of water can be first removed by cooling the gas stream. The limitation is the temperature of hydrate formation which, for the usual pressure, is about 15 °C. As a common practice, the gas is not to be cooled down below 20 °C. Alternatively, water is commonly removed by absorption using a glycol solution or a solid dessicant.

Bulk removal of water can be achieved using glycol type contactors. Because of its hydroscopic property, washing on a glycol contactor permits a dew point depression of 20 to 50 °C depending on glycol concentration. The glycol unit consists of an absorber fed on top by lean glycol. Rich glycol from absorber bottom is stripped in the regenerator while the lean glycol is pumped back to the top of the absorber. Efficiency of the system can be improved by operation below the hydrate point. But in this case, glycol injection has to be made ahead of the corresponding chiller. Nevertheless, the glycol units must be followed by finishing units using solid dessicant to obtain the requested moisture limit.

Two beds of adsorbent are used and operate on a cycle basis (typically 8 or 12 hours) with one bed in operation, while the other is being regenerated. Apart of dry gas (10 to 15%) is sent to a heater then to the bed to be regenerated where water desorption occurs. Hot and wet gas which goes out of this bed is cooled in order to condense and remove the water. The gas is recycled to the inlet of the section by means of a booster. After water removal the heater is by-passed and the bed is then cooled to be ready for adsorption phase.

Natural gas to be liquefied is usually at ambient temperature with a pressure that ranges between 30 and 70 bars. The gas composition varies from one gasfield to another. Before it is liquefied, the gas has to be basically free of any products liable to solidify at low temperatures such as acid gases, or water vapor as described previously.

In order to liquefy natural gas, it has to be cooled to a temperature below -160 °C so that it can be stored at atmospheric pressure. The exact temperature depends on the composition of the liquefied natural gas.

During the cooling process it may be of advantage to extract heavier hydrocarbons like butane, propane or even ethane. It is also possible during liquefaction to reduce the nitrogen content of natural gas if it is high, in order to increase the heating value of the liquefied gas and above all prevent subsequent transmission of useless mass of nitrogen.

Generally, three ways exist of generating low temperature on an industrial basis:
Joule Thomson expansion method by free expansion, Georges Claude method by external work expansion at the turn of the century, and the cascade method or condensation-vaporization cycle (Pictet cycle). These three methods can be used together or separately. For the liquefaction of natural gas, particularly in large-size units, the cascade cycle is virtually the only one employed.

2.3 MAIN EMISSION SOURCES

Pollution is emitted into the atmopshere from a large number of different kinds of sources, atmosphere dilution in the first hundred meters of air above the ground can vary dramatically over fairly wide limits, because of the temperature gradient, which governs the rate of dilution (Haugen, 1975).

The major emission sources in a natural gas processing industry are compressor engines, acid gas wastes, fugitive emissions from leaking process equipment, and gas flares. Pressure relief and blowdown are intermittent releases and usually occur during maintenance and abnormal operations when the plant or equipment has to be depressurized. All vessels and equipment are protected by pressure relief valves, and these lines are directed to the flares or vents. Some fugitive emissions are inadvertent leaks from process components such as valves, connectors, etc.

Utility systems, which are the major source of combustion emissions, form part of production system and in some cases support for operating personal. Sources of emissions from the exhausts of those utilities may incorporate gas turbine drives, diesel and gas engines, heaters, and boilers (Code of Practice for Natural Gas Refining and Associated Processes).

Emissions from the above sources may include, carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC) which include methane (CH_4) and other volatile organic compounds (VOCs), nitrogen oxides (NO_x), nitrous oxide (N_2O), sulphur dioxide (SO_2), and particulates.

Potential sources of emission to air include some or all of the following:

- Flares (emergency flares, process flares).
- Plant and equipment (gas refrigeration systems, heaters, and recovery).
- Acid gas treatment (hydrogen sulphide, sulphur recovery).
- Process plant (nitrogen removal, process gas recompression, process-incinerators, condensate handling /storage).
- Chimneys and vents.

As an example for this study one of the major emission sources under upset or emergencies is flares which have a large impact in producing pollutants emitted to the atmosphere. Mainly flares are utilized to prevent the release of any unburned gas. It is a high temperature oxidation process for disposal of waste gases (Leite, 1992). A flare is a burner specially designed to burn waste gas originated in refineries, chemical plant and production facilities during normal operations or emergencies. Flares are employed for excess process streams due to unexpected equipment failure or major plant emergencies, such as instrument malfunctions, power failures or plant fires.

There are three general types of flares required in the industry; the least complex and most limited is the non-smokeless flare. It is used for hydrocarbon or vapor streams, which burn readily and do not produce smoke. Heavier hydrocarbons can be flared using this design, but only with considerable smoke and lower combustion efficiency. This may be tolerated, if flaring occurs only infrequently during short emergency upsets. A second type of flare is used for the heavy hydrocarbons. It is designated the smokeless flare. This flare will provide clean, efficient disposal of all hydrocarbon streams. Smokeless flares are required for any paraffin above methane, and all olefins, diolefins and aromatics. These flares use steam, high-pressure fuel gas, water spray, high velocity vortex action, or an electric air blower to produce smokeless operation and improved combustion performance. All smokeless flares utilize outside momentum sources to provide efficient gas/air mixing and turbulence for complete combustion. The third type of flare is used for low heat content waste streams and toxic vapors. This unit is called a fired or endothermic flare, because it provides additional energy to the waste stream for complete oxidation. Fired flares are used for sulphur tail gas and ammonia waste streams (Leite, 1991; Straiz, 1994).

2.4 ENVIRONMENTAL AND HEALTH IMPACT OF EMISSIONS

Carbon dioxide (CO_2) is a major product resulting from the combustion of fossil fuels. The increase in atmospheric concentration of CO_2 since the beginning of the industrial age raised concerns related to a possible rise in global temperature and escalated global warming. Under conditions of incomplete combustion, carbon monoxide will be emitted. This is a toxic gas since it reduces oxygen transport in the blood of animals. Methane is a naturally occurring hydrocarbon gas and is the major constituent of produced natural gas. Methane has a global warming potential twenty-one times higher than that of CO_2.

The major concern of releasing Volatile Organic Compounds (VOCs) is their ability to form photochemical oxidants (ozone) by reactions with nitrogen oxides in the presence of sun light. In addition to having a global warming potential, certain VOCs such as benzene are harmful to health and some are stratospheric ozone depletion substances.

Nitrogen oxides include nitric oxide (NO) and nitrogen dioxide (NO_2). These emissions occur almost exclusively from the combustion of fossil fuels for industry, and transport, and from the burning of biomass. When initially formed during combustion, the major proportion of NO_x is normally present as NO. However, NO are converted in the atomsphere to NO_2. Nitrogen oxides, as a final oxidative product, a component of acid rain and can lead in the presence of VOCs and sunlight to the formation of photochemical oxidants.

Nitrous oxide (N_2O) is produced both naturally and by combustion of fuels. Small, generally insignificant amounts are produced during combustion of fossil fuels, especially those operating at low temperatures such as fluidised bed boilers.

Sulphur dioxide (SO_2) is a colorless gas with a sharp odor that accounts for about 18% of all air pollution, making it second only to carbon monoxide as the most common urban air pollutant. It is an acidic gas produced during the combustion of fuels which contain sulphur compounds. It may also be produced photochemically when H_2S is released to the atmosphere. As is the case with ozone, exposure to low concentrations of SO_2 can damage plants and trees.

Hydrogen sulphide (H_2S) is a toxic gas with an extremely low odour threshold at low concentration occuring naturally during decomposition. Natural gas is normally treated to remove this H_2S to form sulphur or it can be burned (E & P Fourm, 1994). The sources and environmental impact of the different emitted pollutants are summarized in Table 2.2.

Table 2.2 Sources and environmental impact of emitted pollutants

Gaseous Pollutant	**Source**	**Effect/ Impact**
Carbon dioxide	Combustion	•Green house effect •Global warming
Carbon monoxide	Incomplete Combustion	•High toxicity •Green house effect •Global worming
Hydrocarbons	Oil and Gas Operations	•Ozone depletion •Photochemical smog, high toxicity/ carcinogenic(in some case)
Methane	Natural gas	•Global warming
Nitrogen oxides	Combustion Atmospheric nitrogen	•Photochemical smog •Acid deposition
Sulphur dioxide	Combustion	•Acid deposition
Hydrogen sulphide	Sour gas	•High toxicity (Precursor of SO_2)

The effect of emission into the air is greatly dependent on the type of components involved, the nature of the receptors and the time scale considered. Furthermore, emissions of specific components generally have a specific environmental impact and a typical scale of effects (Al-Wasity,1994).

Global effects like ozone layer depletion, and the green house effect are well known. Smog formation and acid rain are middle scale effects. Odour, dust and toxicity are relatively small scale effects. The effects of these pollutants on a local, regional, and global scale are illustrated in Tables 2.3 and 2.4 by Cronenberg and Eckford (1998).

Table 2.3 Scale of effects on environment and health

Sphere of influence	**Typical distance (km)**	**Impact**	**Type of risk**	**Control criteria**
On site/in-fence	--	contaminating nuisance corrosive	safety health	exposure levels (short,medium and long term) emission standards
local	0-20	contaminating nuisance	health	air quality standards emission standards
Regional	20-200	contaminating acidifying	health ecology	critical loads target levels emission standards
Continental	200-2000	acidifying	ecology	critical loads target levels emission standards
Global	>2000	greenhouse ozone depleting	climate	control of total amount of emissions emission standards

The scale of effects of pollutants including a broad range components. First, there are the combustion gases (CO_2, CO, NO_2 and SO_2) from incinerators, flares and gas turbines. The effect of scale of these components is principally regional or larger. The other, more important group is the fugitive emissions of volatile organic compounds and H_2S. The effect of these components is both local and global as given in Table 2.4.

Table 2.4 Scale of effects for typical polluting components related to gas processing[1]

Sphere of influence	**Component sources**	**Impact**	**Typical sources**
On site and local	H_2S	contaminating	vent stacks/fugitive
	organics	contaminating	vent stacks/fugitive
	mercaptans	nuisance (odour)	vent stacks/fugitive
	benzene	contaminating	glycol units/fugitive
	dust	contaminating/nuisance	flares
	CO	contaminating	combustion/flares
Regional and continental	NO_x	contaminating/acidifying	heaters/combustion
	SO_2	contaminating/acidifying	heaters/combustion
Global	CO_2	green house	heaters/combustion
	CH_4	green house	fugitive

[1] Gas Processing Symposium, May 98

2.5 REGULATIONS ON EMISSIONS AND AIR QUALITY

The ambient air quality standard is a target for the improvement of environmental pollution. In general all those standards are desgined to avoid short term effects and will provide sufficient control to avoid demonstrable longer term effects.

The Abu Dhabi National Oil Company (ADNOC) has control limits for emissions to atmosphere and Air Quality Standards, which are based upon World Health Organization (WHO) Guidelines. These control limits and air quality standards are shown in Tables 2.5 and 2.6, respectively. In addition, there is a draft code of Practice for Natural Gas Refining and Associated Process which has been submitted to Abu Dhabi Government by the Food and Environment Council as listed in Table 2.7.

Table 2.5 ADNOC control limits for air emission discharged into the atmosphere

Substance	**Concentration**
Sulphur dioxide	200 mg/m^3
Carbon monoxide	625 mg/m^3
Hydrogen sulphide	5 ppm
Total Suspended Particulate	100 mg/m^3

Table 2.6 ADNOC air quality standard[1]

Substance	**Averaging period**	**Time weight average concentration**
SO_2	1 hr	350 μg/m^3
	24hr	125 μg/m^3
CO	1 hr	30 mg/m^3
H_2S	30 min	7 μg/m^3
NO_2	1 hr	400 μg/m^3
O_3	1 hr	200 μg/m^3

[1] ADNOC Guidelines and Standards.

Table 2.7 shows that the proposed regulatory limit values are lower than the present ADNOC limits, and are extended to all combustion equipment and includes a wider range of emission gases.

Table 2.7 Proposed emission concentrations in the draft code of practice
for National Gas Refining and Associated Processes

Substance	**Concentration (mg/m^3)**[1]
SO_2	
Fuel type :	
- liquid	1700
- LPG	5
- gas	35
NOx (as NO_2)	350
Total Suspended Particulate	50
H_2S	5
Hydrocarbons (as total carbon).	As low as possible

[1] Refers to concentration at reference conditions of dry, 273 K, 101.3 kPa and 3 % oxygen content.

In accordance with the clean Air Act Amendments of 1970 the Environmental Protection Agency (EPA) established air quality standards at primary and secondary levels as summerized in Table 2.8. Primary standards are required to be set at levels that will protect public health as safety margin regardless of whether the standards are economically or technologically achievable. However, secondary standards are established to protect public welfare such as structures, crops, fabrics and animals (Peavy et al.,1986).

Table 2.8 EPA air quality standard

Pollutant	**Averaging time**	**Federal primary**	**Federal secondary**
CO	8 hr 1 hr	10 mg/m^3 40 mg/m^3	NA NA
NO_2	Annual 1 hr	100 µg/m^3 NA	Same NA
Ozone	1 hr	235 µg/m^3	Same
SO_2	Annual 24 hr 3 hr 1 hr	80 µg/m^3 365 µg/m^3 NA NA	NA NA 1310 µg/m^3 NA
PM10	Annual	50 µg/m^3	Same
Lead	24 hr 1 month 3 months	150 µg/m^3 NA 1.5 µg/m^3	Same NA Same

NA: not available.

WHO set out guidelines, explaining other factors need to be taken into account. These factors are meteorological and topographical features of the area and types of sources involved, all of which influence the way in which concentrations may vary from time to time, and turn the way in which standards are defined (WHO, 1980).

CHAPTER 3

SITE DESCRIPTION

3.1 INTRODUCTION

ADGAS was set up in agreement with Tokyo Electric Power Company for the supply of liquefied gas for their power generating plants. Construction of ADGAS began in 1973 and was completed in 1977. Until the early seventies, gas liquefaction plants all over the world used to process either associated gas, extracted from crude oil, or natural gas. But ADGAS Plant was the first in the world to process both types of gas. The raw gas is delivered to the Plant at five different pressure levels, which are then regularized into a uniform gas pressure to facilitate the liquefaction process. This is a unique facility among the several liquefaction plants in the world.

The initial Plant consisted of two identical process trains arranged in parallel to permit safe overhaul of one train while the other remains in service. The process plant is integrated with a utility complex, which can be shut down in sections for maintenance overhaul while production continues subject to same limitation.

3.2 GEOGRAPHICAL LOCATION

The LNG plant of ADGAS is located in Das Island about 180 km north west of Abu Dhabi city. The Island (about 2.5 km long and 1.5 km wide) is also the focal process area for Abu Dhabi Marine Operating Company (ADMA-OPCO) as shown in Fig 3.1. Gas feedstock for ADGAS Plant comes from numerous oil fields surrounding Das Island. The associated and non-associated gas streams from different gas sources are sent to ADGAS-LNG Plant as shown in Fig 3.2. The general terrain at Das Island is mainly flat in the south with land rising to around 30m above sea level in the northwest to north.

The population of the Island at normal working operation is about 3000 and up to 4500 at overhaul shutdown for plant maintenance. Most workforce is residential working with different cycle leave around the year, and all associated with or support the oil and gas operations in Das Island.

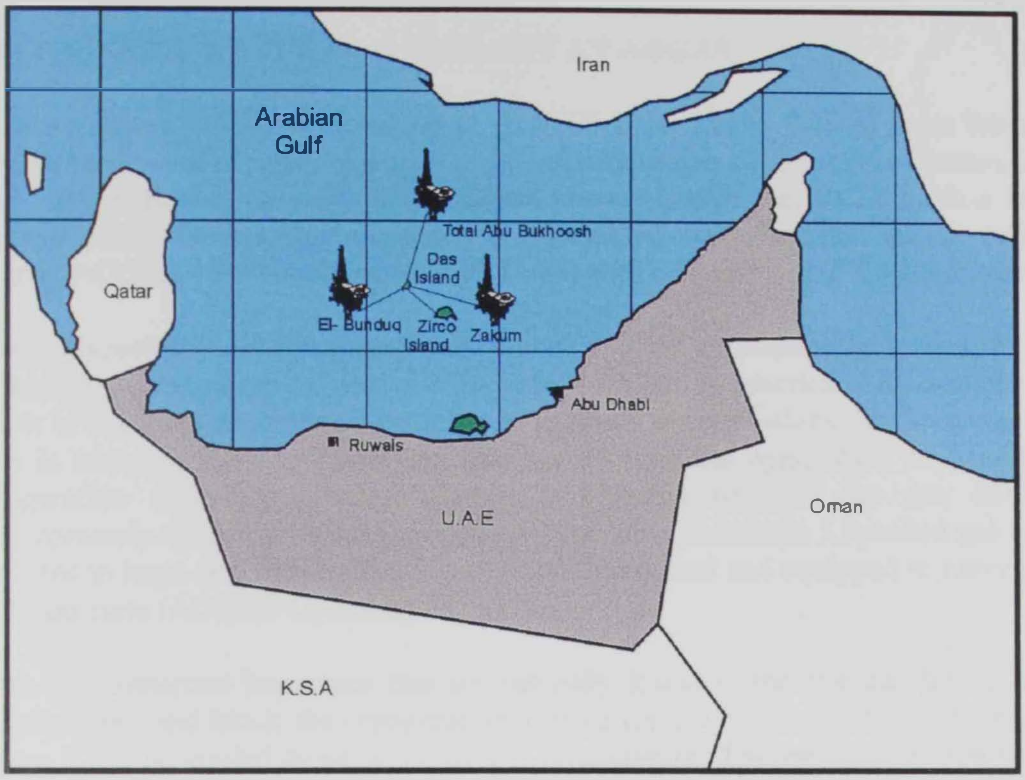

Fig 3.1 Das Island and main sources of gas supply

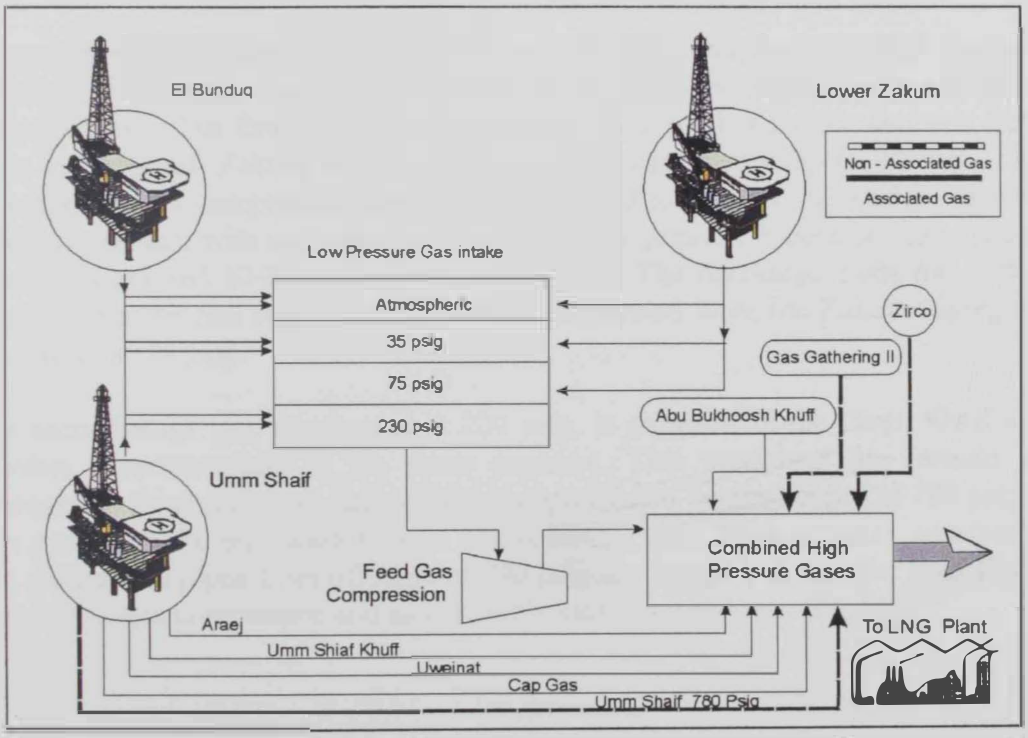

Fig 3.2 Main sources of gas supply

3.3 LIQUEFIED NATURAL GAS PLANT AT ADGAS

Currently, three trains are operating at ADGAS LNG Plant. Two of these trains are identical and were designed for a total annual production of 2.3 million tonnes LNG, 0.65 million tonnes propane, 0.42 million tonnes butane, and 0.22 million tonnes pentane plus. To meet the Company's contractual commitments and to optimise returns, ADGAS constructed a third LNG train with a capacity of 2.5 million tonnes.

The gas liquefaction is a relatively new branch of modern technology, and it is highly sophisticated and complex, as well. In order to make it practical and commercially viable to transport gas from one country to another, the gas volume has to be reduced. This is accomplished by liquefying the gas through the application of proprietary refrigeration technology, which makes it possible to cool the gas down to approximately -160 °C, resulting in a 600 fold volume reduction. Liquefied gas is then exported in huge-size tankers that are especially designed and equipped to carry gas in its liquid state (ADGAS Operating Manual).

Since the numerous impurities that are naturally found in the raw gas freeze at low temperatures, and block the cryogenic section of the plant, the gas has to be purified before it can be cooled down to cryogenic temperature. The gas liquefaction process can be divided into five main stages as shown in Fig 3.3 and discussed below.

3.3.1 Compression

Compression is required for the associated gas only and was provided for the two identical LNG trains. Each train of the plant has two feed-gas compressors driven by steam turbines. The first is booster compressor, which takes the atmospheric flow gas from Umm Shaif, Zakum and El-Bunduq and compresses it up to 30 psig. The gas from the booster compressor forms part of the feed to the first stage of the three-stage feed compressor, with the other part being the low-pressure separator gas of the Umm Shaif, Zakum and El-Bunduq production plants. The discharge from the first stage passes to the second stage together with a gas stream from the Zakum high-pressure separators at 75 psig.

The second-stage gas, discharged at 230 psig, is joined with the Umm Shaif and El-Bunduq separators gas of the same pressure. This combined gas stream passes through the third and final stage of the compressor to be discharged at 780 psig when it is passed to the purification (acid gas removal) unit. High pressure associated gas and natural gas pipes from offshore at 780 psig are introduced into the final discharge of the feed-gas compressor and also directly into the third train (Fig 3.3).

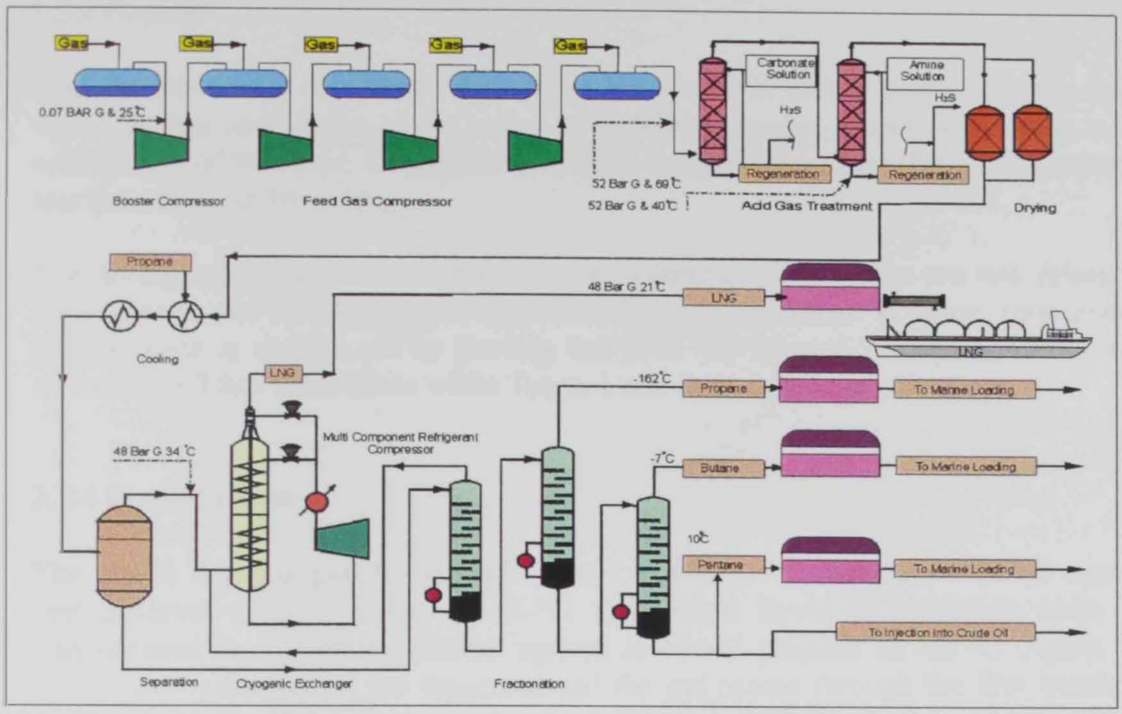

Fig 3.3 Gas liquefaction process at ADGAS

3.3.2 Sweetening

The feed gas that enters the plant contains a number of impurities, that should be reduced to the minimum in order to meet certain technical requirements that are related partly to the specification set by the customers. Among these impurities, carbon dioxide has to be removed, or reduced to the minimum, since it freezes at low temperatures and would, therefore, block the cryogenic sections of the Plant when the gas is cooled to -160 °C. Secondly, hydrogen sulphide is a major pollutant. Its presence in the liquefied gas must be reduced to the minimum to satisfy customer's requirements and specifications. The extracted hydrogen sulphide is further processed to produce liquid sulphur, an essential process in itself as it helps protecting the environment.

ADGAS produces about 1000 tonnes per day of liquid sulphur, which is shipped to ADNOC's facilities in Ruwais where it is stored, granulated and exported. The feed-gas received by the plant contains 2.5 % - 5.5 % H_2S and 4.5 % - 6.5 % CO_2. In the first purification stage, the feed gas is treated with hot potassium carbonate solution, which reduces CO_2 and H_2S content to 2000 and 800 ppm, respectively. The gas then passes to the second absorber where it is treated with the diethanolamine solution to further reduce the H_2S content to less than 3 ppm and CO_2 to about 30 ppm.

3.3.3 Drying

The gas that leaves the purification (acid-gas removal) unit is saturated with water vapor. Before cooling the gas to below 0 °C, it must be dried to avoid freezing in the cold section of the Plant. The driers have been designed to reduce the water content to less than 0.1 ppm by volume.

The drying agent used in ADGAS Plant is molecular sieve. There are two driers for each stream; the first would be operational while the other is being regenerated. Regeneration is carried out by passing hot (310 °C) dry gas through the molecular sieve. Train 3 has three driers while Trains 1 and 2 have two each.

3.3.4 Fractionation

The sweet dry gas passes through a heat exchanger where it is cooled against medium-level propane down to -1 °C. Condensed liquid is separated while the uncondensed feed gases are cooled against low-level propane to -34 °C. Again, the condensed hydrocarbons are separated and the gas passes through the first bundle in the main cryogenic exchanger, where the gas is cooled to around -45 °C and the remaining LPG that has condensed already is separated out. The remaining uncondensed gas, which is predominantly methane and ethane, passes back into the main cryogenic exchanger for liquefaction.

In the de-ethanizer column, methane and ethane in the feed boil-off overhead are sent to the main cryogenic exchanger for liquefaction. The bottoms from the de-ethanizer pass to the de-propanizer where propane is distilled overhead, cooled, condensed and pumped to storage. The bottoms from the de-butanizer contain the pentane and heavier hydrocarbons .

3.3.5 Liquefaction

Liquefaction of methane and ethane takes place in the main cryogenic exchanger. The feed gas, mainly methane and ethane with some residual propane, enters the lower bundle at -34 °C. It passes through the lower (or warm) bundle and emerges at -50 °C. At this stage, almost all the propane in the feed gas has condensed and is separated from the gas for recovery in the fractionation section. The uncondensed gas passes through the middle and, then the cold, third bundle where it is cooled to approximately -160 °C. At this temperature, the gas condenses to liquid and is sent to the refrigerated storage tanks.

Cooling in the cryogenic exchanger is provided by a conventional compression-based refrigeration loop using a multi-component refrigerant (MCR) through a two-stage compressor.
The MCR gas is made up of approx. 7 % nitrogen, 38 % methane, 41 % ethane and 14 % propane.

3.3.6 Sulphur Recovery

Hydrogen sulphide, which is highly poisonous and has a very penetrating and irritating smell, produces sulphur dioxide when it is safely flared. The immediate effects of inhaling even small quantities of sulphur dioxide are coughing, chest pain and shortness of breath. Sulphur dioxide is thought to contribute to bronchitis and other lung diseases. In addition, when released to air, sulphur dioxide reacts with water vapor to form sulphuric acid. This is slowly oxidized by oxygen in the air to sulphuric acid, which has a very corrosive and damaging effect on fish, trees and building materials. Besides, emission of sulphur dioxide is believed to be a major factor that contributes to the concrete cracking and equipment corrosion.

The recovery of sulphur from acid gases is considered one of the most important methods of avoiding air pollution that results from the flaring of H_2S. This is achieved by separating the acid gases from the hydrocarbons in the natural gas, and feeding them to the Sulphur Recovery Units (SRUs), which convert hydrogen sulphide in the acid gases to high purity sulphur by the Claus process. ADGAS Plant has three SRUs, which have a total design production capacity of 1500 tonnes of liquid sulphur per day.

In addition to its main value of removing sulphur dioxide, sulphur is vastly used in the commercial production of many chemicals, vulcanization of rubber, ointments for some skin diseases and sulfa drugs, as well as in the manufacture of insecticides, fungicides and plant fertilizers.

3.3.7 Utilities

The performance of ADGAS Plant involves a number of utilities and services. The following are the most important:

1. Six forced draft, gas-fired boilers, each having a rated capacity of 360 tonnes per hour of steam at a pressure of 60 bars and a temperature of 440 °C.
2. Seawater cooling is provided by nine pumps each with a rated capacity of 16,500 m^3 of water per hour.
3. Three firewater pumps; each can provide 1200 m^3 of water per hour into the fire water system.
4. Compressed air is provided for four nitrogen production units and then dried and supplied to all pneumatically operated instrumentation.
5. All the industrial fresh water requirement of the LNG Plant are provided by three sea water desalination units, each has a proven production capacity of 35 tonnes per hour. Water required for boiler water feed is further treated in six

demineralization units. There is an extensive steam condensate recovery system that exceeds 95 %.

6. Electric power generation capacity of 105 megawatts is provided by two steam turbine generators, each of 17.5 megawatts; and four gas turbine generators; each of 17.5 megawatts.

Besides supplying power to the Plant, the utilities section provides power requirements for the whole Island.

3.3.8 Storage Tanks

Originally, ADGAS had two storage tanks to keep LNG at -160 °C, propane plus at -45 °C, butane at -6 °C, and pentane at ambient temperature. But with the increase in production that exceeded the Plant's original capacity, and in order to meet future requirement, the two storage tanks were decommissioned after the construction of seven new tanks built in conformity with the most advanced international specification. The seven storage tanks included three each of 80,000 m^3 capacity for the LNG and four LPG tanks each of 50,000 m^3 capacity. The construction of these tanks was completed in 1986. Finally, these tanks are utilized to load tankers with LNG to be exported.

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.1 INTRODUCTION

Data required for conducting this study are preseneted in this chapter, and the methodology through which the data were obtained was outlined. Several visits to Das Island were conducted to collect the information needed from technical personnel at the Department of Health, Safety and Environment, and Operations and Process Engineering Departments at ADGAS. Obtained data were collected by ADGAS staff during 1996 and 1998. Additional data were obtained from a study conducted by W. S. Atkins (1997). The information obtained for the year 1996 was more comprehensive than that for the year 1998. Thus, this study is solely based on the data for 1996. However, emissions reported in the two years were sometimes preseneted for comparison purposes.

Air dispersion models require meteorological data to produce air quality estimates. Some of these models, including the one that will be used in this study, require an hourly meteorological data. However, no comprehensive record of hourly meteorological data is available during 1996-1997 for Das Island. Therefore, meteorological data were collected from Abu Dhabi International Airport (ADIA), which is the closest meteorological station to Das Island, and the data were utilized in this study. Applicability of using these data to simulate ground concentration resulting from emissions releases at Das Island was discussed below.

4.2 METEOROLOGICAL DATA

The prevelling wind direction on the west coastal of the UAE including Das Island is different in winter and summer as a result of air pressure and movement patterns. In winter, high pressure centered bringing a flow of dry air to the island from the north east. However, a strong thermal low-pressure flow extends from Pakistan and Iran with a moist airflow from the south east during summer. Prevailing wind goes up to 20 km/h from north west (310°).

To be able to utilize the meteorological data collected from ADIA, a comparison was made between average monthly highest and lowest temperature recorded at Das Island during1956-1964 with the 1996 data at ADIA as shown in Fig 4.1. The figure shows that the meteorological conditions from a temperature point-of-view are close for the two locations. Therefore, the assumption was made that wind direction and speed at ADIA will be applicable to this study.

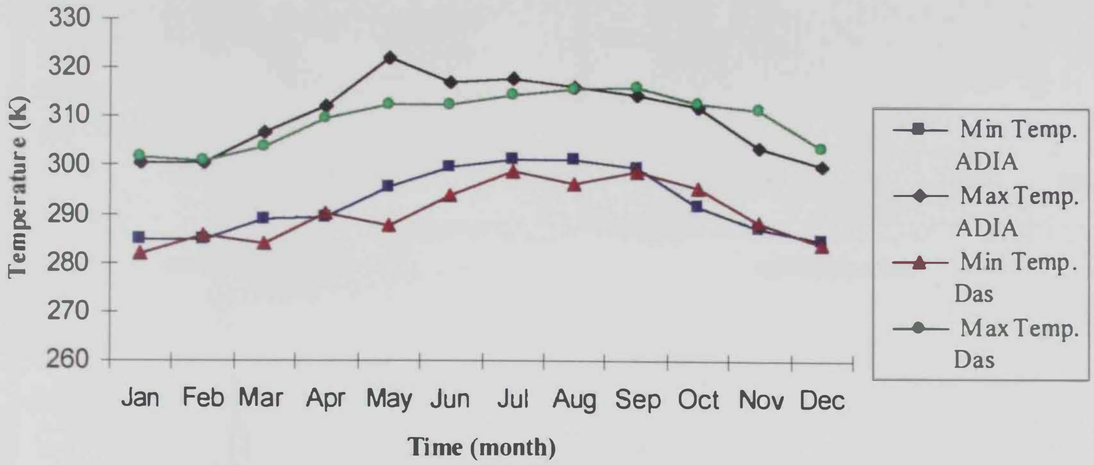

Fig 4.1 Temperature comparison between Das and ADIA

Collected meteorological data include full one year hourly average temperature, wind direction, wind speed, stability class and mixing heights. A sample example for one day meteorological data is shown in Appendix A (Table A.1). The average monthly temperature and wind speed and the standarad deviation (from the average) in monthly temperature and wind speed are shown in Table 4.1. Monthly variations (from the average) in temperature are not as high as those associated with wind speed. On the other hand, the average monthly wind speed does not exceed 5 m/s. Fig 4.2 shows hourly wind speed and temperature for the months of January and July.

Table 4.1 Summary of meteorological data at ADIA for 1996

Month **Parameter**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average Temperature (°C)	19.5	19.7	23.4	26.6	31.7	34.2	36.3	35	32	28.3	24.2	20
Standard deviation	2.85	2.88	3.32	4.11	4.68	3.42	3.87	3.4	2.95	3.89	3.3	3.23
Average Wind speed (m/s)	3.05	3.11	4.85	3.77	3.13	3.65	3.44	3.21	3.22	3.14	3.42	2.78
Standard deviation	1.89	1.9	2.33	2.05	2.4	1.96	2.29	1.64	1.63	1.63	1.83	1.52

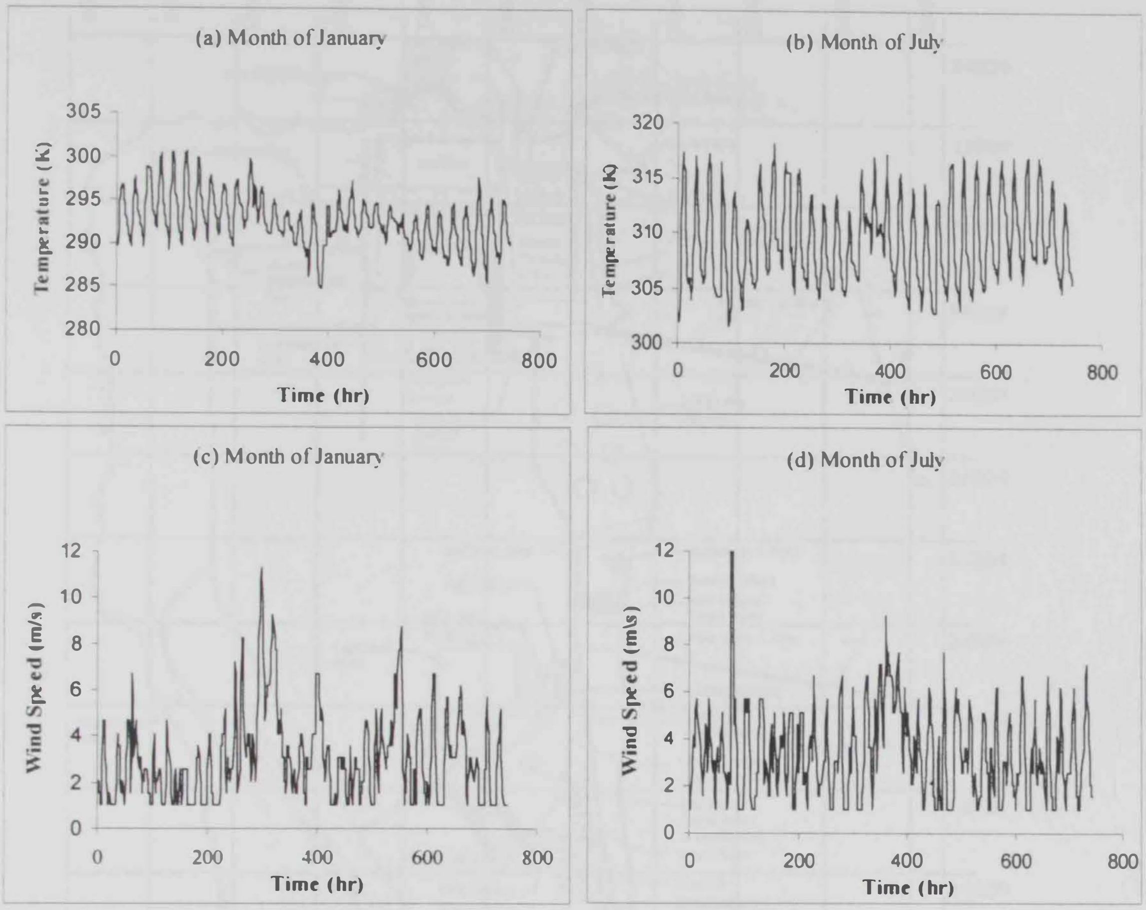

Fig 4.2 Temperature and wind speed fluctuations reported at ADIA.

4.3 EMISSION SOURCES

A general map of the study area including the main sources and receptors is shown in Fig 4.3. There are 26 major emission point sources at ADGAS LNG Plant, and those sources are located at the North side of the Island as shown in Fig 4.4. These sources can be categorized into five groups: boiler stacks; regeneration gas heater stacks; gas turbine stacks; sulphur recovery incinerator stacks; and flares. Besides their different locations on the Island, the emission sources have different stack diameters and heights as outlined in Table 4.2. The rate of emission from these emission sources varies with the operating conditions. These conditions are classified as emergency or normal. Emergency conditions results in shutdown of certain operations, and occurs due to power loss or feed gas over flow or instrument malfunctions. In this case, the gas which was supposed to be processed, is bypassed to the flares. Thus, emissions from non flare sources are a result of normal operations. However, some of these sources do not receive emission gases under emergency conditions.

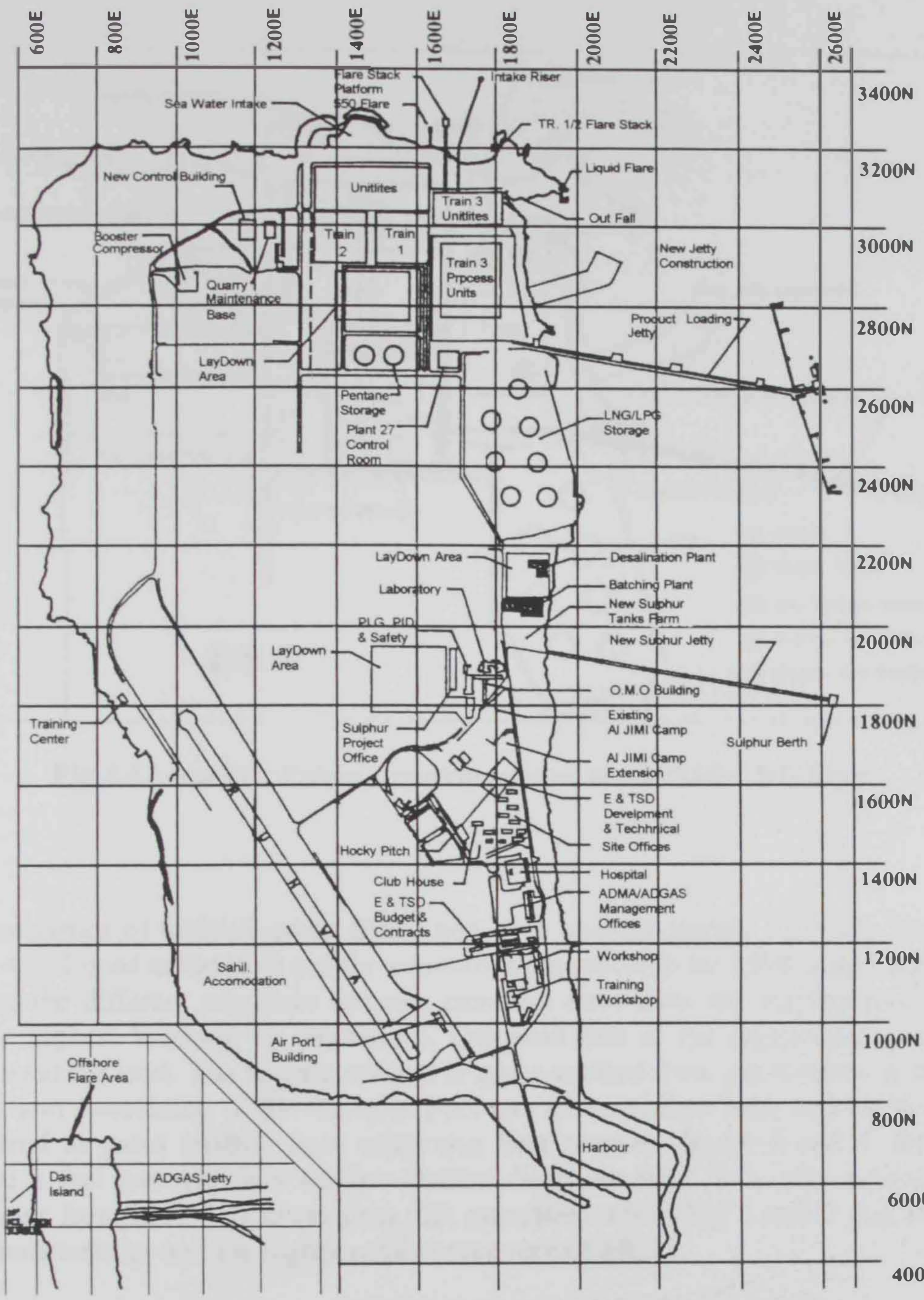

Fig 4.3 Das Island Map

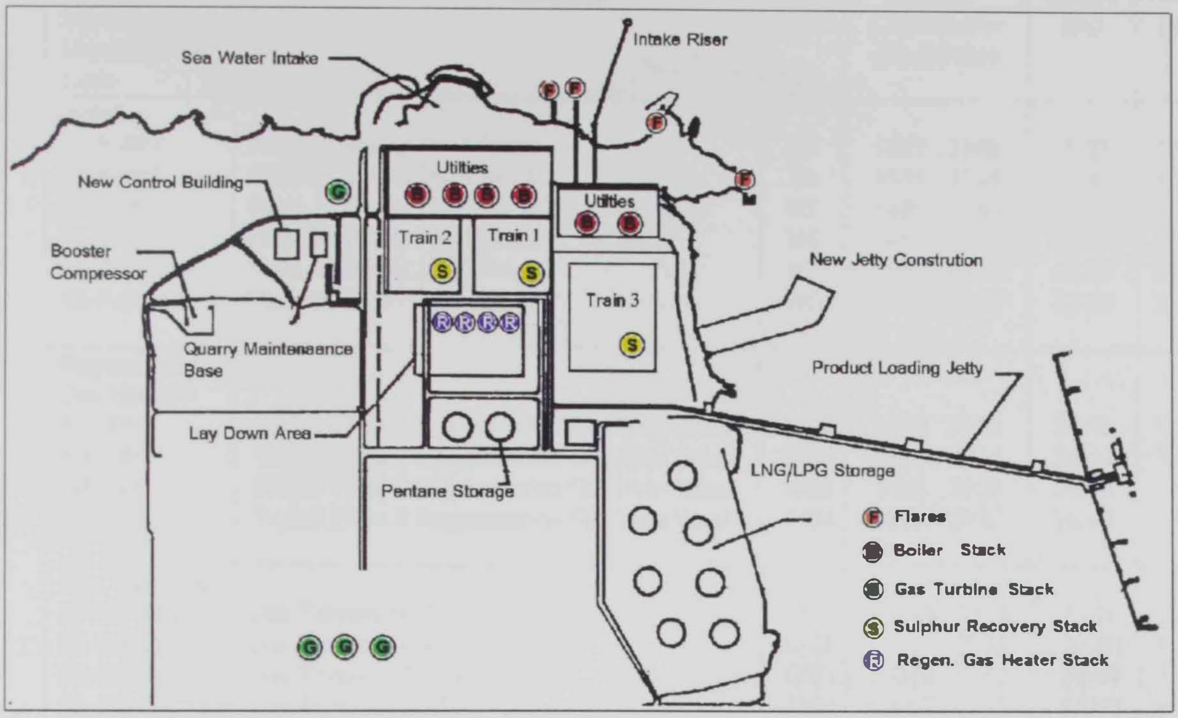

Fig 4.4 Location of main emission sources at ADGAS-LNG Plant

Characteristics of emitted gases from non flare sources during 1996 are presented in Table 4.3. Listed in the table are the emission rates reported for 1998 from these sources. Among the different non flare sources, emission rates from the sulphur recovery units are the highest followed by the boilers. Emission rate of the regenerator gas heater is considered the least. The sulphur content in gases emitted from gas turbines is the highest due to non sweetening of the fuel gas. Fuel gas to the boilers have less sulphur content compared to gases emitted from other non flare sources. Boiler 5 and 6, for example receive a fuel gas with low sulphur content from the field. It is also noticed that the emissions from SRU 3 is lower than that associated with SRU 1 and 2 due to different gas characteristics and the higher sulphur recovery of SRU 3.

Comparison of emission rates from same sources during 1996 and 1998, shows that the two values are close, with the exception of the values associated with the sulphur recovery units. Differences between the values reported in the two years, are possibly due to number of shutdowns of the SRU that had occurred in 96 as compared to those in 98.

Table 4.2 Physical properties of the emission sources at ADGAS

ADGAS Source Identification Code	Source Description	Our Code	Location Coordinates [1] E(m):N(m)	Height (m)	Dia (m)
Boilers					
31-F-001	Plant 31 Boiler No.1 Stack	B1	1527 : 3148	30.85	3.5
31-F-002	Plant 31 Boiler No.2 Stack	B2	1503 : 3148	34.85	3.5
31-F-003	Plant 31 Boiler No.3 Stack	B3	1480 : 3148	34.85	3.5
31-F-004	Plant 31 Boiler No.4 Stack	B4	1457 : 3148	34.85	3.5
45-F-005	Plant 45 Boiler No.5 Stack	B5	1803 : 3075	43.30	3.8
45-F-006	Plant 45 Boiler No.6 Stack	B6	1772 : 3075	43.30	3.8
Regeneration Gas Heaters					
3-F-101	Train1 Plant 3 Regeneration Gas Heat Stack	RG1	1500 : 2920	26.40	1.32
3-F-201	Train2 Plant 3 Regeneration Gas Heat Stack	RG2	1370 : 2902	26.40	1.32
9-F-101	Train1 Plant 9 Regeneration Gas Heat Stack	RG3	1508 : 2920	26.40	1.32
9-F-201	Train2 Plant 9 Regeneration Gas Heat Stack	RG4	1363 : 2920	26.40	1.32
Gas Turbines					
80-GT-101	Gas Turbine (GT1)	GT1	1352 : 3113	13.00	3.25
80-GT-201	Gas Turbine (GT2)	GT2	1013 : 2252	20.00	3.25
80-GT-301	Gas Turbine (GT3)	GT3	1040 : 2252	20.00	3.25
31-PT- 5 C	Gas Turbine (LG5)	GT4	1067 : 2252	20.00	3.84 [2]
Sulfur Recovery Incinerators					
7-F-105	Train 1 Sulfur Recovery Stack	SRU1	1616 : 2928	46.00	2.00
7-F-205	Train 2 Sulfur Recovery Stack	SRU2	1478 : 2928	46.00	2.00
7-F-321	Train 3 Sulfur Recovery Stack	SRU3	1780 : 2751	70.25	4.20
Flares					
17-F-301	Train 3 Sweet Gas High Level Flare	F31	1713:3350	75	1.80
17-F-302	Train 3 Sour Gas High Level Flare	F32	1713:3342	75	1.07
17-F-303	Train 3 Continuous Sour Gas High Level Flare	F33	1713:3333	75	0.77
17-F-101	LNG/LPG Flare	F11	1632:3284	75	0.91
19-F-101	LPG Tankage Flare	F12	1835:3205	60	0.76
19-F-103	Sour (Warm) Liquid Burner	F13	1835:3208	10	N/A
19-F-104	LNG Burner	F14	1835:3208	10	N/A
19-F-103	Trains 1 and 2 Sweet Gas High Level Flare	F15	1713:3325	75	0.60
19-F-106	Trains 1 and 2 Sour Gas High Level Flare	F16	1713:3317	75	0.82

[1] The origin point (0:0) is located at latitude 25°:10′ and longtidude 25°:50′.

[2] GT4 has a rectangular cross-section and an equivalent diameter is estimated.

Table 4.3 Emissions from non flare sources (based on process design criteria. ADGAS, 1998)

Source	Emission Condition	Emissions Rates kg/hr		Gas M.Wt	H_2S %	Emission Factor[4]		Emission Characteristics		
		1996[2]	1998[3]			CO_2	SO_2	Flow Rate m^3/s	Velocity m/s	Exit Temp K
B 1	N[1]	18.818		20.23	0.06	2.830	0.0012	165.6	17.2	570
B 2	N	17,970		20.23	0.06	2.830	0.0012	153.2	15.9	570
B 3	N	19,107		20.23	0.06	2.830	0.0012	169.6	17.6	570
B 4	N	19,323		20.23	0.06	2.830	0.0012	170.3	17.7	570
B 5	N	24,950		18.04	0.00	2.790	0.0000	152.0	13.4	467
B 6	N	25,353		18.04	0.00	2.790	0.0000	156.2	13.8	467
Total		**125,521**	**118,813**							
RG 1	N	657		20.23	0.007	2.830	0.00014	11.9	8.7	1044
RG 2	N	657		20.23	0.007	2.830	0.00014	14.0	10.2	1002
RG 3	N	628		20.23	0.007	2.830	0.00014	12.6	9.2	1196
RG 4	N	268		20.23	0.007	2.830	0.00014	11.7	8.5	1105
Total		**2,210**	**2,120**							
GT 1	N	1,308		20.51	2.53	2.835	0.0506	29.2	3.5	533
GT 2	N	6,367		20.51	2.53	2.835	0.0506	148.7	17.9	558
GT 3	N	1,336		20.51	2.53	2.835	0.0506	29.7	3.6	531
GT 4	N	4,829		20.03	2.53	2.830	0.0506	140.4	12.1	678
Total		**13,840**	**21,000**							
SRU 1	N	124,230		32.55	0.338	NA	NA	91.5	29.1	873
SRU 2	N	124,320		32.55	0.338	NA	NA	91.5	29.1	867
SRU 3	N	90,488		31.43	0.340	NA	NA	89.8	6.7	908
Total		**339,038**	**1,514,000[5]**							

[1] Normal operation.

[2] Simulations for current and modified scenarios based on the 1996 data.

[3] Personal communication with ADGAS HS&E Department.

[4] Emission factors for pollutants other than CO_2 and H_2S are tabulated in Tables A.2 through A.2 in Appendix A

NA: Not applicable for SRU. However, calculations of emission rates for all pollutants in this case are based on flow rates from the incinerator and the use of the ideal gas law. A sample calculation for CO_2 and SO_2 emissions is presented in the Appendix A.

[5] Including normal and emergency shutdown conditions.

Characteristics of emitted gases from flares under normal and emergency conditions are listed in Table 4.4. The main emission under normal operating conditions are due to LNG/LPG shipment loading and some flaring of cryogenic leak, with a very high emission rate during this loading, but low annual during operating hours. Purge and pilot flaring constitute a small portion of that emitted gas through flare stacks. Rate of emission under emergency situations are very high, however, not all labelled emergency values occurs at the same time. The worst case of emergency situations is explored in chapter 6.

Table 4.4 Emissions from flares (based on desgin criteria compiled from Atkins, 1996 and ADGAS, 1998)

Emission Conditions			Annual Emissions			H_2S %	Emission Factor	
Source	Description	Emission Type[1]	hrs	kg/hr	M.Wt		CO_2	SO_2
F31	Purge and Pilot	N	8760	250	18.04	0.1800	2.65	0.00360
	Flaring cryogenic leak	N	8760	4320	28.90	0.0005	2.77	0.00001
	Total Plant Failure	E	10	883,700	28.90	0.0005	2.77	0.00001
	Blocked outlet	E	10	1,086,000	28.90	0.0005	2.77	0.00001
F32	Purge and Pilot	N	8760	250	18.04	0.1800	2.65	0.0036
	Maximum Relief Rate	E	40	545,600	20.40	3.0000	2.69	0.0600
	Plant 6 imbalance	E	550	1,776	20.40	0.1800	2.69	0.0036
F33	Purge and Pilot	N	8760	250	18.04	0.1800	2.65	0.0036
	Acid Gas Flaring (min crude production case)	E	80	85,325	39.33	25.490	2.84	0.5098
	Acid Gas Flaring (max crude production case)	E	80	56,334	39.33	21.560	2.84	0.4312
F11	Purge and Pilot	N	8760	250	20.23	0.1800	2.69	0.0036
	LPG Recovery System Shutdown	E	48	55,268	18.20	0.0000	2.65	0.0000
	LNG Loading	N	600	38,000	18.20	0.0000	2.65	0.0000
	Normal Boil off gas	E	2000	5,969	18.20	0.0000	2.65	0.0000
F12	Purge and Pilot	N	8760	250	20.23	0.1800	2.69	0.0036
	LPG Loading with Recovery Syetem Shutdown	E	60	6,371	46.30	0.0000	2.86	0.0000
	LPG Loading with Normal Boil off gas	E	600	6,154	48.00	0.0000	2.87	0.0000
F13	Purge and Pilot	N	8760	250	20.23	0.1800	2.69	0.0036
	Maximum Relief Rate	E	24	40,000	3 - 70	3.0000	3.00	0.0600
F14	Purge and Pilot	N	8760	750	20.23	0.1800	2.69	0.0036
	Maximum Relief Rate	E	100	136,500	19.00	0.0000	2.67	0.0000
F15	Purge and Pilot	N	8760	250	18.04	0.1800	2.65	0.0036
	Maximum Relief Rate	E	60	252,000	21.30	0.0500	2.70	0.00001
	Treater Gas Manual Relief	E	730	860	21.30	0.1800	2.70	0.0036
F16	Purge and Pilot	N	8760	250	18.04	0.1800	2.65	0.0036
	Maximum Relief Rate	E	1	362,000	24.70	3.0000	2.75	0.0600
	Failure of One SRU (mixed feed case)	E	170	55,998	24.70	37.500	2.75	0.7500
	Failure of One SRU (high press feed case)	E	80	47,669	24.70	21.900	2.75	0.4380

[1] E for emergency and N for normal condition.

The annual emissions of 8 pollutants from each source under normal and emergency conditions are calculated, unless otherwise indicated, using the gas flow rate and the emission factor for the pollutant under consideration. These values are tabulated in Table 4.5 for non flare sources and Table 4.6 for flares. Emission factors are obtained form (E & P forum, 1994) and are tabulated in Appendix (A). The values shown in Table 4.6 are based on the assumption that the combustion effeceincy is 95%.

Table 4.5 Calculated emission rates for non flare sources

Source	Mass Emission Rates (Tonnes/yr)							
	CO_2	CO	NO_x	N_2O	SO_2	CH_4	VOC	Particulate
B1	466,733	131.88	511.01	36.27	197.70	11.54	0.00	0.00
B2	444,658	125.92	487.99	34.63	189.20	11.02	0.00	0.00
B3	473,040	133.90	518.86	36.83	200.90	11.72	0.00	0.00
B4	479,347	135.42	524.73	37.21	203.10	11.86	0.00	0.00
B5	608,645	174.84	677.55	48.19	0.00	15.29	0.00	0.00
B6	618,106	177.67	688.49	48.85	0.00	15.55	0.00	0.00
Total	3,070,529	879.55	3,408.63	241.98	790.90	76.98	0.00	0.00
RG1	4730	1.33	5.17	0.37	0.20	0.12	0.00	0.00
RG2	4730	1.33	5.17	0.37	0.20	0.12	0.00	0.00
RG3	15,453	4.40	17.06	1.21	0.80	0.38	0.00	0.00
RG4	6,623	1.88	7.28	0.52	0.30	0.16	0.00	0.00
Total	31,536	8.94	34.68	2.47	1.50	0.78	0.00	0.00
GT1	119,837	114.22	283.41	9.30	2,141.30	17.79	0.00	0.00
GT2	32,482	30.94	76.76	2.52	580.30	4.83	0.00	0.00
GT3	157,995	150.58	373.70	12.27	2,820.90	23.43	0.00	0.00
GT4	33,113	31.60	78.40	2.58	592.00	4.92	0.00	0.00
Total	343,427	327.34	812.27	26.67	6,134.50	50.97	0.00	0.00
SRU1	282,373	8.07	31.30	2.22	13,133	0.7	0.00	0.00
SRU2	282,373	8.07	31.30	2.22	13,133	0.7	0.00	0.00
SRU3	241,250	8.81	34.10	2.42	5,248	0.77	0.00	0.00
Total	806,000	24.95	96.70	6.86	31,514	2.17	0.00	0.00
Total	4,245,150	1,240.7	4,352.2	227.9	38,440.9	130.9	0.00	0.00
							Grand Total	**4,289,543**

Note: Discharge rate is calculated by multiplying the gas emission rate by the emission factor tabulated in Appendix A. Tabulated emission factors are based on a 95% combustion effeciency. Emission factors are the stoichiometric coefficients (mass basis) of the combustion reaction multiplied by the combustion effeciency.

Table 4.6 Calculated flares emission rates

Soure Code	Time (hrs)	Emission Rates (Tonnes/yr)							
		CO_2	CO	NO_x	N_2O	SO_2	CH_4	VOC	Particulate
F31	8760	5,803	19.05	3.29	0.18	7.90	76.65	32.85	0.11
	8760	104,826	329.24	56.76	3.06	0.40	1,324.51	567.65	20.02
	10	24,478	76.88	13.26	0.72	0.10	309.30	132.55	4.42
	10	30,082	94.48	16.29	0.88	0.10	380.10	162.90	10.86
F32	8760	5,803	19.05	3.28	0.18	7.90	76.65	32.85	0.11
	40	58,709	189.87	32.74	1.77	1,309.40	763.84	327.36	2.73
	550	2,633	8.50	1.47	0.08	3.50	34.19	14.65	0.05
F33	8760	5,803	19.05	3.28	0.18	7.9	76.65	32.85	0.11
	80	19,385	59.39	10.24	0.55	3,481.30	238.91	102.39	9.80
	80	12,799	39.21	6.76	0.37	1,943.10	157.74	67.60	7.32
F11	8760	5,866	19.05	3.28	0.18	7.90	76.65	32.85	0.11
	48	7,030	23.08	3.98	0.21	0.00	92.85	39.79	0.01
	600	60,415	198.36	34.20	1.85	0.00	798.00	342.00	0.03
	2000	31,680	103.86	17.91	0.97	0.00	417.83	179.07	0.05
F12	8760	5,866	19.05	3.28	0.18	7.90	76.65	32.85	0.11
	60	1,093	3.33	0.57	0.03	0.00	13.38	5.73	1.32
	600	10,584	32.12	5.54	0.30	0.00	129.23	55.39	12.83
F13	8760	5,866	19.05	3.28	0.18	7.90	76.65	32.85	0.11
	24	2,880	8.35	1.44	0.08	57.60	33.60	14.40	21.60
F14	8760	17,660	57.16	9.87	0.53	23.70	229.96	98.55	0.33
	100	36,446	118.76	20.48	1.11	0.00	477.75	204.75	0.34
F15	8760	5,803	19.05	3.28	0.18	7.90	76.65	32.85	0.11
	60	40,824	131.54	22.68	1.22	0.20	529.20	226.80	2.27
	730	1,695	5.46	0.94	0.05	2.30	21.97	9.42	0.09
F16	8760	5,803	19.05	3.28	0.18	7.90	76.65	32.85	0.11
	1	995	3.15	0.54	0.03	21.70	12.67	5.43	0.54
	170	26,194	82.82	14.28	0.77	7,139.6	333.19	142.79	11.42
	80	10,483	33.18	5.72	0.31	1,670.4	133.47	57.20	5.91
Total		547,504	1751.1	301.9	18.8	15,716.6	7,044.8	3019.2	112.8
								Grand Total	**575,472.47**

CHAPTER 5

AIR DISPERSION MODELING

5.1 INTRODUCTION

Dispersion modeling is a method used for predicting and estimating concentrations of pollutants resulting from atmospheric emissions. A single equation based upon the Gaussian plume equation can be used to estimate an air pollutant concentration at a single receptor from a single source. However, when multiple sources, multiple receptors, varying plume rise, varying meteorological conditions, building wake effects, or other factors that affect atmospheric dispersion must be considered, a series of equations are needed. Thus, a computer model is required to conduct the repetitive calculations and simulate the atmospheric concentrations (Fig 5.1) over a particular simulated period.

The alternative to dispersion modeling is to make actual air quality measurements. Measuring the actual level of pollutants is more accurate than modeling. However, if a source has not been constructed, there is no way to measure the effects of its emissions, and modeling must be used to predict its effect. Even if a source does exist, modeling can make estimation of concentration at thousands of locations for the price of a single set of measurements. While modeling does introduce errors in the calculations, these errors are considered acceptable under certain situations. Examples where air dispersion modeling is required include health risk analyses, evacuation studies or ambient air monitoring projects. Furthermore, most regulatory agencies require dispersion modeling in support of local and federal permit applications.

5.2 MODELING TECHNIQUES

Air quality modeling procedures can be divided into mainly four techniques: Gaussian, numerical, statistical (or empirical), and box technique. The Gaussian technique is widely used for estimating the impact of non reactive pollutants. It has a good mathematical approximation of plume behavior for periods of about five minutes to one hour. Numerical techniques find applicability in situations where pollutant reactivity and formation of secondary pollutants is expected. As an example, production of ozone as a result of photochemical reaction of oxides of nitrogen and the various species of hydrocarbons.

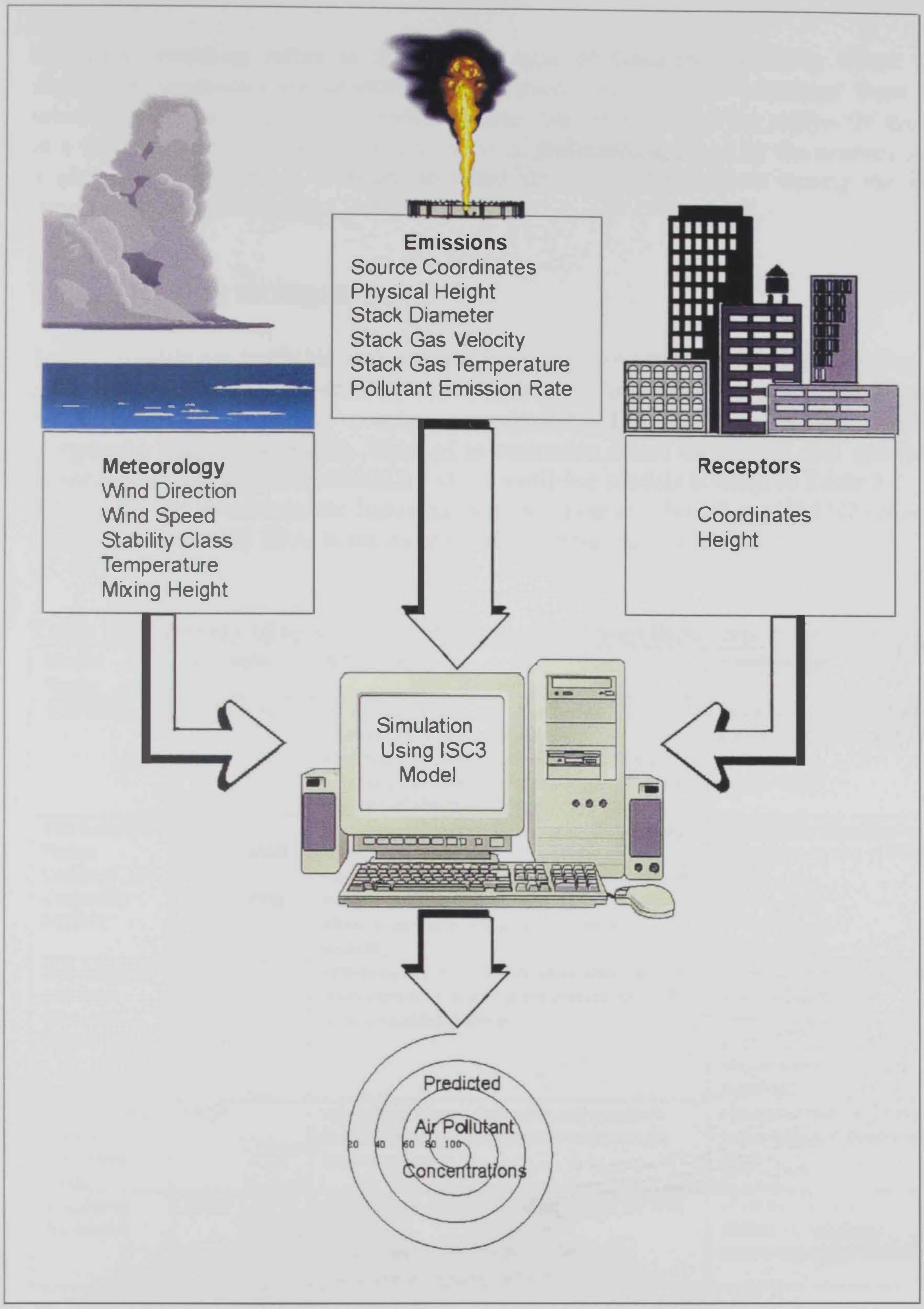

Fig 5.1 Air dispersion modeling framework

Statistical modeling refers to a particular type of Gaussian modeling where the dispersion parameters are determined from short-term statistics calculated from the wind fluctuations. Simple box models assume that all pollutants are uniformly mixed in a volume of finite dimensions. The mass of pollutants, emitted by the sources over a given time interval, is assumed to equal the mass of pollutants exiting the box through the downwind face (Turner, 1994).

5.3 AVAILABLE MODELS

Several models are available with various limitations and capabilities of responding to different settings of a number of options (Table 5.1). Among the variables that dictate model suitability are time average concentration (1hr, 24 hrs, annual), terrain complexity (flat or complex), level of urbanization (rural or urban), and precision (screening or refined). The suitability of the available models is listed in Table 5.2. Among the above models, the Industrial Source Complex Short Term (ISCST) model, developed by the US EPA, is the most suitable for the current study.

Table 5.1 Summary of several air dispersion models with their limitations[1]

Model Name	**Acronym**	**Advantages**	**Limitations**
SCREEN2	SCREEN2	•Provides an easy way to screen individiual sources (point,area, and volume). •Estimates maximum concentrations for a number of downwind distances and gives the distance of the maximum concentration.	•Estimates only one hour concentrations for only one source.
The Industrial Source Complex Dispersion Models	ISC: ISCST: short term ISCLT: long term	•Multiple point source emissions from stacks, flares, and other types of emissions. •Includes estimates of building downwash for many point sources. •Makes estimates for area and volume sources.	•Deposition algorithm is not as superior as that of FDM model
Buoyant Line and Point Sources Model	BLP	•Preferred model that estimates concentrations from buoyant line and point sources for short term averaging periods.	•Unique modeling problems that contain buoyant, elevated line sources. •Limited to rural areas, simple terrain and short distances.
Offshore and Coastal Dispersion Model	OCD	•Simulates plume dispersion and transport from offshore point sources to receptors on land or water.	•Requires both overwater and overland meteorological data.
Regulatory Air Model	RAM	•Includes a fast executing algorithm for area sources. •Useful for emissions that have small variations of adjacent area emission rates.	•Flat terrain only. •Effect of building downwash is not considered.

Table 5.1 Continue…..

Point-Area-Line Model	PAL	•Useful for analysis of area sources such as parking lots and parking structures. •Has a superior algorithm for area sources and a deposition algorithm better than the one in ISC.	•Requires meteorological data input in a different format from the hour-by-hour data format from preprocessor PCRAMMET. •The time average periods is good for only one hour to one day.
Fugitive Dust Model	FDM	•Has a superior method of analyzing area sources and an improved deposition and impaction algorithm for particulate matter compared to the ISC models.	•Does not include tabulated data for deposition to handle sources with release heights greater than 20m. •Can not include buoyant or momentum plume rise from sources.
Continuous Release Short Term Elevated Receptors Model	CRSTER	•Can make estimates for receptors with elevations up to that of the stack top.	•Considers all sources to be co-located, and applicable for only single point sources or screening of multiple sources.
VALLEY	VALLEY	•Provides estimates of concentraion for receptors on terrain with elevation near plume centerline heights.	•Limited number of point and area sources.
Complex Terrain Screen Model	CTSCREEN	•Provides estimates of maximum concentrations for complex terrain receptors, and no meterological data need to be collected.	•Very conservative. •Estimates are made for only one hour averaging periods.
Complex Terrain Model	COMPLEX	•Provides estimates where receptor elevations exceed the elevation of the stack top.	•This model requires terrain elevations for each receptor.
SHORTZ	SHORTZ	•Provides estimates from area and point sources in urban areas with complex terrain.	•Short term concentration.
LONGZ	LONGZ	•Provides estimates from area and point sources in urban areas.	•Long term concentration.
Rough Terrain Diffusion Model	RTDM	•Provides a more realistic simulation of plume centerline behavior with respect to terrain features as compared to VALLEY and COMPLEX	•Terrain elevation must be provided for each receptor. •Needs detailed meteorological data.
Complex Terrain Dispersion Model Plus	CTDMPLUS	•Provides a more realistic simulation of plume centerline behavior with respect to terrain features as compared to VALLEY, COMPLEX, and RTDM.	•Requires detailed description of the terrain feature by specification of coordinates of elevation contours.

[1] Practical guide to atomspheric dispersion modeling.

Table 5.2 Suitability of the available air dispersion models

Refined long term[1]	Refined short term	Screening	Terrain complexity and urbanization	
ISCST or ISCLT	ISCST OCD[2] BLP[2] FDM	SCREEN2	Rural	Flat or Simple Terrain
ISCST or ISCLT	ISCST RAM FDM	SCREEN	Urban	
	CTDM Plus	CTSCREEN VALLEY[3] COMPEX RTDM	Rural	Complex Terrain
		CTSCREEN VALLEY SHORTZ LONGZ	Urban	

[1] ISCST3 and ISCLT3 use the ISC algorithm for simple terrain, the Complex I algorithm for complex terrain, and the greater value of the two for intermediate terrain at each receptor.

[2] OCD is used to analyze concentrations from over water sources. BLP is used to analyze concentrations from buoyant line sources.

[3] A VALLEY screening model is included in COMPLEX-I and SCREEN.

5.4 INDUSTRIAL SOURCE COMPLEX MODEL (ISC3)

The Industrial Source Complex Version 3.0 (ISC3) short term model is used and developed by the US EPA. It provides options to model emissions from a wide range of sources that might be present at a typical industrial source complex. It is the most popular air dispersion model for continuous emission from point (stationary) industrial sources. Also, it is used to assess the impact of air emissions in the simple, intermediate and complex terrain.

The basis of the model is the straight line, steady-state Gaussian plume equation. The equation is used with some modifications to model simple point source emissions from stacks. Emissions from stacks that experience the effects of aerodynamic down wash due to nearby buildings, isolated vents, multiple vents, storage piles and conveyor belts.

Emission sources are categorized into several types of sources; point source, flares, volume source, area sources and open pit sources. The volume source and the area source are options that may also be used to simulate line sources.

The ISC3 short-term model accepts hourly meteorological data records to define the conditions for plume rise, transport, diffusion and deposition. The model estimates the concentration or deposition value for each hour of input meteorology and calculates user selected short-term averages. For deposition values, either the dry deposition flux, or the total deposition flux may be estimated. The total deposition flux is simply the sum of the dry and wet deposition fluxes at a particular receptor location.

5.5 GENERAL ASSUMPTIONS ASSOCIATED WITH ISC3 MODEL

There are several assumptions associated with ISC3 model including:

1. Wind from the source stack to the receptor is constant in velocity and direction throughout any particular averaging time.

2. Atmospheric turbulence conditions are constant and homogeneous throughout the vertical and crosswind regimes from source stack to the receptor.

3. There is no deposition of plume components, all of the effluent remains in the atmosphere and such components which reach the ground are totally reflected back into the plume.There is no absorption of plume components by the ground bodies of water or vegetation, nor is there any chemical transformation of plume components.

4. Dispersion on the downwind direction is negligible relative to the wind transport. Only vertical and crosswind dispersion occurs.

5. Diffusion patterns are probabilistic and can be described by Gaussian distribution.

6. The plume expands in a conical fashion in its travel downwind.

7. Emission rates are assumed to be constant and continuous. This may not be the case in such facilities as boilers, where loads fluctuate with steam demand.

8. No variations occur in wind speed, wind direction, or Pasquill stability class during transport from source to receptor (Pasquill suggested the most commonly used scheme to describe the atmosphere so that the classification can be interpreted in terms of atmospheric dispersion). This assumption is good within a few kilometers of a source, it may not be reasonable for receptor distances on the order of 50 km or more or during periods of relatively rapid change of meteorology. At a wind speed of 2 m/s, it will take nearly seven hours for a plume to travel 50 km, during which the sun can set or rise and clouds also can form or dissipate causing changes in stability class.

Due to the above assumptions, Gaussian modeling does not replicate the phenomena of the the atmosphere causing the following limitations:

1. The effects of the rapid changes in wind speed and turbulent eddy sizes near the ground can not be accurately simulated by use of a single wind speed and the off-the-shelf dispersion parameters.

2. A fixed link between horizontal and vertical dispersion parameters provided by stability classes is not necessary an accurate representation of the atmosphere.

3. Under unstable atmosphere situations, the distribution of few updrafts causes the vertical distribution of concentrations to be non Gaussian.

5.6 MODEL EQUATIONS

The concentration of a certain pollutant according to a Gaussian dispersion equation is given as:

$$C(x,y,z;h_e)=\frac{VQ}{2u\pi\sigma_y,\sigma_z}e^{\left(\frac{-y^2}{2\sigma_y^2}\right)} \qquad (5.1)$$

where C is the concentration ($\mu g/m^3$), x is the downwind distance from the emission source (m), y and z are crosswind and vertical locations from the emission source (m), Q is the rate of pollutant from a continuous source (g/s), σ_z and σ_y are the standard deviations of the vertical and horizontal pollutant distribution (m), u is the wind speed at the stack height (m/s), and the factor of V is vertical term of the Gaussian plume equation (dimensionless) and is given by:

$$V=e^{\left(-0.5\left(\frac{h_e+z}{\sigma_z}\right)^2\right)}+e^{\left(-0.5\left(\frac{h_e-z}{\sigma_z}\right)^2\right)} \qquad (5.2)$$

Here, h_e is the effective stack height which is the sum of the physical stack height and any plume rise due to momentum or buoancy effect and is given as:

$$h_e=h_s+\Delta h \qquad (5.3)$$

Δh is dependent on atmospheric stability and flux buoyancy or momentum buoyancy. In our case, momentum buoyancy will not be considered since the temperature of the released emissions is higher than the surrounding temperature and building wake effects are also not considered. Flux buoyancy (F_b) is determined by:

$$F_b = \frac{gvd^2\Delta T}{4T_o} \tag{5.4}$$

Where g is acceleration of gravity (9.8 m/s^2), v is stack emission exit velocity (m/s), d is top inside stack diameter (m), and ΔT is temperature difference between stack emission (T_o) and ambient air temperatures (T) in K.

For unstable conditions with $F_b < 55$, Δh is given by:

$$\Delta h = 21.425\frac{F_b^{\ 0.75}}{u} \tag{5.5}$$

If $F_b \geq 55$, Δh is given by:

$$\Delta h = 38.71\frac{F_b^{\ 0.6}}{u} \tag{5.6}$$

For stable conditions, Δh is estimated using:

$$\Delta h = 2.6\left(\frac{F_b}{us}\right)^{0.33} \tag{5.7}$$

Where s is stability parameter given by:

$$s = \frac{g\dfrac{\partial \theta}{\partial z}}{T} \tag{5.8}$$

$$\frac{\partial\theta}{\partial z}=\frac{\partial T}{\partial z}+\Gamma \tag{5.9}$$

Where $\partial\theta/\partial z$ is the potential temperature gradient (K/m), $\partial T/\partial z$ is the actual temperature gradient (0.015-0.02 K/m) and Γ is the adiabatic lapse rate (0.01 K/m for dry air).

5.7 MODEL VERIFICATION EXAMPLE

To verify model output, a hypothetical situation was assumed where an emission point source (stack) was selected with an emission rate of 414 g/s, stack temperature of 873 K, stack diameter of 2.0 m, stack height of 46 m, and stack emission exit velocity of 29 m/s. Meteorological data for this case were created such that the ambient temperature (298 K), wind speed (2.6 m/s) and wind direction (180 °) at 10 m elevation level were kept constant for simplicity.

The model prediction showed that the maximum ground level concentration is 23.7 $\mu g/m^3$ at a distance of 4 km downwind. The concentration at 4 km downwind was then manually calculated using the above equations, with a stability class F. The velocity at the stack height is determined using the following equation:

$$u=u_m\left(\frac{Z}{Z_m}\right)^P \tag{5.10}$$

where u_m is the wind speed at 10 m elevation reference (m/s), Z and Z_m are vertical distance at stack height and at reference level (anemometer height) in (m), respectively, and P is a factor or exponent that depends primarily on the atmospheric stability which varies from around 0.07 for unstable conditions to about 0.55 for stable ones and is given according to Table 5.3.

Table 5.3 Values of the exponent P in equation (5.10)

Pasquill Stability Class	Rural Conditions	Urban Conditions
A	0.07	0.15
B	0.07	0.15
C	0.10	0.20
D	0.15	0.25
E	0.35	0.30
F	0.55	0.30

The estimated wind speed at the stack height using the value at the reference level was found to be 6 m/s. Also, the estimated effective stack height was 124 m. To calculate factor *V*, the value of σ_z needs to be determined. The model uses the values tabulated in Table B.1, B.2 and B.3 by Pasquill-Gifford (Appendix B), to determine σ_z and σ_y from the tables since for a distance range there is only one value of σ_z, then the model assumes the highest value as a conservative measure.

Consistent with the model way of prediction, the value of σ_z determined in the calculations was 40 m. It is important to realize at this point that the model is more sensetive to changes in σ_z and stack height than it is to σ_y as demonstared in Fig 5.2.

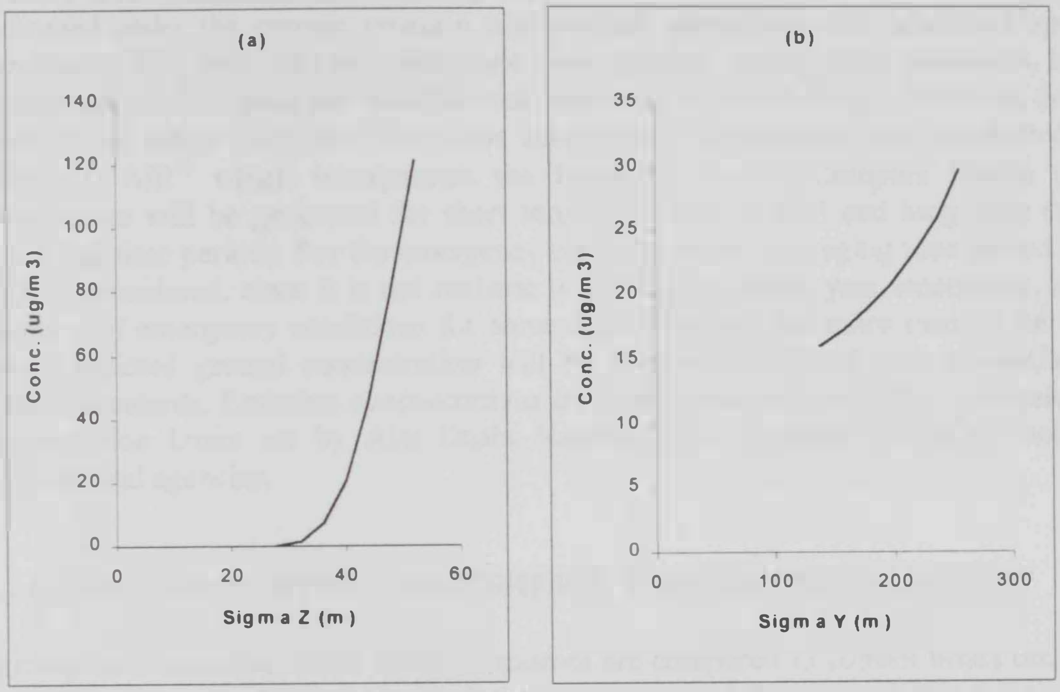

Fig 5.2 Sensitivity of (a) σz and (b) σy.

From the above data the ground level concentration was found to be 22.85 $\mu g/m^3$.
This is close to the value predicted by the model (i.e. 23.7 $\mu g/m^3$).
It is realized that the model is more conservative and always takes a higher value than the actual ones.

CHAPTER 6

MODELING OF GROUND CONCENTRATIONS UNDER EXISTING OPERATIONS

6.1 INTRODUCTION

Ground level concentrations resulting from emission sources at ADGAS facility were estimated under the current situation with normal, emergency and combined operating conditions. SO_2, NO_x, CO and particulate were selected, among other pollutants, because of their established local and international maximum exposure limits. However, emission rates for all major pollutants have been determined. Simulations were conducted using BREEZE AIR® which incorporates the Industrial Source Complex Model (ISC3). Simulations will be generated for short term (1 hr and 24 hrs) and long term (annual) averaging time periods. For the emergency cases, however, averaging time period of 1 hr will be considered, since it is not realistic to consider a whole year emergency, and the duration of emergency conditions for some units does not last more than 10 hrs (Table 4.4). Predicted ground concentration will be compared to local and international air quality standards. Emission concentrations from each source type will be compared with the emission limits set by Abu Dhabi National Oil Company (ADNOC) and other international agencies.

6.2 COMPLIANCE WITH ATMOPSHERIC EMISSION REGULATIONS

Atmospheric emissions from ADGAS sources are compared to control limits established by ADNOC and the Natural Gas Refining & Associated Processes. Table 6.1 shows the emission concentration for SO_2, NO_x, and CO from each none-flare emission source at ADGAS. Particulate is not listed because its emission rate from these sources is negligible. No SO_2 emissions from boiler 5 and 6 due to insignificant concentration of H_2S in the utilized fuel gas.

Emission values in Table 6.1 were obtained from Table 4.3 and Table 4.5 after being converted to normal flow rates. The annual mass emission rates for the considered pollutants were then divided by the normal flow rates to obtain pollutant concentrations in mg/Nm^3. Flare sources were not considered because no control limits were established for these sources by ADNOC or other international agencies. As Table 6.1 shows, sulphur recovery units (SRUs) followed by gas turbines are the major sources of SO_2. Furthermore, gas turbines and boilers are the major sources of NO_x and CO.

Comparing the emission concentration of SO_2, NO_x, and CO from the sources at ADGAS with the reported control limits (Table 6.2) showed that emission concentrations of SO_2 from sulphur recovery units and gas turbines are highly exceeding the control limits. Emission concentrations of NO_x from boilers and gas turbines are also exceeding the limits by approximately 3 folds. Emission of CO from all the sources are below the control limits.

Under normal operation conditions, the average efficiency of the sulphur recovery units in Train 1 and 2 reaches 96%, and that in Train 3 reaches around 97%. One of the possible solutions to achieve acceptable control limit for SO_2 is to upgrade plant recovery to the 97.5% efficiency set by ADNOC. This modification is explored in chapter 7.

Table 6.1 Emission concentrations for non flare sources

Source Code	**SO_2** (mg/Nm^3)	**NO_x** (mg/Nm^3)	**CO** (mg/Nm^3)
B1	79.0	204.3	52.7
B2	81.8	211	54.4
B3	78.4	202.6	52
B4	64.7	204	48.3
B5	0.0	242	62.4
B6	0.0	239	61.7
Total	**304**	**1,303**	**331.5**
RG1	2.0	52.7	13.5
RG2	1.7	43	11
RG3	15.8	188	48.5
RG4	3.3	80	20.6
Total	**22.8**	**364**	**93.6**
GT1	4540	601	242
GT2	253	33.5	13.5
GT3	5858	776	312.7
GT4	332	44	17.7
Total	**10,983**	**1,455**	**586**
SRU1	14,554	36.7	9
SRU2	14,454	34.5	9
SRU3	6,163	40	10.4
Total	**35,171**	**111**	**28.4**

Table 6.2 Compliance of ADGAS to emission regulations under current conditions

Source	**ADGAS Current Situations** (mg/Nm^3)			**ADNOC Limits** (mg/Nm^3)			**Natural Gas Refining & Associated Processes Limits** (mg/Nm^3)		
	SO_2	NO_x	CO	SO_2	NO_x	CO	SO_2	NO_x	CO
Boilers	**304**	**1,303**	331.5	200	NA	625	35	350	NA
Reg. Gas Heaters	22.8	**364**	93.6	200	NA	625	35	350	NA
Gas Turbines	**10,983**	**1,455**	586	200	NA	625	35	350	NA
Sulphur Recovery Units	**35,171**	111	28.4	200	NA	625	35	350	NA

6.3 GROUND LEVEL CONCENTRATION UNDER NORMAL CONDITIONS

Predicted maximum concentration on Das Island resulting from emissions at ADGAS facilities under normal operation conditions is listed in Table 6.3. Predicted values, in this case, reflect the maximum exposure concentration resulting from emissions assuming normal operation where there is no upset situation, which is the case during most of the year. Predictions were made for 1-hr, 24-hr, and annual averaging periods. Also, listed in the table are the concentration at the main receptors of Sahil Camp, Das Island Harbor, Main Offices, and Jimmi Camp locations. These locations are considered sensitive in the sense that two of them are residential areas and the others have large people accessibility. Contour maps representing 1-hr, ground concentration of the four selected pollutants are presented in Fig 6.1 through 6.4. Other contour maps for 24hr and annual periods are presented in Appendix C.

The results in Table 6.3 are compared with acceptable exposure limits set by ADNOC and US EPA. The concentration of SO_2 for 1hr, and 24 hr averaging period exceeds the limits set by ADNOC. The 24-hr maximum SO_2 concentration is, however, slightly higher than EPA limits. The concentration of NO_x (1-hr averaging) exceeds ADNOC limits by 20%, but the other maximum concentrations (24-hr and annual) are below the acceptable values. Carbon monoxide and particulate are below the acceptable limits. Within the four sensitive locations selected, the 1-hr SO_2 concentration is obviously problematic.

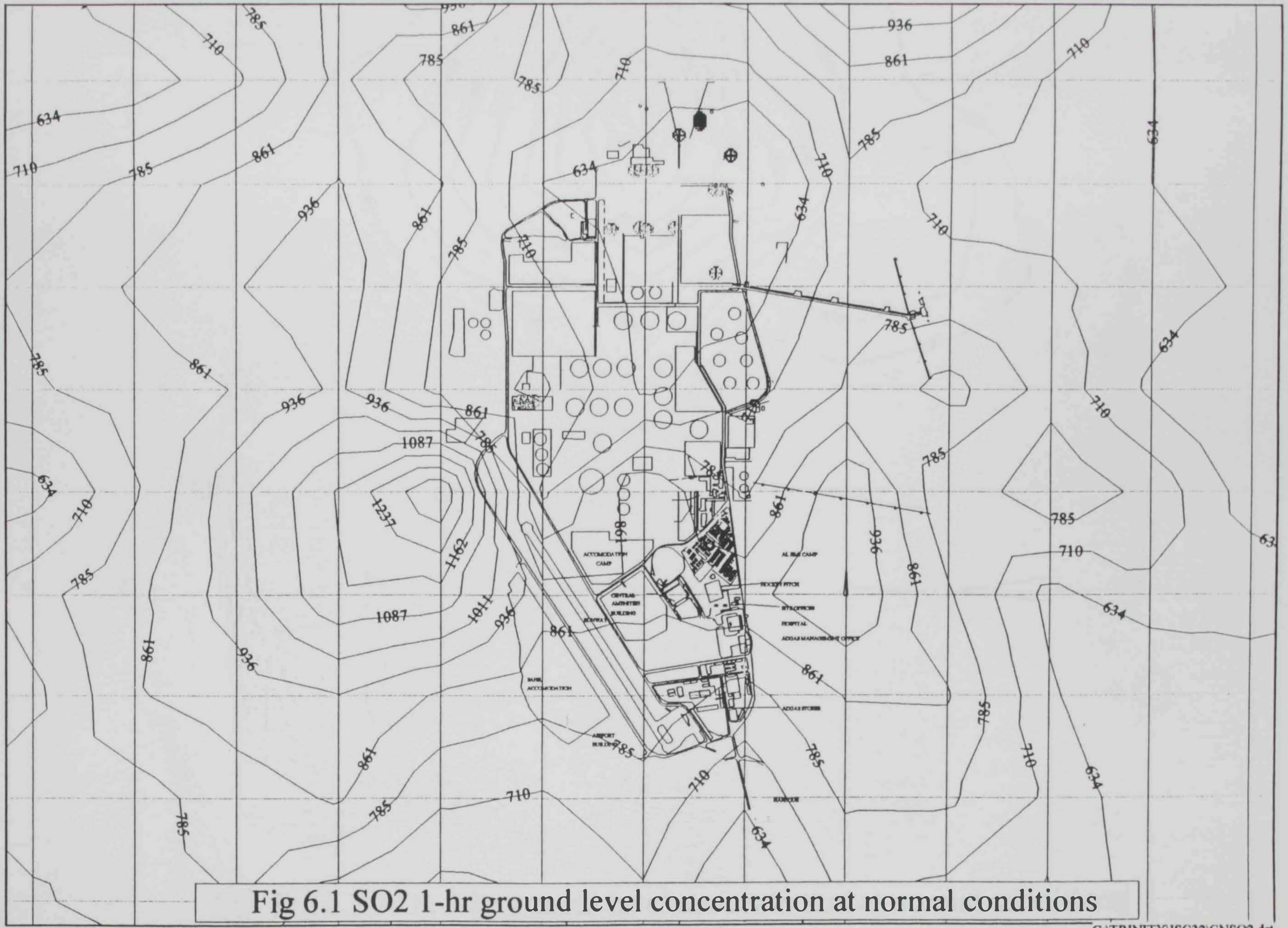

Fig 6.1 SO2 1-hr ground level concentration at normal conditions

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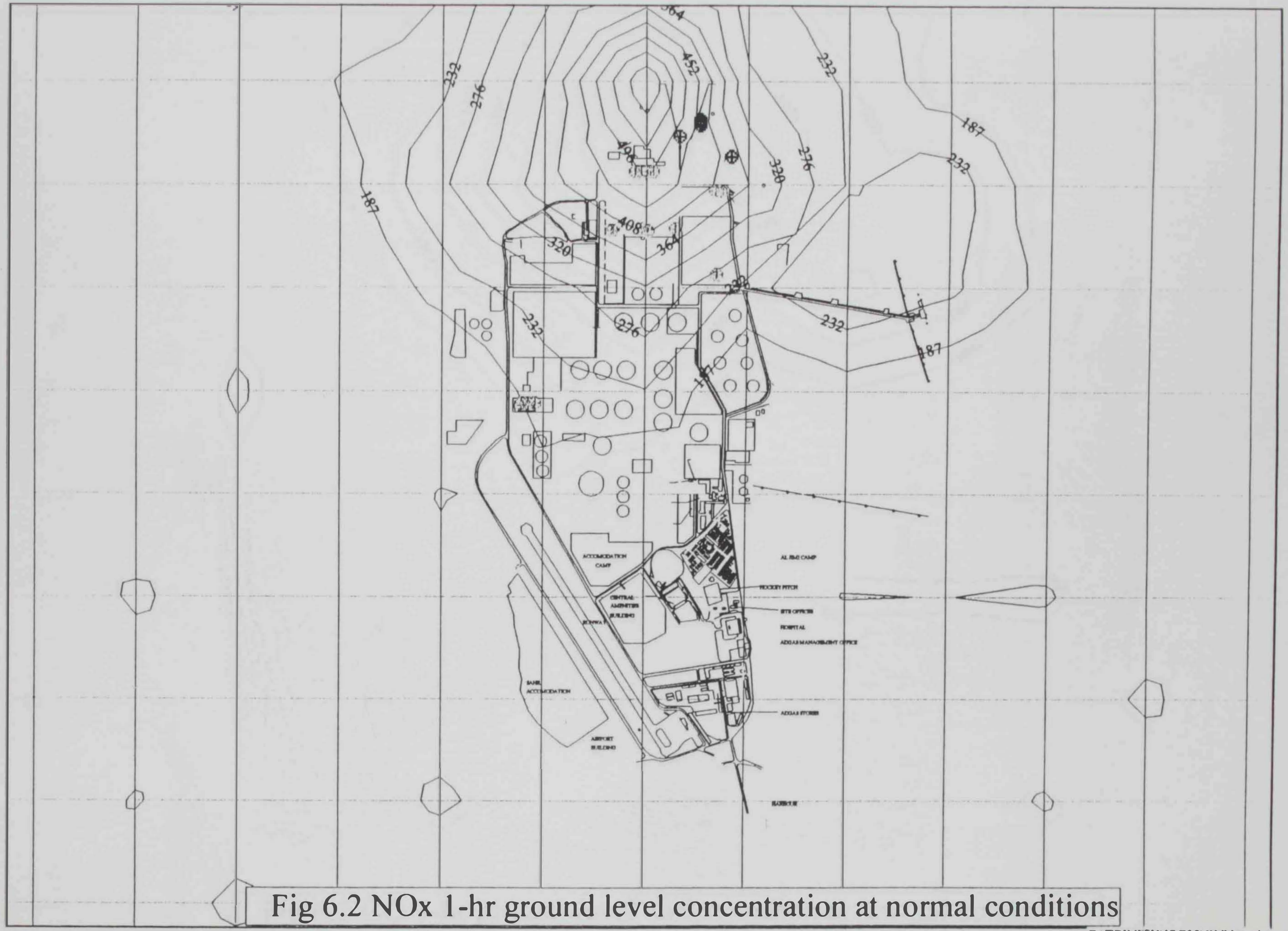

Fig 6.2 NOx 1-hr ground level concentration at normal conditions

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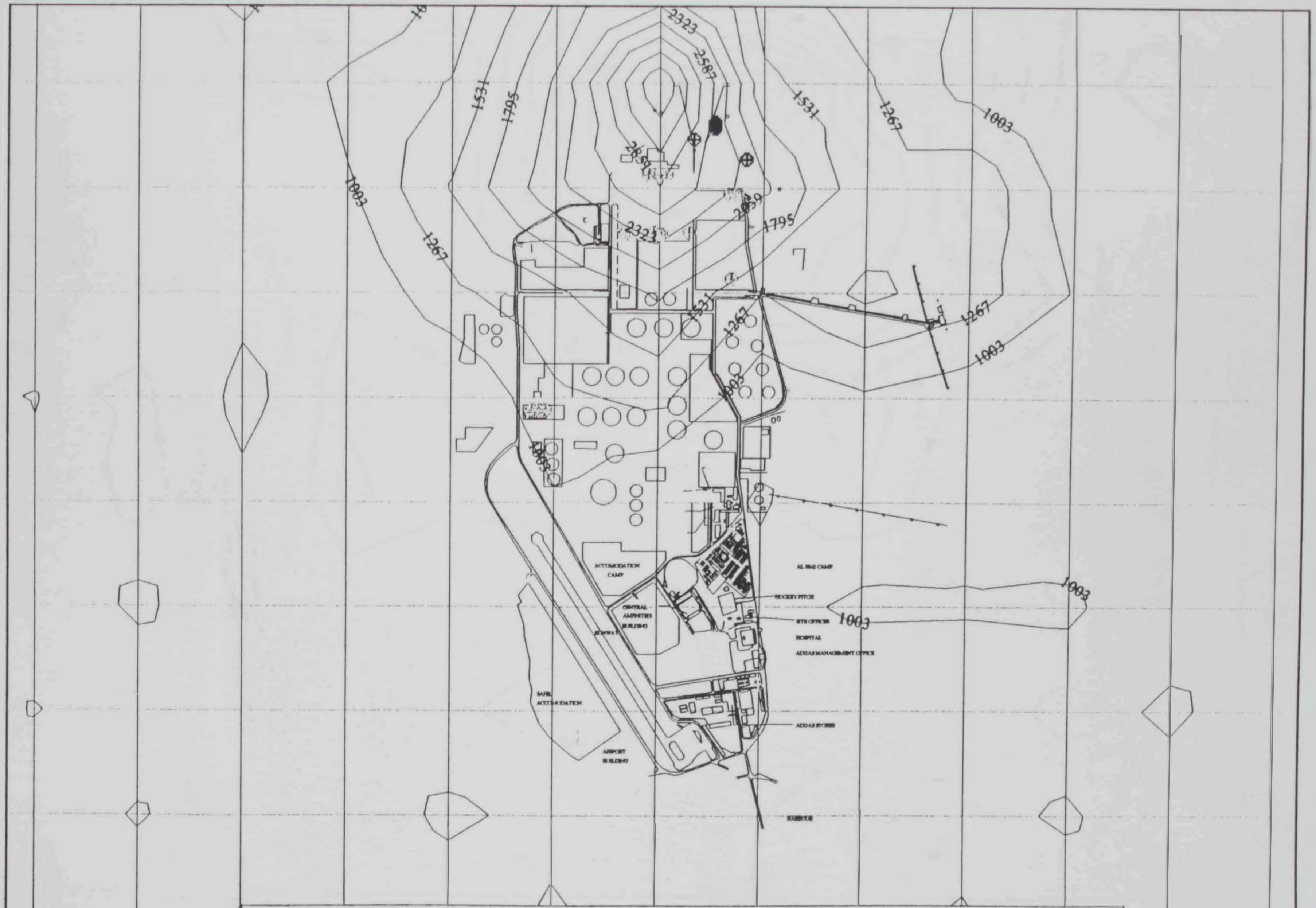

Fig 6.3 CO 1-hr ground level concentration at normal conditions

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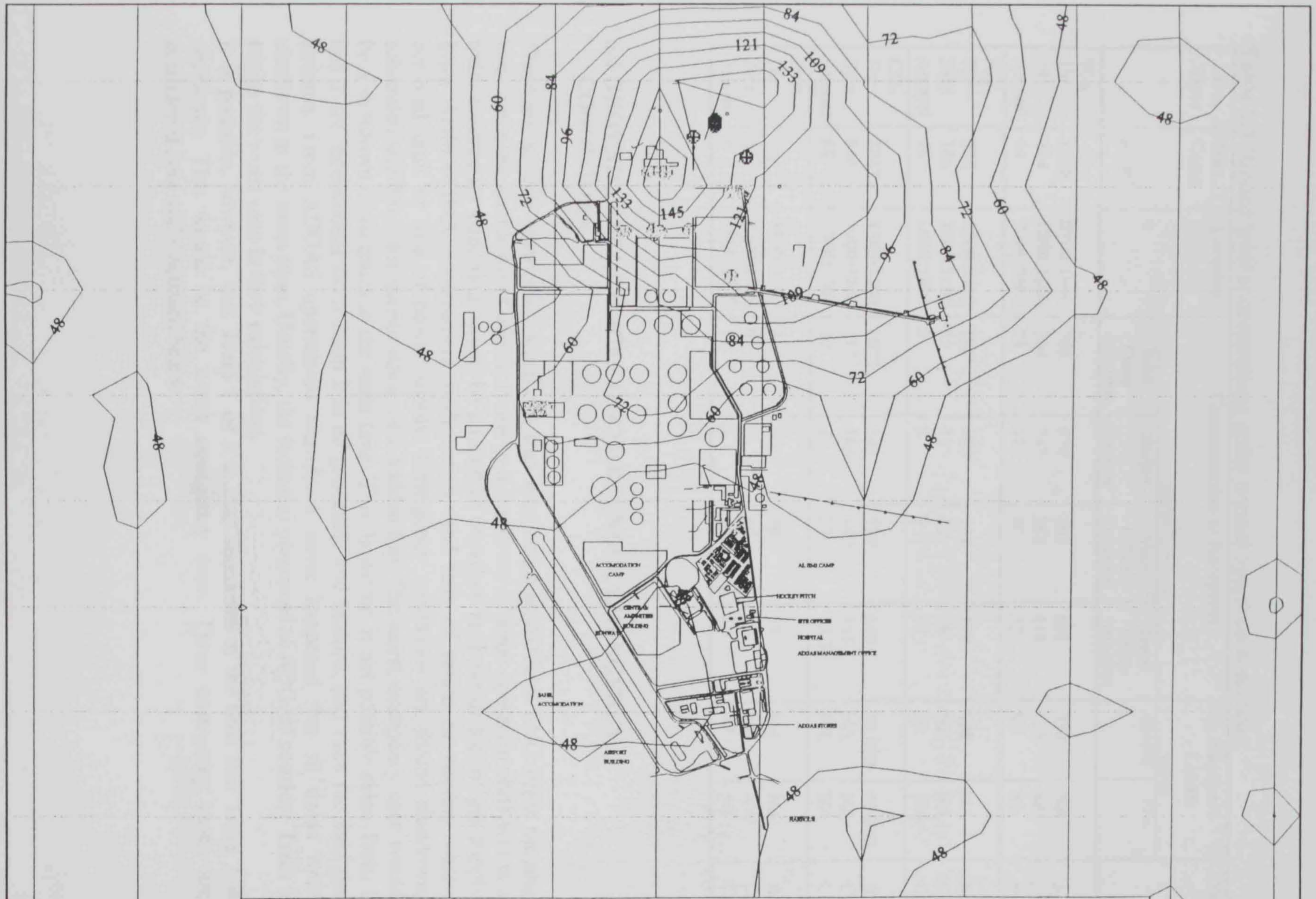

Fig 6.4 PM 1-hr ground level concentration at normal conditions

Table 6.3 Ground level concentrations under normal operation conditions

Ave. Time	**Max. Conc.** µg/m³	**Location** (E : N)	**Concentration at Receptors** µg/m³				**Exposure Limits** µg/m³		**Fig**
			Sahil Camp 1200:1000	Harbor 2000:600	Main Offices 1900:1200	Jimmi Camp 1800:1800	ADNOC	EPA	
SO_2									
1hr	**1388**	0700:1900	760	679	793	891	350	NA	6.1
24hr	**414**	1800:1800	204	235	268	414	125	365	C.1
Annual	44	2000:0600	33	44	40	32	50	80	C.2
NO_x									
1hr	**500**	1500:3100	186	100	101	118	400	NA	6.2
24hr	146	1900:3100	55	41	40	55	NA	NA	C.3
Annual	16	1800:1800	8	9	9	10	50	100	C.4
CO									
1hr	2843	1500:3100	1073	543	570	640	30,000	40,000	6.3
24hr	846	1900:3100	219	165	147	165	NA	NA	C.5
Annual	86	1900:2700	20	23	27	33.5	NA	NA	C.6
Part.									
1hr	170	1500:3100	23	20	39	58	NA	NA	6.4
24hr	31	1500:2300	6	5	14	16	50	150	C.7
Annual	5	1900:2700	1	1	1	2	40	50	C.8

6.4 GROUND LEVEL CONCENTRATION UNDER EMERGENCY CONDITIONS

There are several emergency situations that may occur at ADGAS LNG Plant ranging from complete shutdown of certain trains to a shutdown of some operation units within a train. Emergency conditions could be a result of overflow feed gas or loss of gas supply from ADMA-OPCO, instrument malfunction, and loss of steam or cooling water, personal fault or loss of power supply. Emergency conditions are forced shutdown, scheduled shutdown for maintenance, or a sudden trip. The worst emergency case would be a shutdown of all trains at the same time. This, however, is not possible since Train 1 and 2 are independent from Train 3 in all processes and utilities, and even the feed gas streams. From ADGAS operational records, it never happened that all trains were shutdown at the same time. Usually, the technical personnel at ADGAS consider Train 3 trip as the worst case in their calculations.

It is possible, however, that Train 1 or 2 is also shutdown at the time that Train 3 is shutdown. This would be the worst emergency case. Three emergency cases are considered here and discussed below.

Case 1. Train 3 and Train 1 shutdown

In this case all the cooling water, multi-component refrigerant (MCR) and propane compressor are tripped. All MCR is sent to sweet gas header for flaring (F31) and whatever left in Plant 4 (fractionation sections) is also sent to sweet gas header due to loss of cooling water. The remainder of the processed gas in the main exchanger will be also sent to sweet header flares. All LNG and LPG boil off gas (BOG) compressors are shutdown. Sulphur recovery units for Train 3 and 1 are shutdown and four boilers (B1, B2, B5, and B6) are also shutdown. Emission flow rates from each source is listed in Table 6.4.

Case 2. Train 3 and Train 1 SRU shutdown

In this case, Train 3 is shutdown with a maximum relief rate of gas sent to the flare (F32). Sulphur recovery units for Train 3 and 1or 2 are shutdown and four boilers (B1,B2, B5, and B6) are also shutdown (Table 6.4).

Case 3. Train 3 shutdown

In this case, Train 3 is shutdown with a maximum relief rate of gas sent to the flare (F32). Sulphur recovery unit for Train 3 is shutdown and two boilers (B5, and B6) are also shutdown (Table 6.4).

Results of model simulations for the above three cases are presented in Table 6.5. Representative contour graphs for 1-hr ground concentration on Das Island under the above emergency conditions are shown in Fig 6.5 through 6.8 for case1. The other cases are shown in Appendix C. Table 6.5 shows that the concentration of the pollutants under case 1 emergency conditions are higher than their concentration under normal conditions. However, NO_x and CO only increased by approximately 1.5 times more than that under normal conditions. This is mainly due to having no emissions from 4 boilers (B1, B2, B5, and B6). As discussed before and presented in Table 6.1, boilers are the major sources of NO_x and CO emissions at ADGAS Plant. The impact of having 4 boilers shutdown does not affect the concentration of particulate since emissions from these sources are free of particulate. Also, SO_2 emissions from boilers are not as significant as that from turbines and sulphur recovery units (Table 6.1).

Table 6.5 shows that SO_2 and particulate concentration increase under case 1 emergency conditions by 15 and 47 times their concentration under normal operations, respectively. As shown in Table 4.6, major sources of SO_2 and particulate under emergency conditions (case 1) result when directing unprocessed feed gas to flare stack (F32), flaring acid gas at F33, flaring mixed feed gas at F16 due to failure of one SRU in Train 1 or Train 2. The reason that particulate increases by a higher percentage as compared to SO_2, is the additional emissions through the F13 stack which is relatively low in SO_2 but very high in particulate.

Fig 6.5 SO2 1-hr ground level concentration at emergency case 1

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Fig 6.6 NOx 1-hr ground level concentration at emergency case 1

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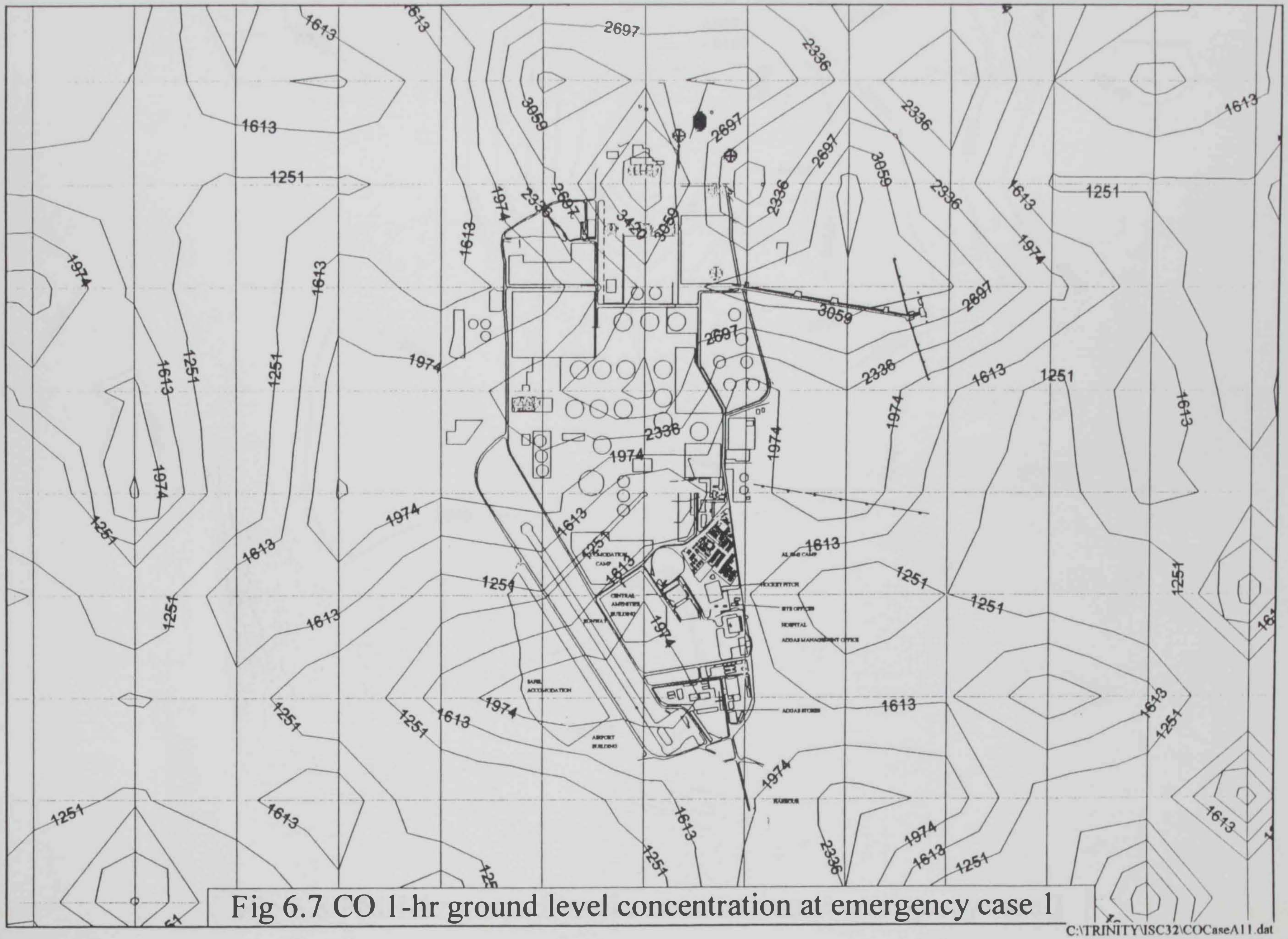

Fig 6.7 CO 1-hr ground level concentration at emergency case 1

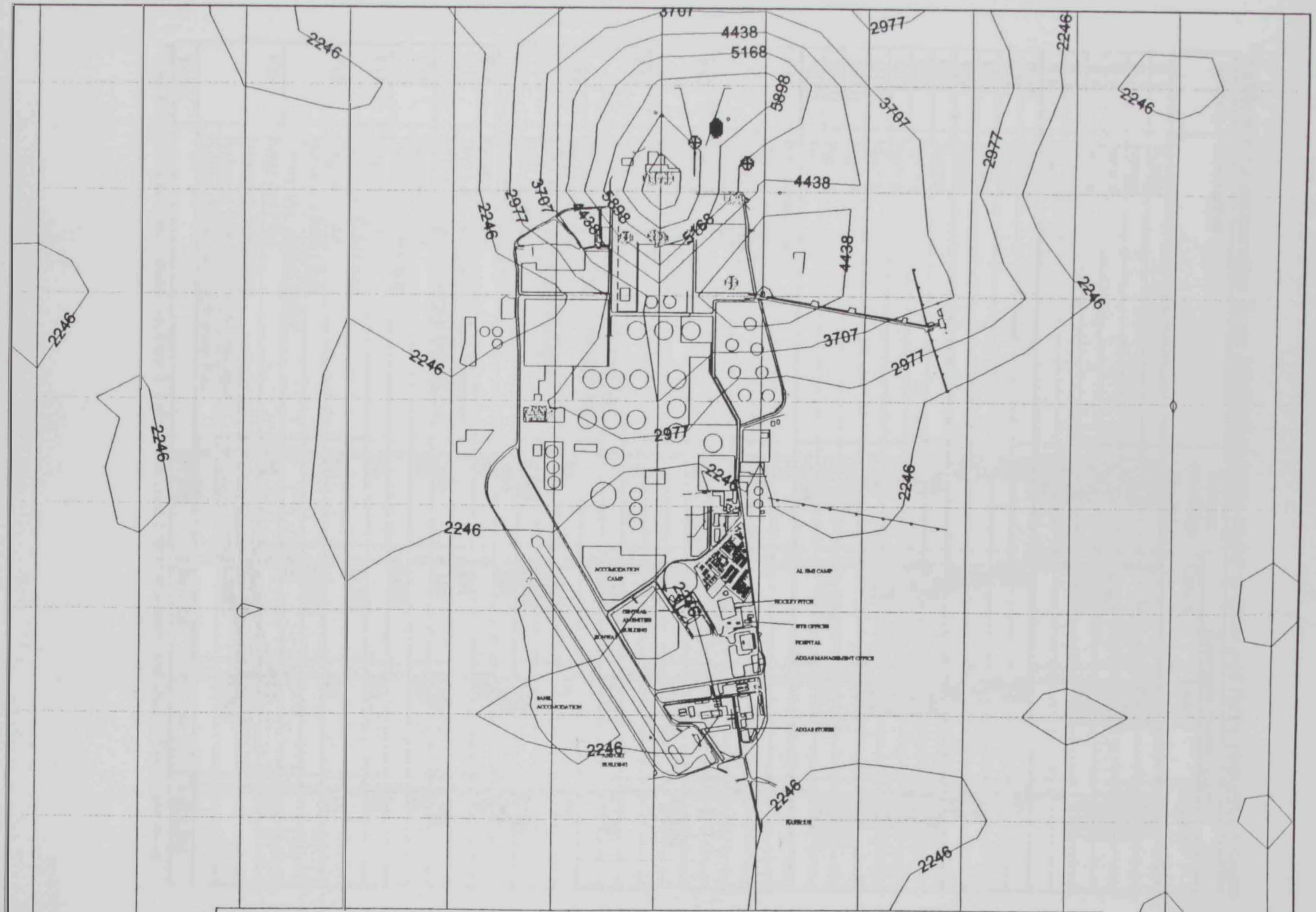

Fig 6.8 PM 1-hr ground level concentration at emergency case 1

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Table 6.4 Emission rates from ADGAS sources under normal and three emergency cases

Source	Description	Normal Condition (kg/hr)	Emergency cases[1] (kg/hr)		
			Case 1	Case 2	Case 3
B 1	Normal	18.818	0	18.818	18.818
B 2	Normal	17,970	0	17,970	17,970
B 3	Normal	19.107	19.107	19.107	19,107
B 4	Normal	19.323	19.323	19,323	19,323
B 5	Normal	24,950	0	0	0
B 6	Normal	25,353	0	0	0
RG1	Normal	657	657	657	657
RG2	Normal	657	657	657	657
RG3	Normal	628	628	628	628
RG4	Normal	268	268	268	268
GT1	Normal	1,308	1,308	1.308	1.308
GT2	Normal	6,367	6,367	6.367	6,367
GT3	Normal	1,336	1,336	1,336	1,336
GT4	Normal	4.829	4,829	4,829	4,829
SRU1	Normal	124.230	0	0	124,230
SRU2	Normal	124,320	124,320	124,320	124,320
SRU3	Normal	90,488	0	0	0
F31	Purge and Pilot	250	0	0	0
	Flaring cryogenic leak	4320	0	0	0
	Total Plant Failure	0	0	0	0
	Blocked outlet	0	1,086,000	0	0
F32	Purge and Pilot	250	0	0	0
	Maximum Relief Rate	0	545,600	545,600	545,600
	Plant 6 imbalance	0	1,776	0	0
F33	Purge and Pilot	250	0	0	0
	Acid Gas Flaring (min crude prod case)	0	85,325	85,325	85,325
	Acid Gas Flaring (max crude prod case)	0	0	0	0
F11	Purge and Pilot	250	0	250	250
	LPG Recovery System Shutdown	0	6,371	0	0
	LNG Loading	38,000	38,000	38,000	38,000
	Normal Boil off gas	5,969	5,969	5,969	5,969
F12	Purge and Pilot	250	0	250	250
	LPG Load- Recovery System Shutdown	0	6,371	0	0
	LPG Loading with Normal Boil off gas	6,154	6,154	6,154	6,154
F13	Purge and Pilot	250	0	250	250
	Maximum Relief Rate	0	40,000	0	0
F14	Purge and Pilot	750	0	750	750
	Maximum Relief Rate	0	136,500	0	0
F15	Purge and Pilot	250	0	250	250
	Maximum Relief Rate	0	252,000	0	0
	Treater Gas Manual Relief	0	860	0	0
F16	Purge and Pilot	250	0	250	250
	Maximum Relief Rate	0	362,000	0	0
	Failure of One SRU/mixed feed case	0	55,998	55,998	0
	Failure of One SRU/high press feed	0	0	0	0
Total		**537,802**	**2,807,724**	**954,634**	**1,022,866**

[1] Case 1: Train 3 and Train 1 shutdown, Case 2: Train 3 and Train 1 SRU shutdown, and Case 3: Train 3 shutdown.

Table 6.5 Maximum 1-hr ground concentrations under three emergency cases

Pollutant	**Normal condition** ($\mu g/m^3$)	**Emergency cases** [1] ($\mu g/m^3$)		
		Case 1	**Case 2**	**Case 3**
SO_2	1388	21,574	7,360	4,974
NO_x	500	718	564	121
CO	2843	4143	3359	101
Particulate	170	8090	19	17

[1] Case 1: Train 3 and Train 1 shutdown. Case 2: Train 3 and Train 1 SRU shutdown. Case 3. Train 3 shutdown.

It is interesting to see that the concentration of particulate under the emergency case 2 and 3 are less than the value under normal conditions, although the emission rates in these cases are higher than that under normal conditions. This is due to the high heat release of the flares during emergency, which reduces particulate (soot) formation. To verify this, the input heat release for F32 and F33 (the major sources of particulate in case 3) were changed to low heat values as those used under normal conditions (i.e. from approximately 2×10^9 to 8×10^5 cal/s). The predicted 1-hr particulate concentration just from these two sources with the low heat release values was found to be 1657 $\mu g/m^3$. The same reason explains the lower concentration of NO_x and CO under emergency conditions (case 3) as compared to the values under normal operation.

Comparing the 1-hr maximum concentration values under the three considered emergency cases (Table 6.5) with ADNOC and US EPA 1-hr limits show that SO_2 should be the major concern, and that NO_x is slightly above the standard values. Particulate and CO ground concentrations are below the allowable limits, with the exception of particulate under the conditions of case 3. Since the possibility of having case 3 emergency condition is very slight, then particulate levels should not be a major concern.

6.5 GROUND LEVEL CONCENTRATION UNDER COMBINED CONDITIONS

The annual average concentration of a certain pollutant caused by emissions from ADGAS facility can be determined by considering the total emissions of that pollutant throughout the year. This is determined by determining the geometric average of emission of that pollutant at each source under normal and emergency conditions. Geometric average values are then used in the simulation model to predict ground concentration. The maximum annual concentration for SO_2, NO_x, CO and particulate on Das Island and the four sensitive locations on the Island are listed in Table 6.6. Representative concentration contour maps are shown in Appendix C. The concentration of SO_2 and particulate exceed the allowable limits with SO_2 level posing a major concern. No annual exposure limits for CO, but NO_x is below the established limits.

Table 6.6 Annual ground concentrations under combined conditions

Pollutant	**Max. Conc.** µg/m³	**Location** (E : N)	**Concentration at Receptors** µg/m³				**Exposure Limits** µg/m³		**Fig**
			Sahil Camp	Harbor	Main Offices	Jimmi Camp	ADNOC	EPA	
SO_2	**526**	1900:2700	**124**	**204**	**259**	**266**	50	80	C.14
NO_x	20.5	1900:2700	9	12.5	16.2	16.5	50	100	-
CO	113	1900:2700	29	43	68	74	NA	NA	-
Particulate	**194**	1900:2700	24.4	35	**64**	**78.5**	40	NA	C.15

6.6 SUMMARY

Ground concentration of SO_2 caused by emissions from ADGAS Plant were predicted under three conditions: normal operation; emergency; and combined. Comparison between predicted values and established exposure limits showed that SO_2 level would be a major, followed by, but a much lower degree, NO_x and particulate. Efforts thus should be directed to reduce SO_2 concentration by enhancing sulphur recovery, or reducing emission quantities. Several modification options are explored in the following chapter, and their impact on reducing ground concentration is discussed. It should be realized at this point that other emission sources from ADMA-OPCO facilities would result in higher predicted concentration levels on Das Island. However, the main objective of this study is to manage emissions of ADGAS-LNG Plant. Further studies are needed to address and quantify pollutant concentration resulting from ADMA-OPCO emissions.

CHAPTER 7

MODELING OF GROUND CONCENTRATIONS UNDER MODIFIED OPERATING CONDITIONS

7.1 INTRODUCTION

The previous chapter shows that some of the emission rates and ground level concentrations of SO_2 and NO_x exceed ADNOC and other standards. Thus, efforts that are directed towards reducing emission rates and the resulting ground level concentrations should be devised. It is our objective in this chapter to investigate the impact of certain proposed modification schemes on the unit processes at ADGAS Plant to meet regulatory standards.

There are two approaches for better emission management; reduction of gases going into the stacks and enhancement of gas combustion efficiency. Zero flaring, for example, would be the best approach to eliminate gases going into the flares, recovering these gases, and recompressing them to be used later as fuel gas or process gas. This will not only protect the environment, but will also lead to economical benefits. Zero flaring is applicable, however, for only normal operation with low continuous flow rates, but does not work under emergency conditions. Furthermore, it does not work under unsteady operations with varying feed gas characteristics and pressures, such as the case at ADGAS-LNG plants. In addition to the above, zero flaring is an expensive technology, and requires an expansion area, making it not feasible with the limited space on Das Island (SAAS Safety System and Flares Control).

Reduction of gases going into the flares may be accomplished using gas separation membranes to separate higher molecular weight gases from the gas mixture. This will reduce emission of higher molecular weight hydrocarbons and, with good separation, results in smokeless flares. Membrane separation may be feasible under steady and low flow rates. In case of upset and emergency situation, it will not be applicable due to sudden high flow rise and the complexity of gas composition, that must be flared, and thus it will damage the membrane components (Burggraaf, 1996).

Among other methods of emission reduction that might be applicable to ADGAS plant would be the improving sulphur recovery units in all trains by enhancing recovery efficiency to minimize emissions of SO_2 and installing additional compressor units for gas capture from the source and run down lines. The latter might be necessary to avoid flaring low-pressure associated gas coming from ADMA-OPCO under conditions of excess crude oil production due to the extra load on processing units at ADGAS Plant.

Capturing boil-off-gases (BOG) wasted during loading and shipments at the production facilities is yet another way of reducing emissions. Existing BOG compressors can not recover all boil-off gases. Additional compressor will recover the waste gas and return it to the production lines or use it directly as fuel gas for some of the utilities.

Currently, fuel gas purge is used at ADGAS Plant to maintain positive pressure in the flare stacks. Replacement of fuel gas by nitrogen purge will be considered as another process that can be used to reduce emissions to the flares. Nitrogen purging is applicable to flares other than acid gas flares since acid gas waste requires fuel gas purge for good mixing and combustion to prevent emissions of H_2S. Also, nitrogen purge may deactivate the ignition system at the flare tip.

Considering steam-assisted flares can enhance gas combustion efficiency. Steam-assisted flares are the most common method utilized to produce smoke-free flares. It is used for low-pressure gases and is widely used in major oil and gas industries. Steam is used to introduce air and provide good mixing into the flame for efficient combustion. This will reduce some of particulate and carbon monoxides emissions (Leite, 1994).

The impact of enhancing sulphur recovery, adding an additional boil-off-gas compressor, nitrogen purging and other modification options on ground concentration of pollutants emitted from ADGAS Plant is explored below.

7.2 UPGRADING SULPHUR RECOVERY UNITS

The average current efficiency of SRU in Train 1 and 2 is 96% and in Train 3 is 97%. This current efficiency does not comply with the 97.5% ADNOC standard. Upgrading the SRUs at ADGAS can be accomplished by using a Superclaus 99 process. Superclaus process recovers up to 99% of the sulphur in the acid gas stream. Thus, enhancement of SRUs performance reduces SO_2 emissions and leads to an increase in sulphur production.

Super Claus process consists of a thermal stage followed by three catalytic reaction stages with sulphur removed between stages by four condensers. Two reactors are filled with standard Claus catalyst while the third reactor is filled with the new selective oxidation catalyst. In the thermal stage, the acid gas is burned with a substoichiometric amount of controlled combustion air such that the tail gas leaving the second reactor contains 0.8 to 1.5 % H_2S by volume. The remaining tail gas is completely oxidized in an incinerator before being sent to the stack.

Upgrading the SRUs at ADGAS LNG Plant requires installing a reactor of newly selective oxidation catalyst and hydrogenation reactor between third and second stage reactors. The new catalyst in the third reactor oxidizes H_2S to sulphur at an efficiency of more than 85%. This is due to its selectivity for the direct oxidation of H_2S to elemental sulphur, with no reverse reaction sulphur and water to H_2S and SO_2.

With 99% sulphur recovery, the emission rates of SO_2 from Train 1 and Train 2 are 52 g/s and 27 g/s, respectively. Since ADNOC requires 97.5% or 0.2 g/Nm^3, enhancing the recovery to 99% may not, from ADGAS point-of-view, be economically justified. Lagas et al. (1989) reported that it would be expensive to move from 96% to 99% sulphur recovery. Therefore, it is important to compare between ground concentration resulting from 99% and 97.5 % sulphur recovery, to see if upgrading the SRUs to 99% would be environmentally justified. With 97.5% sulphur recovery, the emission rates of SO_2 from Train 1 and Train 2 are 115.7 g/s and 70 g/s, respectively. Note that the sum of the corresponding concentrations for these emission rates is still higher than ADNOC limitation (0.2 g/Nm^3).

Table 7.1 summarizes the simulation results of ground level concentrations under normal conditions for different improvement in SRU efficiency. Fig 7.1 to 7.3 shows contour lines for ground level concentrations at 97.5%. Based on the 1-hr averaging time, a 97.5 % SRU efficiency results in a 30% reduction in maximum ground concentration on Das Island. The contribution of the SRU stacks emissions to the ground concentration with 97.5% efficiency is approximately one third. This contribution will reduce to one-sixth for 99% with only an addition of 3% reduction compared to the 97.5% sulphur recovery. Comparing the SO_2 ground concentration for the other averaging times shows that improving sulphur recovery from 97.5 to 99% may not be the right option to reduce SO_2 ground concentration to ADNOC air quality standard. Surprisingly, the maximum concentration based on 24-hr averaging time did not change upon increasing sulphur recovery.

Management of other emission sources including turbines and some of the other flares should be considered for further reduction in SO_2 ground concentration. All those sources contribute to of SO_2 emissions. Another reduction of SO_2 emissions will be considered in another section.

Table 7.1 Ground level concentration of SO_2 ($\mu g/m^3$) under current and modified SRU efficiency

Averaging Time	Current	97.5% Efficiency	99% Efficiency	Contribution of SRUs at 97.5%	Contribution of SRUs at 99%
1hr	1388	971	917[1]	303	133
24hrs	414	414	414	56	25
Annual	44	37	35	6	3

[1] Contour map for 1hr 99% SRU efficiency is shown in Fig C.16 Appendix C.

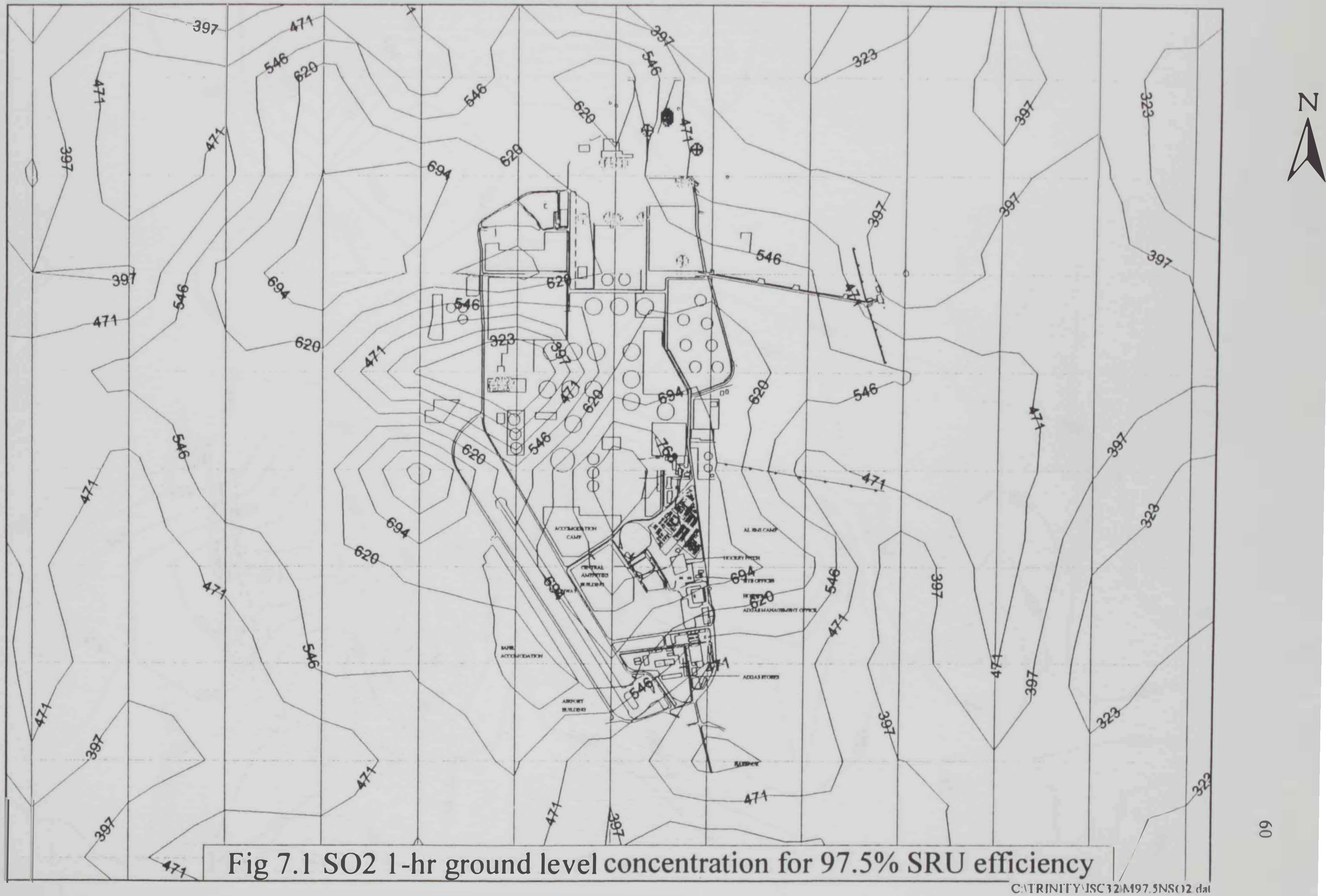

Fig 7.1 SO2 1-hr ground level concentration for 97.5% SRU efficiency

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Fig 7.2 SO2 24- hr ground level concentration for 97.5% SRU efficiency

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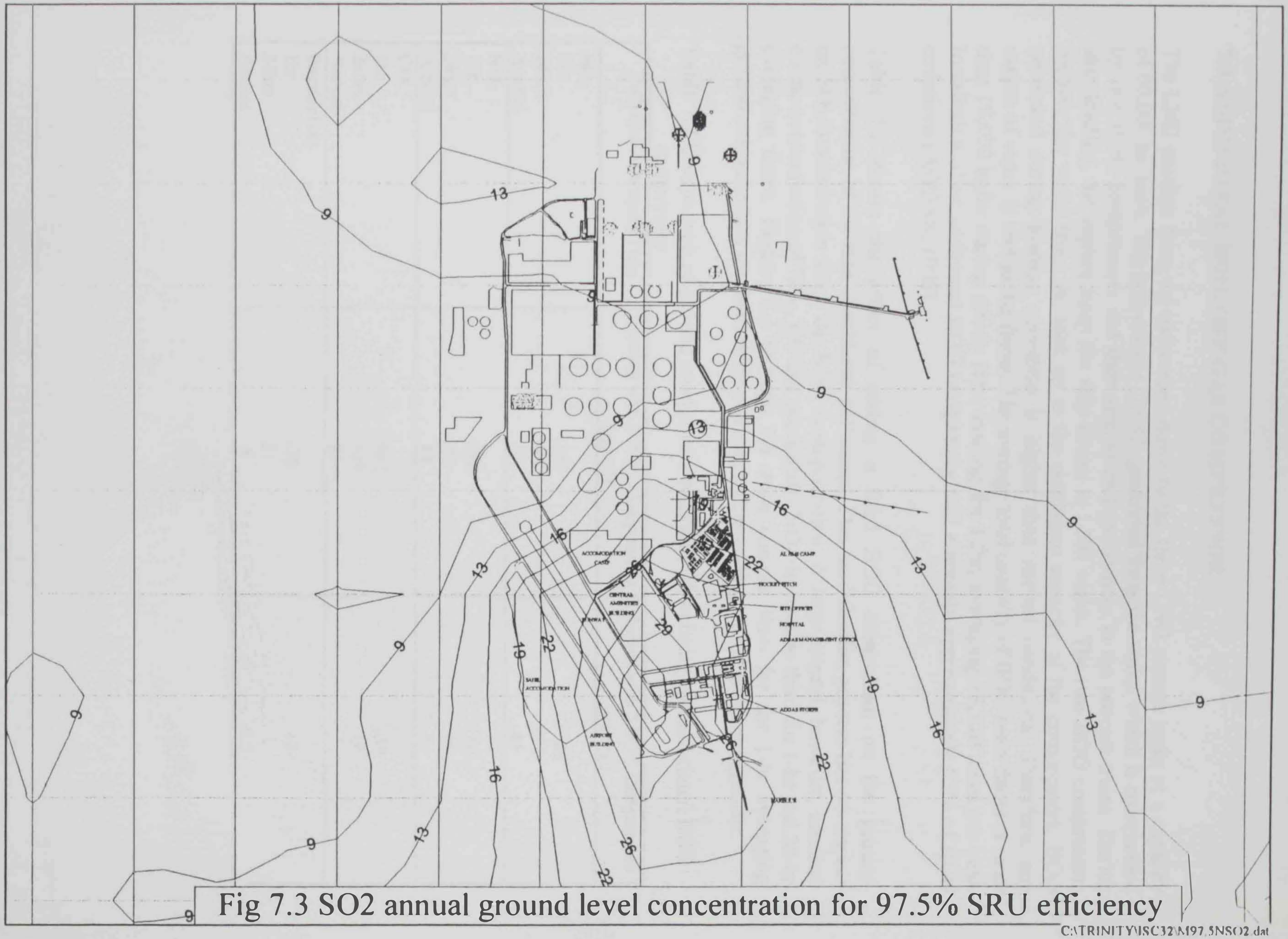

Fig 7.3 SO2 annual ground level concentration for 97.5% SRU efficiency

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7.3 ADDITIONAL BOIL OFF GAS COMPRESSOR

The LNG product from the trains runs down to the three LNG storage tanks at a capacity of 80,000 m^3 each. The boil-off-gas (BOG) generated from the tanks, which is compressed by two BOG compressors and then sent to fuel gas system in the process trains. During ship loading, the vapors from the ship return to LNG tanks. The two BOG compressors recover the vapor from the tank up to the maximum capacity of the compressors. BOG generated during loading operation is higher than normal conditions. Therefore, any excess of vapor is sent to the flares. The average total quantity of BOG been flared is more than 18,000 kg/hr during steady state loading for 12hr, averaging 18,720 tones per year. Installation of an additional BOG compressor will eliminate approximately 95% of BOG emissions (ADGAS, 1998).

Table 7.2 shows the effect of adding a third BOG compressor on the ground concentration of the four considered pollutants. This modification process has no impact on SO_2 concentration since the BOG is sulphur-free. A large impact, however, resulted on the concentration of NO_x, CO and particulate. NO_x dropped to third for 1-hr and 24-hr averaging times. Figures 7.4 through 7.6 show contour lines for the 1-hr averaging ground concentration for these three pollutants after adding a third BOG compressor.

Table 7.2 Comparison of ground level concentrations with existing and additional BOG compressor

Pollutant/Averaging Time	Normal with 2 BOG Compressors ($\mu g/m^3$)	Normal with 3 BOG Compressors ($\mu g/m^3$)
SO_2		
1hr	1388	1388
24hrs	414	414
Annual	44	44
NO_x		
1hr	500	166
24hrs	146	55
Annual	10	6
CO		
1hr	2842	259
24hrs	1639	29
Annual	85	5
Particulate		
1hr	170	12
24hrs	31	1
Annual	5	0.5

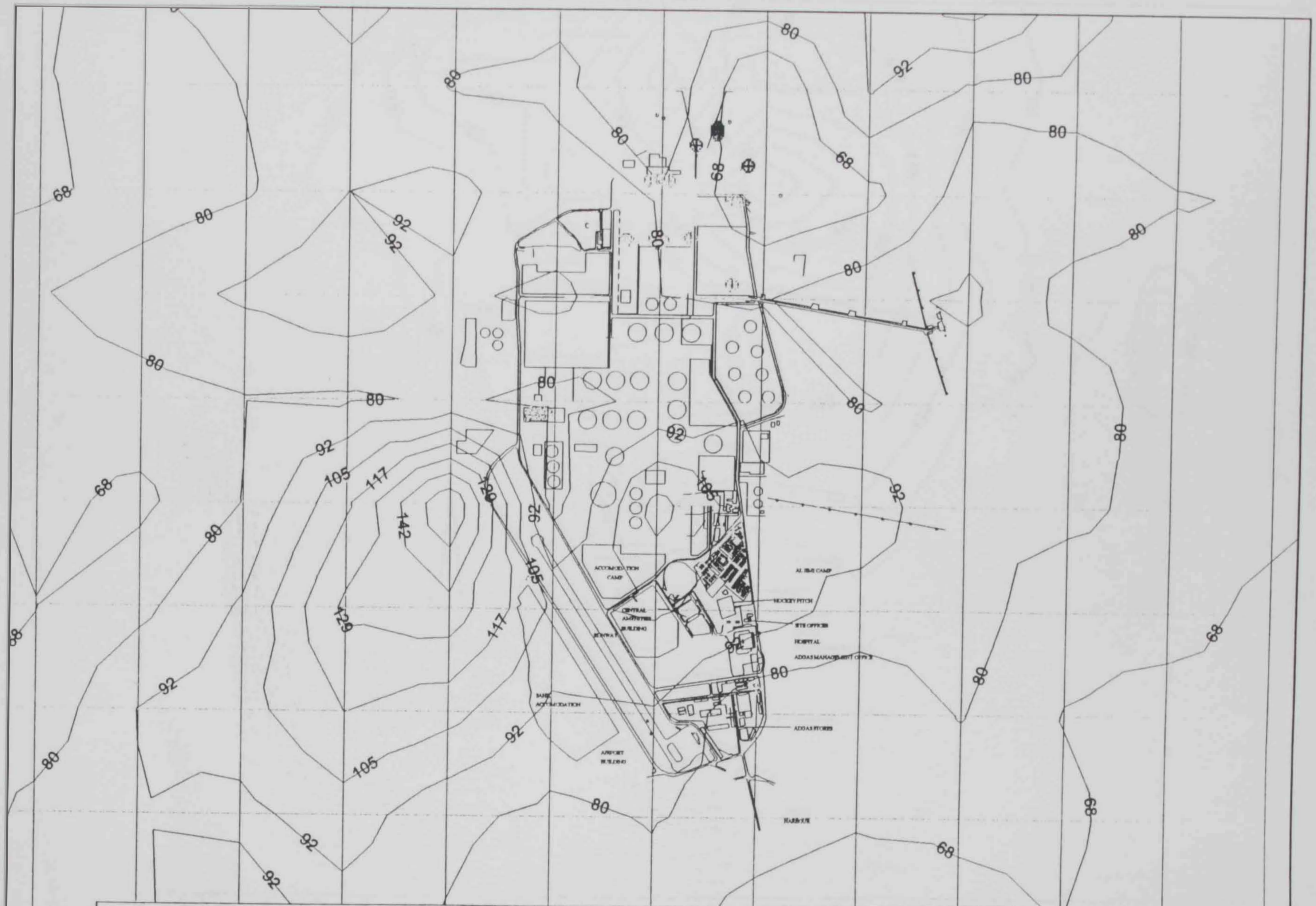

Fig 7.4 NOx 1-hr ground level concentration with additional third BOG compressor

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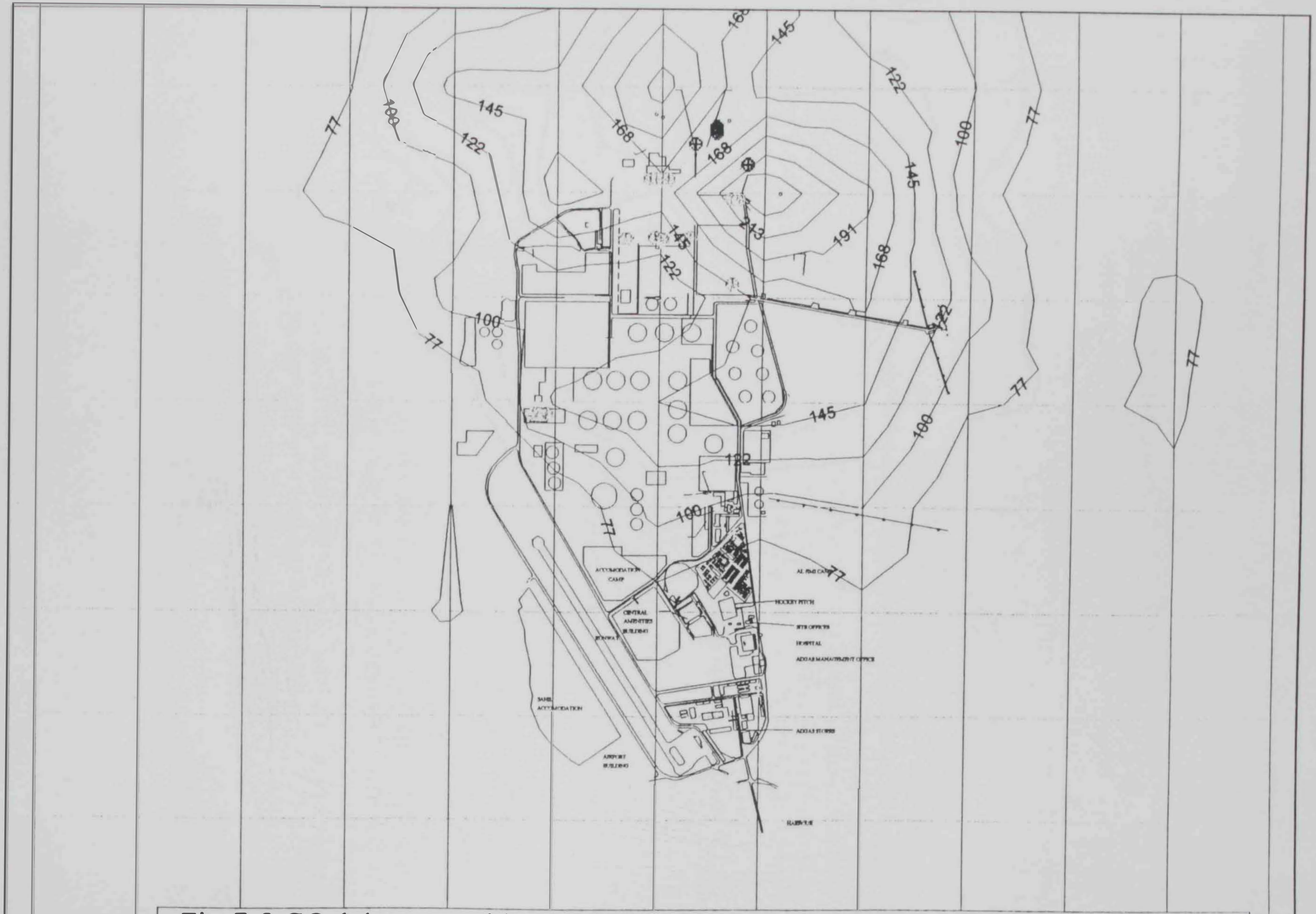

Fig 7.5 CO 1-hr ground level concentration with the additional BOG compressor

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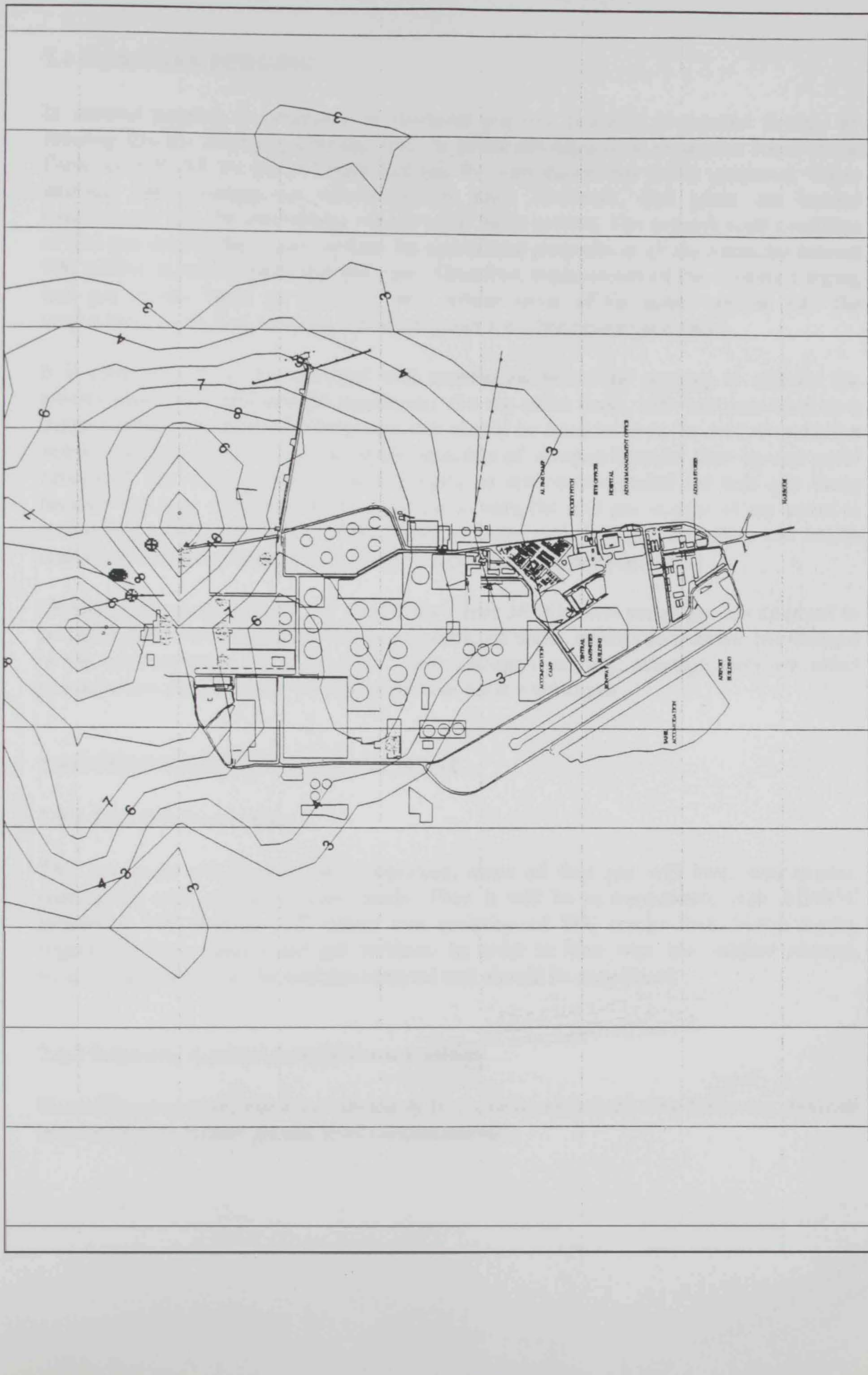

Fig 7.6 PM 1-hr ground level concentration with the additional third BOG compressor

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7.4 NITROGEN PURGING

In general purging is necessary to maintain positive pressure to prevent having air entering into the flaring system and thus, to avoid any hazardous situations. Most of the flares in ADGAS are purged with fuel gas for operational and safety purposes. Those existing flares system are non-smokeless flare. However, fuel gases are burned continuously into the atmosphere via the plant flares system. The average total quantities of fuel gas used in the flaring system for operational purposes at all the trains are around 900 million standard cubic feet per year. Therefore, replacement of the existing purging fuel gas in the flares by nitrogen, will reduce some of the gases emitted into the atmosphere, as well as, utilizing the saved gases for other operational uses.

It is clear that flares are operated with continuous pilots and purging to activate the system under safe and reliable conditions. On the other hand, with nitrogen used as a purge gas there are some disadvantages that should be considered in the control system; a sudden release could push a considerable quantity of nitrogen from the flare tip and could extinguish the pilots. Also, nitrogen purging is not recommended for acid gas flares because this type of flares requires fuel gas to burn the acid gas in case of any upset or emergency conditions. This acid gas shall be burnt with fuel gas for safety and health reasons to avoid any hazardous hydrogen sulphide releases (Selle, 1992).

Ground concentration under the conditions where all pilot and purge gas are assumed to be negligible were compared with those predicted under normal conditions. No changes in the concentrations were observed. Thus, nitrogen purging, although does not affect ground concentration, may be utilized to save some wasted gas.

7.5 OTHER EMISSION IMPROVEMENT

7.5.1 Fuel Gas Sweetening

This approach will be definitely important, since all fuel gas will have less sulphur content for utilities and process needs. Then it will be in compliance with ADNOC standards. This in turn will ensure low emission of SO_2 results from boiler stacks, regeneration gas heaters and gas turbines. In order to have very low sulphur content, some modifications in the acid gas removal unit should be considered.

7.5.2 Reducing Ground Level Concentrations

Ground level concentration can obviously be reducing emissions. The following methods may be used to reduce ground level concentrations:

1. Adding heat to stack gases or fuels to a flare to increase plume rise.
2. Construction stack nozzles to reduce building down wash.
3. Using a segmented stack to replace a series of stacks.
4. Reducing emissions temporarily when air quality standards are threatened.
5. Introducing low NO_x burners for boilers, regeneration gas heater and gas turbine.
6. Increasing stack height.

7.5.3 Flare Improvement

Introducing steam-assisted flares for some existing ones in the plant will reduce the impact on smoke and heat radiation. Steam injection will provide a better mixing and turbulence of air to gas ratio and efficient combustion will lead to smokeless situations (Straitz, 1994). Availability of steam on site makes it more economically to be utilized for controlling emissions. Also flare tip design improvement will enhance a better mixing and distribution of the flare gases to provide higher combustion efficiency, as a result for smokeless operations (Leite, 1992).

7.6 SUMMARY

Modification of unit processes is needed to reduce emission rates and resulting ground concentration from ADGAS sources. Since SO_2 concentration under current conditions are above the acceptable air quality limits, upgrading the SRUs was explored first and was found to reduce the SO_2 concentration, but not to the acceptable limits. Further reduction is required possibly through sweetening of fuel gas utilized by gas turbines and boilers. However, purging flares with nitrogen instead of fuel gas, which have a minor impact on reducing SO_2 concentration. This will be, on the other hand, a step for conservation of wasted fuel gas.

Since NO_x, and particulate concentration is a concern under current conditions, addition of a third BOG compressor was investigated and was found to positively reduce the concentration of the two pollutants within the acceptable limits. The economical benefit in recovering BOG should make this modification on the top of any emission management list.

High levels of communication between the up stream operating company ADMA-OPCO and down stream company ADGAS during upset situations is critical to minimize emissions resulting from uncontrolled flaring of the associated gas. However, any emission management strategy at Das Island should take area availability into consideration. For example, expansion of a unit operation within a train may not be feasible due to area limitations and safety requirements.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The main objective of this study was to better manage emissions from gas processing companies at the UAE ADGAS LNG Plant was considered as the case study. The approach selected was to establish a baseline for current emissions and ground level concentrations of several pollutants, and then to explore different modification scenarios to reduce emissions and ground concentration exceeding regulatory standards. Although other emission sources from ADMA-OPCO side are contributing to ground concentration on Das Island, this study should be very beneficial for any future management effort by ADGAS as it identifies current emissions from its sources and their contribution to pollution level on Das Island. Air dispersion modeling was utilized to predict ground concentration under actual and hypothetical operation conditions. Emission rates, source location, and emission characteristics were obtained from ADGAS Operation Department, and Department of Health, Safety, and Environment. Meteorological data were obtained from Abu Dhabi International Airport, as it is the closest station to Das Island.

Two main approaches were considered to minimize ground level concentrations emitted from LNG plant at ADGAS. First, reducing flow of gas into the flares by adding compressors in order to recover any excess gas from going into the flares during operations as well as replacing fuel gas purging to nitrogen. Second, upgrading sulphur recovery units to a higher efficiency by modifying the units using Superclaus technology in order to meet ADNOC control limits and enhancing combustion efficiency of the waste gas by flare improvement using, for example, steam-assisted flares.

In this study, four pollutants were considered namely; sulphur dioxide, nitrogen oxides, carbon monoxide and particulate. Selection of these pollutants was done to allow comparison between predicted concentrations and the air quality values established by ADNOC and other international agencies. From this study we conclude that:

1. Emission rates for those pollutants are exceeding the exposure limit of ADNOC and US EPA, under all considered emergency cases and current normal operations. SO_2 maximum average concentration level was the highest among the other pollutants.

2. Under current situation gas turbines and boilers are the major sources of NO_x and CO, whereas, SO_2 emissions from SRUs and gas turbines are highly exceeding the regulation limits. However, CO emission from all the sources is below the air quality limits.

3. Under emergency conditions, maximum average ground concentrations of SO_2 and NO_x were found to be much higher than the allowable limits. Particulate and CO concentrations are less than their corresponding values under normal operation due to the high heat release associated with the flares.

4. The maximum annual concentrations of SO_2 and particulate resulting from emission at ADGAS LNG Plant are exceeding ADNOC allowable limits.

5. Upgrading sulphur recovery units to 97.5% resulted in 30% decrease in SO_2 concentration. Further recovery to 99% resulted in additional 3% decrease only.

6. Adding a third BOG compressor resulted in a significant decrease in NO_x, CO and particulate concentrations.

7. No change in ground concentration has resulted by replacing fuel gas by nitrogen purge.

8.2 RECOMMENDATIONS FOR THIS STUDY AND FOR FUTURE WORK

It is highly recommended that, the modifications and improvement of minimizing emissions start from management side to make a good decision for controlling and selection for the appropriate use. There are some recommendations for a better management of emission at ADGAS as listed below:

1. It is recommended to upgrade the SRUs to reduce SO_2 emissions and meet ADNOC regulations. Further reduction can be accomplished through sweetening of fuel gas directed to utilities.

2. A third compressor to recover BOG during normal and LNG/LPG loading will significantly reduce emissions of wasted hydrocarbons and other pollutants.

3. Investigating the impact of steam assisted flares on reducing ground level concentrations.

4. Introducing low NO_x burner for boilers, and improving flare tip design for efficient mixing with waste gas to avoid soot formation and smoke should be explored.

5. Explore fuel gas sweetening by revamping acid gas removal units as a means for further reducing SO_2 emissions.

6. Stationary and mobile measurement devices for monitoring ground concentration of emitted pollutants is greatly needed, especially at the sensitive receptors located at the south part of the Island.

7. Installation of sampling ports for measuring continuous releases from emission sources will be preferable.

8. Shortening the duration of the planned overhaul shut down.

9. Coordination between ADMA-OPCO and ADGAS is greatly required to reduce emissions during sudden emergency and upset conditions.

10. Future expansion in oil and gas production on Das Island requires prior assessment using air dispersion modeling for better air quality management.

11. Studying the effect of injecting acid gas to underground oil & gas reservoirs on reducing SO_2 emissions.

12. Modeling ground level concentration at zero wind case for normal operations.

13. Studying the expansion for combined effects of emissions of ADMA-OPCO and ADGAS.

14. Investigating the impact of emissions from Das Island on Coastal Residential Areas.

15. Comprehensive study required for economical impact of proposed modification to this process.

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APPENDIX A

Table A.1 A one-day sample of meteorological data for Abu Dhabi International Airport (1996)

Year	Month	Day	Hour	Flow Vector (deg.)	Wind Speed (m/s)	Temp. (K)	Stability Class	Rural Mix Ht. (m)	Urban Mix Ht. (m)
96	1	1	1	160	2.0576	289.7	6	221	221
96	1	1	2	160	2.0576	289.7	6	221	221
96	1	1	3	160	1.5432	289.7	6	35	50
96	1	1	4	160	1.5432	289.7	6	35	50
96	1	1	5	220	1.5432	291.4	2	660	660
96	1	1	6	270	1.0288	293	2	837	837
96	1	1	7	330	1.0288	294.7	1	970	970
96	1	1	8	280	2.0576	295.4	2	1137	1137
96	1	1	9	240	3.0864	296	3	1321	1321
96	1	1	10	190	4.1152	296.7	3	1474	1474
96	1	1	11	180	4.1152	296.6	3	1575	1575
96	1	1	12	170	4.6296	296.6	3	1576	1576
96	1	1	13	160	4.6296	296.5	3	1610	1610
96	1	1	14	160	4.1152	295.8	3	1554	1554
96	1	1	15	170	3.0864	295	5	512	512
96	1	1	16	170	2.572	294.3	6	377	377
96	1	1	17	180	2.0576	293.8	6	237	237
96	1	1	18	180	1.5432	293.2	6	23	30
96	1	1	19	190	1.0288	292.7	6	8	20
96	1	1	20	190	1.0288	292.3	6	8	20
96	1	1	21	180	1.5432	292	6	23	30
96	1	1	22	180	1.5432	291.6	6	23	30
96	1	1	23	170	1.5432	291.3	6	23	30
96	1	1	24	150	1.0288	290.9	6	8	20

Table A.2 Produced gas densities and CO_2 emission factors for a range of molecular weights

Molecular Weight	**Gas Density**		**CO_2 Emission Factor** (tonnes CO_2 /tonne gas burned)
	tonnes/mmscf	Tonnes/10^6 Sm^3	
16	19.2	677	2.75
17	20.4	719	2.77
18	21.6	761	2.79
19	22.8	804	2.81
20	24.0	846	2.83
21	25.2	889	2.84
22	26.4	931	2.86
23	27.6	973	2.87
24	28.8	1015	2.88
25	30.0	1058	2.89
26	31.2	1100	2.90
28	33.6	1185	2.92
30	36.0	1270	2.93
32	38.4	1354	2.95
34	40.8	1439	2.96
38	45.6	1608	2.98
42	50.4	1777	2.99
46	55.3	1947	3.01

Table A.3 Tier three estimation: Draft emission factors for gas combustion equipment (tonnes emission/tonne gas burned)

Emission Gas	**Turbines Factor**	**Engines Factor**	**Heaters & Boilers Factor**
CO_2	2.75	2.75	2.75
CO	0.0027	0.0096	0.0008
NO_x	0.0067	0.076	0.0031
N_2O	0.00022	0.00022	0.00022
SO_2	2.0 x S1	2.0 x S1	2.0 x S1
CH_4	0.00042	0.028	0.00007
VOC	0.000051	0.003	0.00062

Note:

1. Assumes a value for the molecular weight of gas of 16. If the molecular weight of the gas is known, use Table A.1 to convert volumes of fuel gas to weight and use the appropriate emission factor.

2. Expect for CO_2 and SO_x USEPA factors are used.

3. S1 is weight fraction sulphur in the gas. Use a factor of 12.8×10^{-6} tonnes SO_2 per tonne gas assuming a default sulphur content of 6.4 ppm by weight.

Table A.4 Tier two estimation: Draft emission factors
for gas flaring (tonnes emission/tonne gas burned)

Emission Gas	Factor
CO_2	2.61
CO	0.0087
NO_x	0.0015
N_2O	0.000081
SO_2	0.0000128
CH_4	0.035
VOC	0.015

Notes:

1. Assumes that 95 % of gas is combusted: factor =2.75 ^{x} 0.95 except in strongly regulated areas (e.g. US) when factor = 2.75 ^{x} 0.98.

2. Carbon Dioxide Factor assumes a molecular weight of 16. If the molecular weight of gas is known, use the appropriate value shown in Table A.1 in place of 2.75 in the equation .

3. Carbon Monoxide: USEPA emission factor based upon measurements by API/Chemical Manufactures Association data.

4. Nitrogen Oxides: USEPA emission factor based upon measurement by API/Chemical Manufactures Association data.

5. Sulphur Oxides: Assumes sulphur content of 6.4 ppm by weight, for gas flared with higher sulphur content, use an emission factor calculated using the formal S1 ^{x} 2.0 where S1 is the weight fraction of sulphur in fuel.

6. CH_4/VOC: Assumed gas composition : 70 % CH_4, 30 % VOC by weight
   UK inventory used composition from each field.
   Average Composition 51% CH_4, 49 % VOC by weight
   Norway inventory assumed gas composition: 65 % CH_4, 35% VOC by weight.

Calculations for SO_2 and CO_2 Emission Rates

Table A.5 Sour gas feed stream to SRU

Composition	**Mol%**
H_2S	49.6
CO_2	43.7
H_2O	4.7
CH_4	1.8
C_2H_5	0.2
Total	**100**

Table A.6 SRU stack outlet

Composition	**Mol%**		
	dry	wet	dry,3% O_2
SO_2	0.73	0.54	0.67
CO_2	22.61	16.83	20.95
N_2	75.09	55.89	75.38
O_2	1.57	1.17	3.00
H_2O	-	25.57	-
Total	**100**	**100**	**100**

Determination of flow under dry and normal conditions
(from Table A.5 and Table A.6)

Flow = 91.5 m^3/s
Assuming 25.57% water vapour, then the flow on a dry basis is:
Flow = 91.5(100-25.57/100) = 68.1 m^3/s

At normal flow conditions:

Flow = 68.1 (273/873) = 21.3 Nm^3/s (normalized dry flow)
With a 3% O_2, the flow will be:
Flow = 21.3 (100+1.43/100) = 21.6 Nm^3/s
1 mole at standard conditions occupies 22.4 L, (1000/22.4 = 44.64 moles/Nm^3)

For CO_2 emission rate:

Mole CO_2 = 44.64 (20.95/100) = 9.35 mole
9.35 mole X M.wt CO_2 (44 g/mole) = 411.6 g/Nm^3
411.6 g/Nm^3 X 21.6 Nm^3/s = 8890 g/s

For SO_2 emission rate:

Mole SO_2 = 44.64 (0.67/100) = 0.3 mole
0.3 mole X M.wt SO_2 (64 g/mole) = 19.2 g/Nm^3
19.2 g/Nm^3 X 21.6 Nm^3/s = 414.7 g/s

APPENDIX B

Table B.1 Parameters used to calculate Pasquill-Gifford σ_y

	$\sigma_y = 456.11628\,(x)\,\tan\,(TH)$ $TH = 0.017453293\,[\,c - d \ln(x)\,]$	
Pasquill Stability Category	c	d
A	24.167	2.53340
B	18.3330	1.80960
C	12.5000	1.08570
D	8.3330	0.72382
E	6.2500	0.54287
F	4.1667	0.36191

Where (σ_y) is in meters and (x) is in kilometers.

Table B.2 Parameters used to calculate Pasquill-Gifford σ_z

Pasquill Stability Category	x (km)	σ_z (meters) = ax ^{b} (x in km)	
		a	b
A*	< .10	122.800	0.94470
	0.10 – 0.15	158.080	1.05420
	0.16 – 0.20	170.220	1.09320
	0.21 – 0.25	179.520	1.12620
	0.26 – 0.30	217.410	1.26440
	0.31 – 0. 40	258.890	1.40940
	0.41 – 0.50	346.750	1.72830
	0.51 – 3.11	453.850	2.11660
	> 3.11	**	**
B*			
	< .20	90.673	0.93198
	0.21 – 0.40	98.483	0.98332
	>0.40	109.300	1.09710
C*	All	61.141	0.91465
D	< .30	34.459	0.86974
	0.31 – 1.00	32.093	0.81066
	1.01 – 3.00	32.093	0.64403
	3.01 – 10.00	33.504	0.60486
	10.01 – 30.00	36.650	0.56589
	> 30.00	44.053	0.51179

* If the calculated value of σ_z exceed 5000 m, σ_z is set to 5000 m.

** σ_z is equal to 5000 m.

Table B.3 Parameters used to calculate Pasquill- Gifford σ_z

Pasquill Stability Category	x (km)	σ_z (meters) = a x ^{b} (x in km) a	b
E	< 0. 10	24.260	0.83660
	0.10 – 0.30	23.331	0.81956
	0.31 – 1.00	21.628	0.75660
	1.01 – 2.00	21.628	0.63077
	2.01 – 4.00	22.534	0.57154
	4. 01 – 10.00	24.703	0.50527
	10.01 – 20.00	26.970	0.46713
	20.01 – 40.00	35.420	0.37615
	> 40. 00	47.618	0.29592
F	<0. 20	15. 209	0.81558
	0.21 – 0.70	14. 457	0.78407
	0.71 – 1.00	13.953	0.68465
	1.01 – 2.00	13.953	0.63227
	2.01 – 3.00	14.823	0.54503
	3.01 – 7.00	16.187	0.46490
	7.01 – 15.00	17.836	0.41507
	15.01 – 30.00	22.651	0.32681
	30.01 – 60.00	27.074	0.27436
	> 60. 00	34.219	0.21716

APPENDIX C

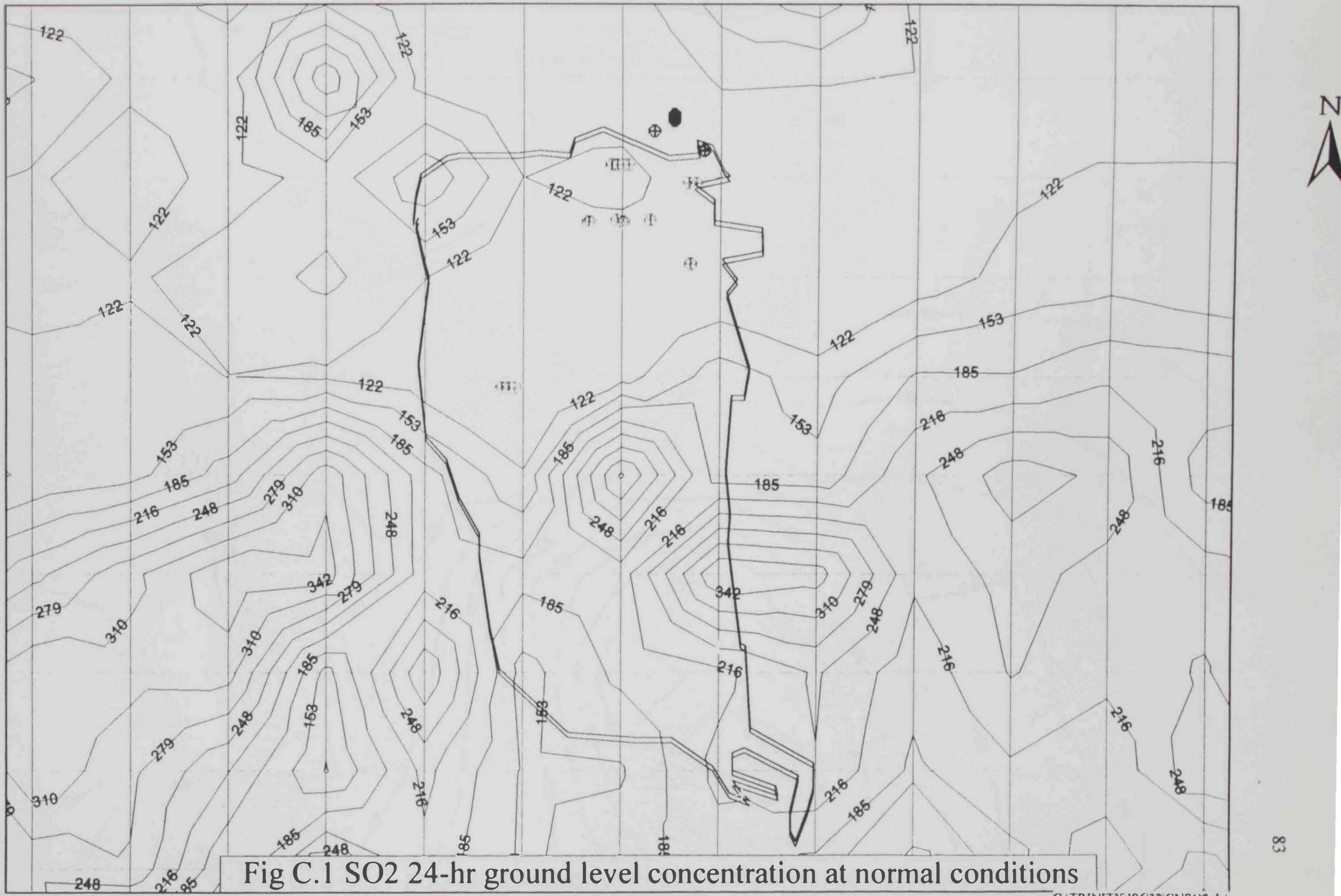

Fig C.1 SO2 24-hr ground level concentration at normal conditions

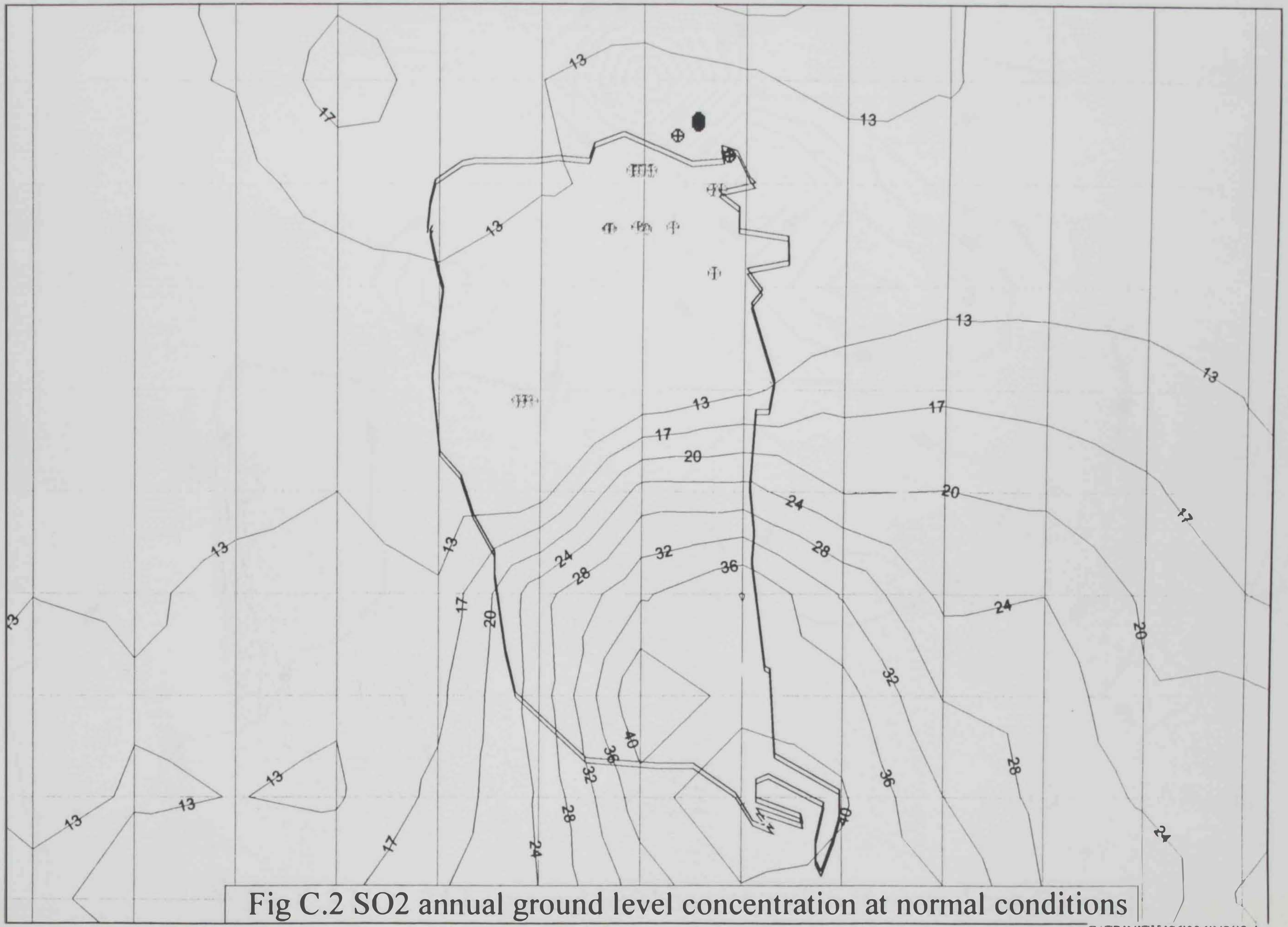

Fig C.2 SO2 annual ground level concentration at normal conditions

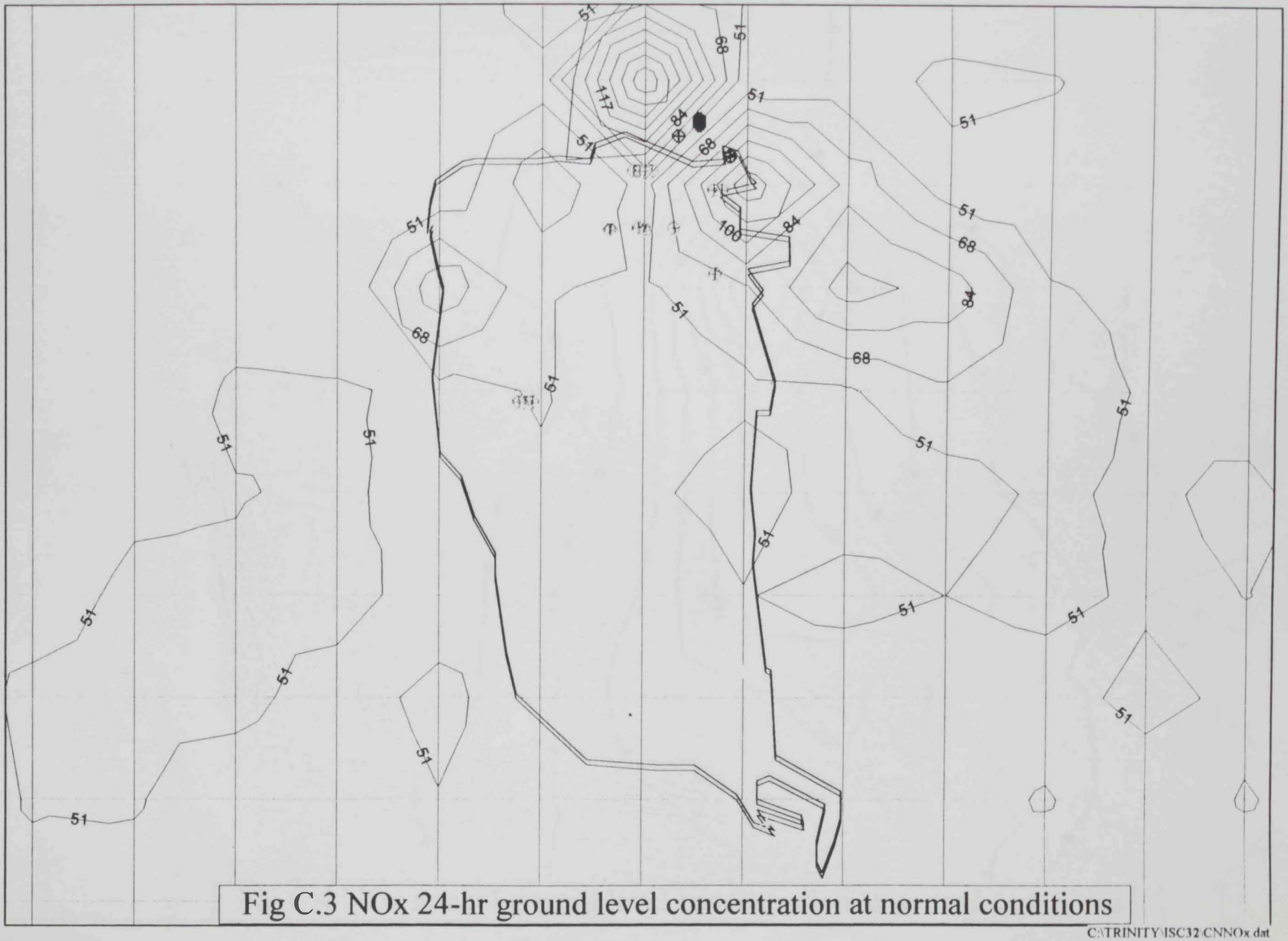

Fig C.3 NOx 24-hr ground level concentration at normal conditions

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Fig C.4 NOx annual ground level concentration at normal conditions

C:\TRINITY\ISC\12 CNNOx.dat

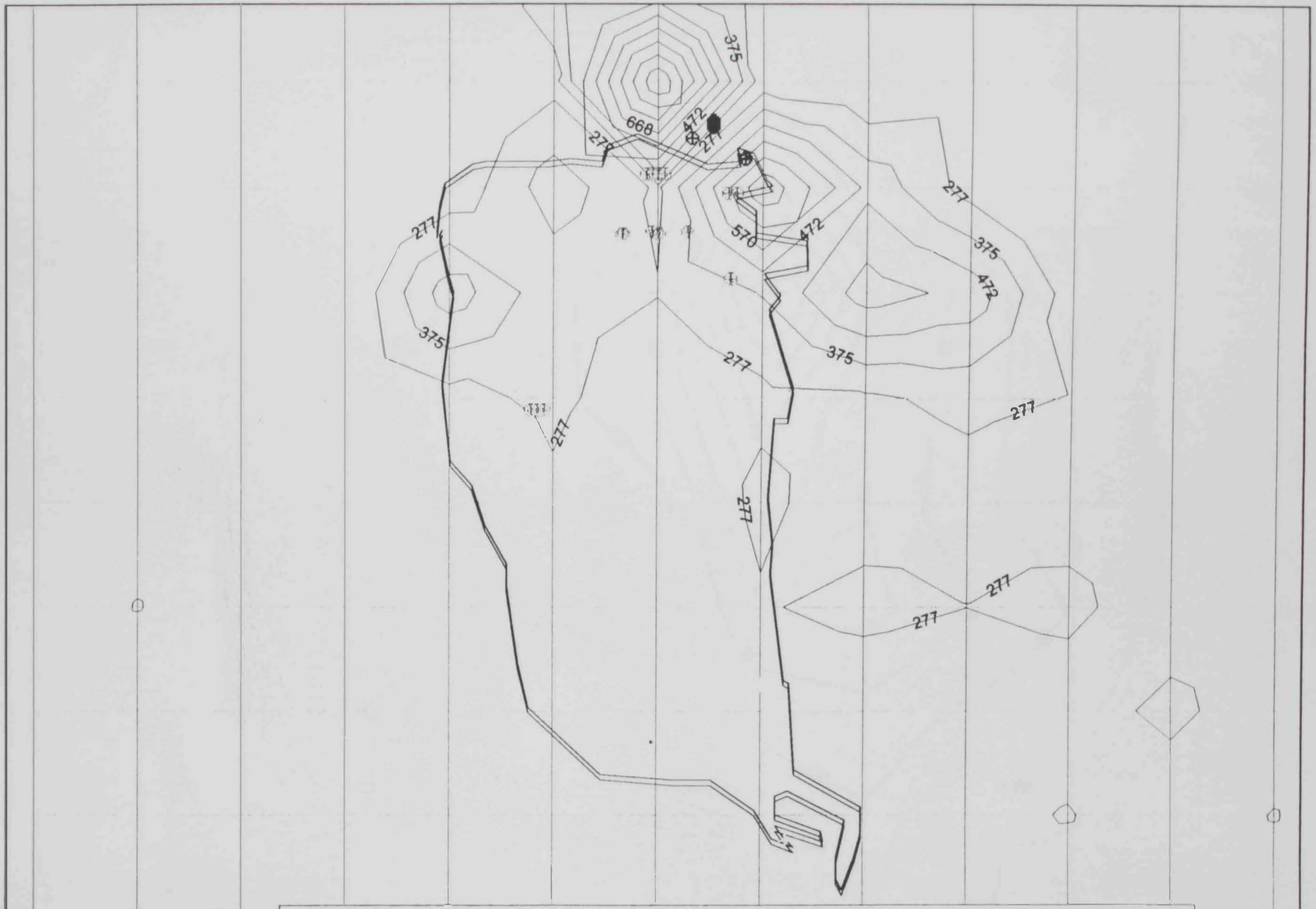

Fig C.5 CO 24-hr ground level concentration at normal conditions

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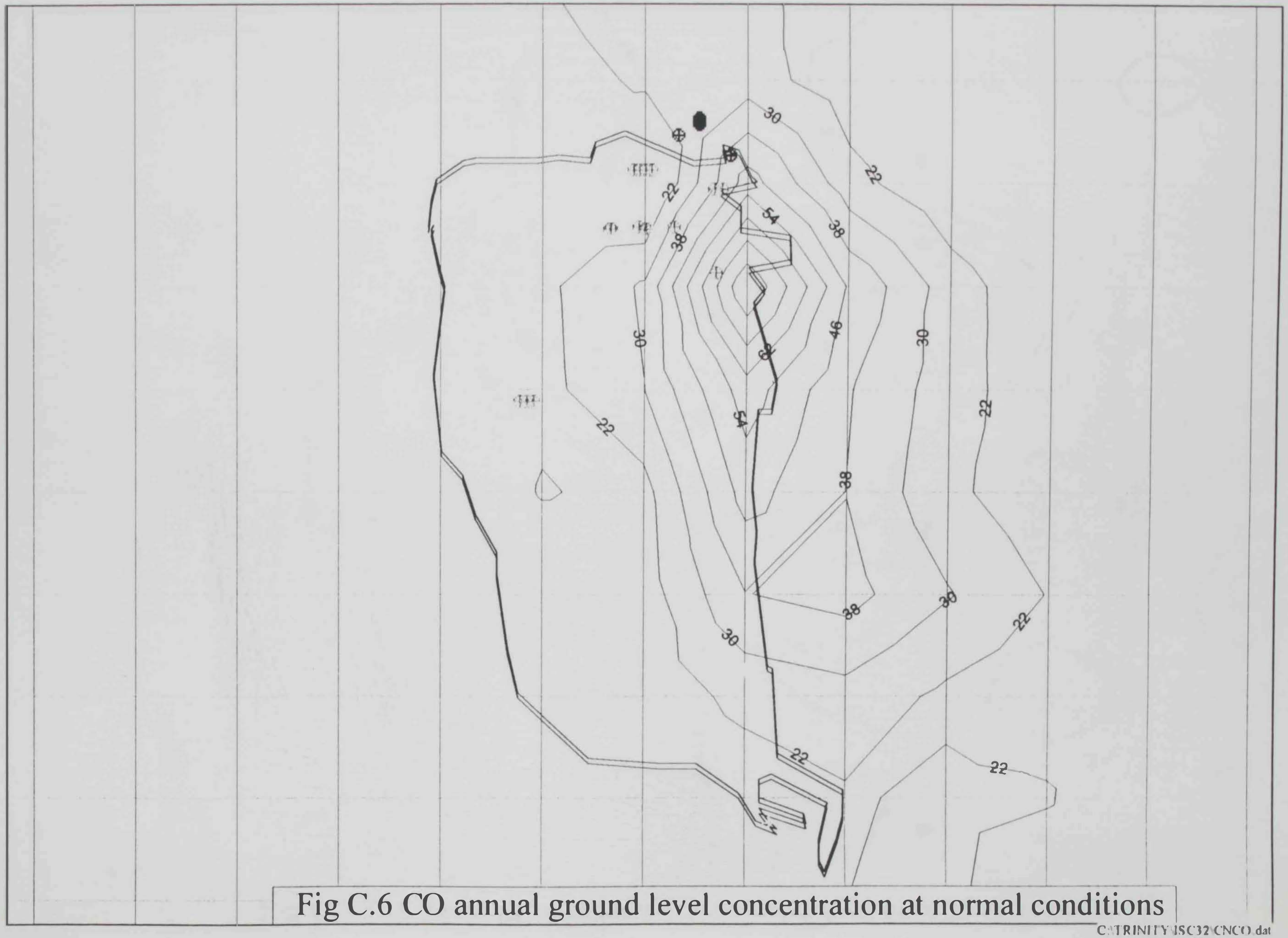

Fig C.6 CO annual ground level concentration at normal conditions

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Fig C.7 PM 24-hr ground level concentration at normal conditions

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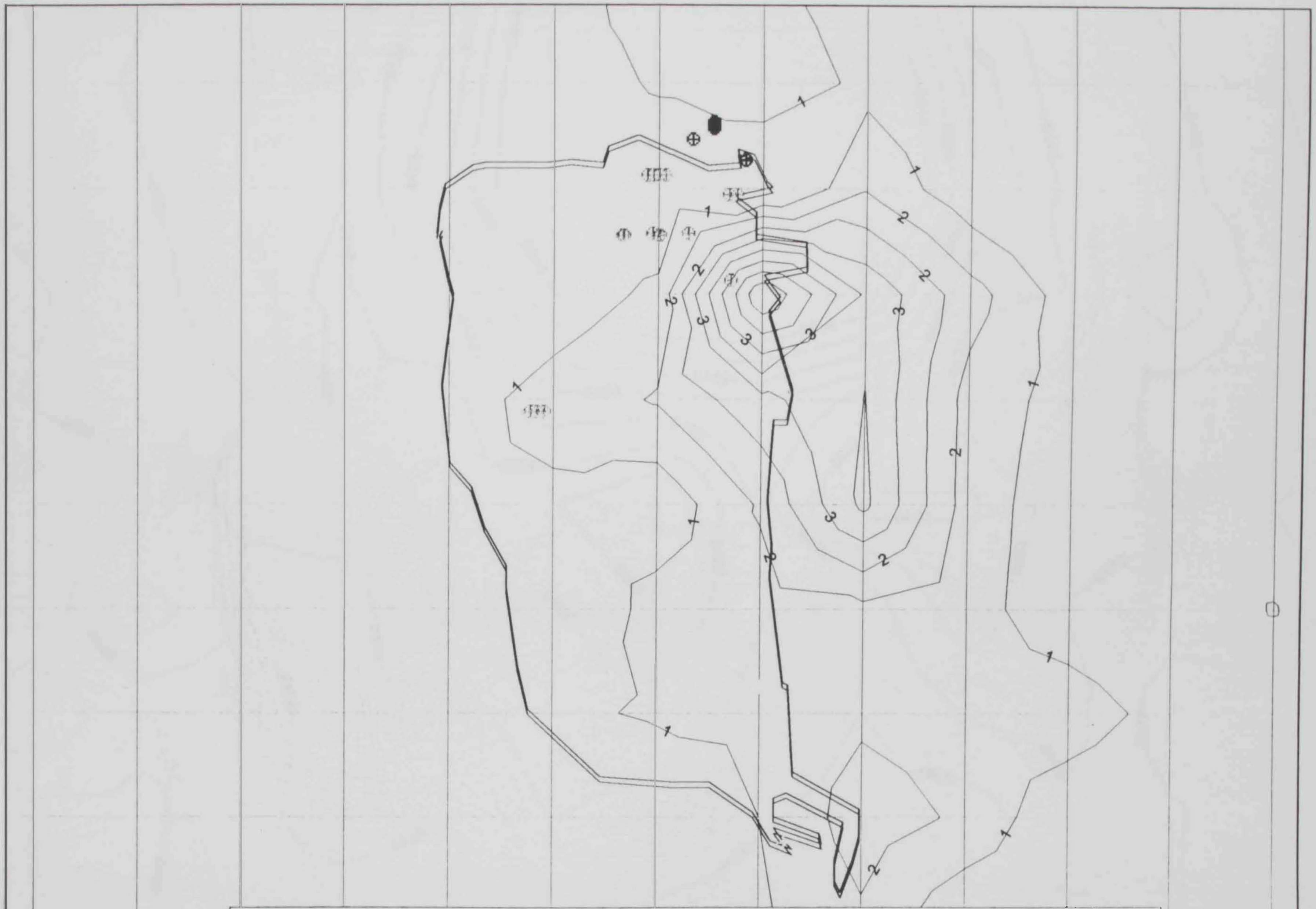

Fig C.8 PM annual ground level concentration at normal conditions

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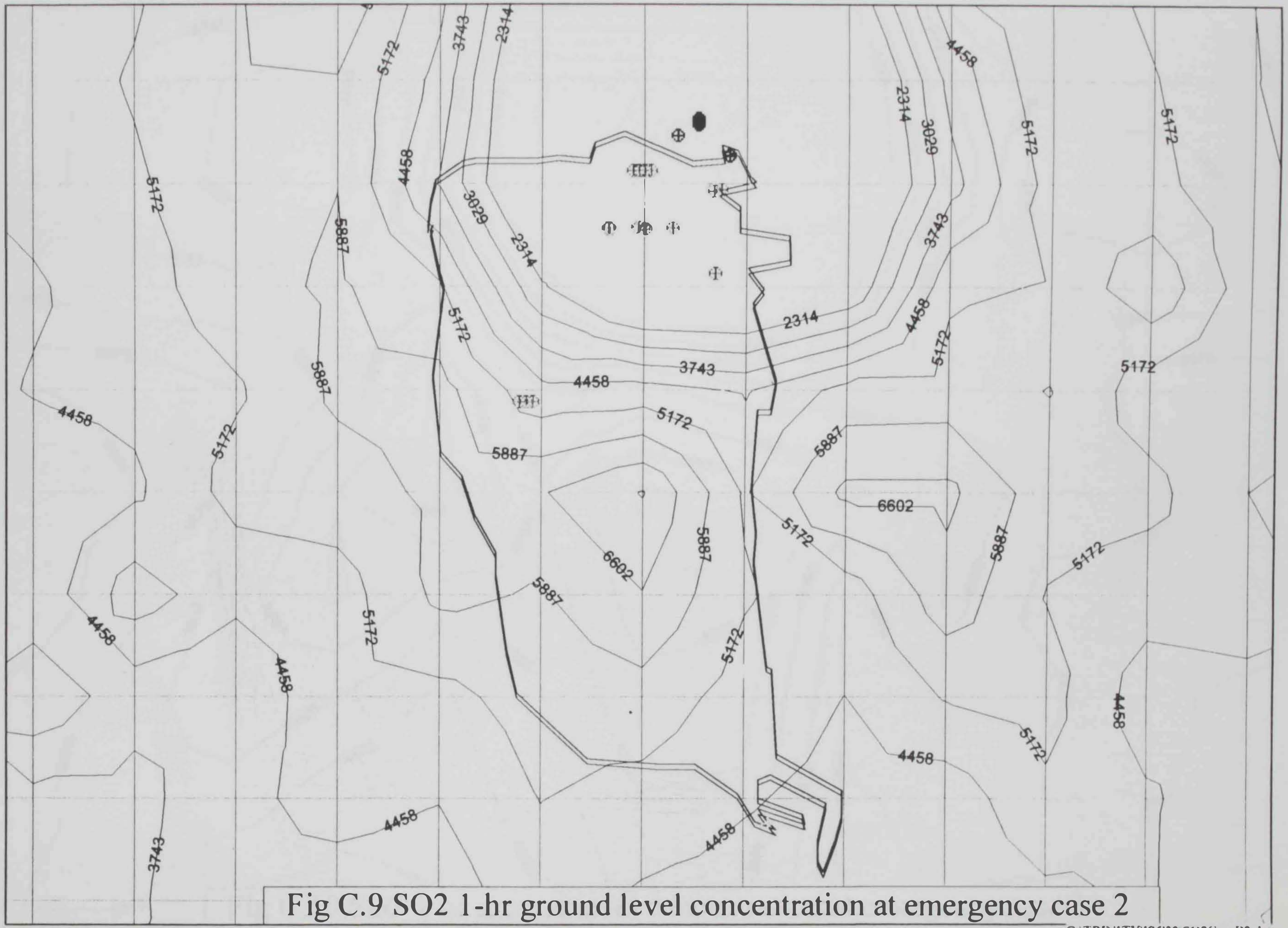

Fig C.9 SO2 1-hr ground level concentration at emergency case 2

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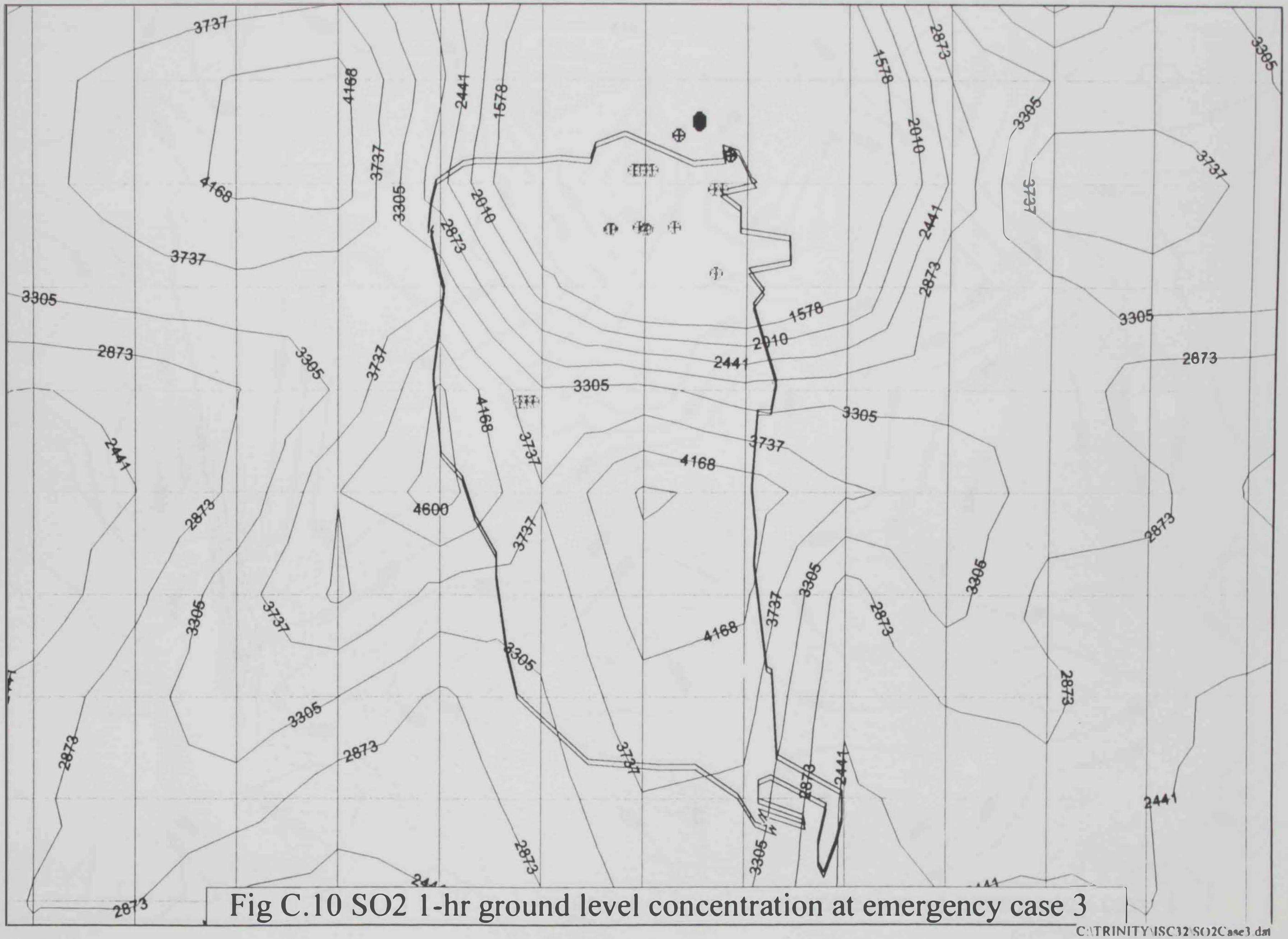

Fig C.10 SO2 1-hr ground level concentration at emergency case 3

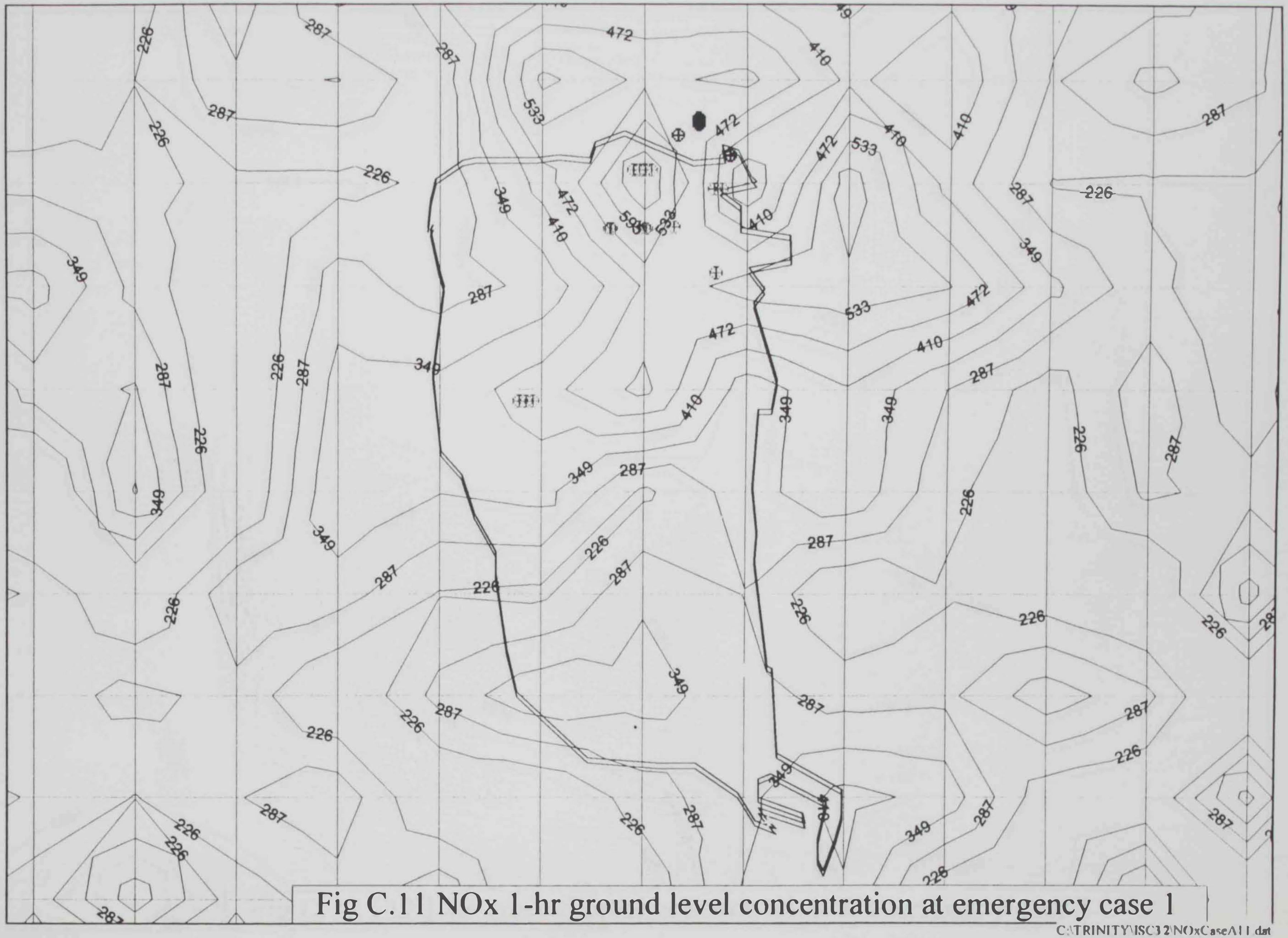

Fig C.11 NOx 1-hr ground level concentration at emergency case 1

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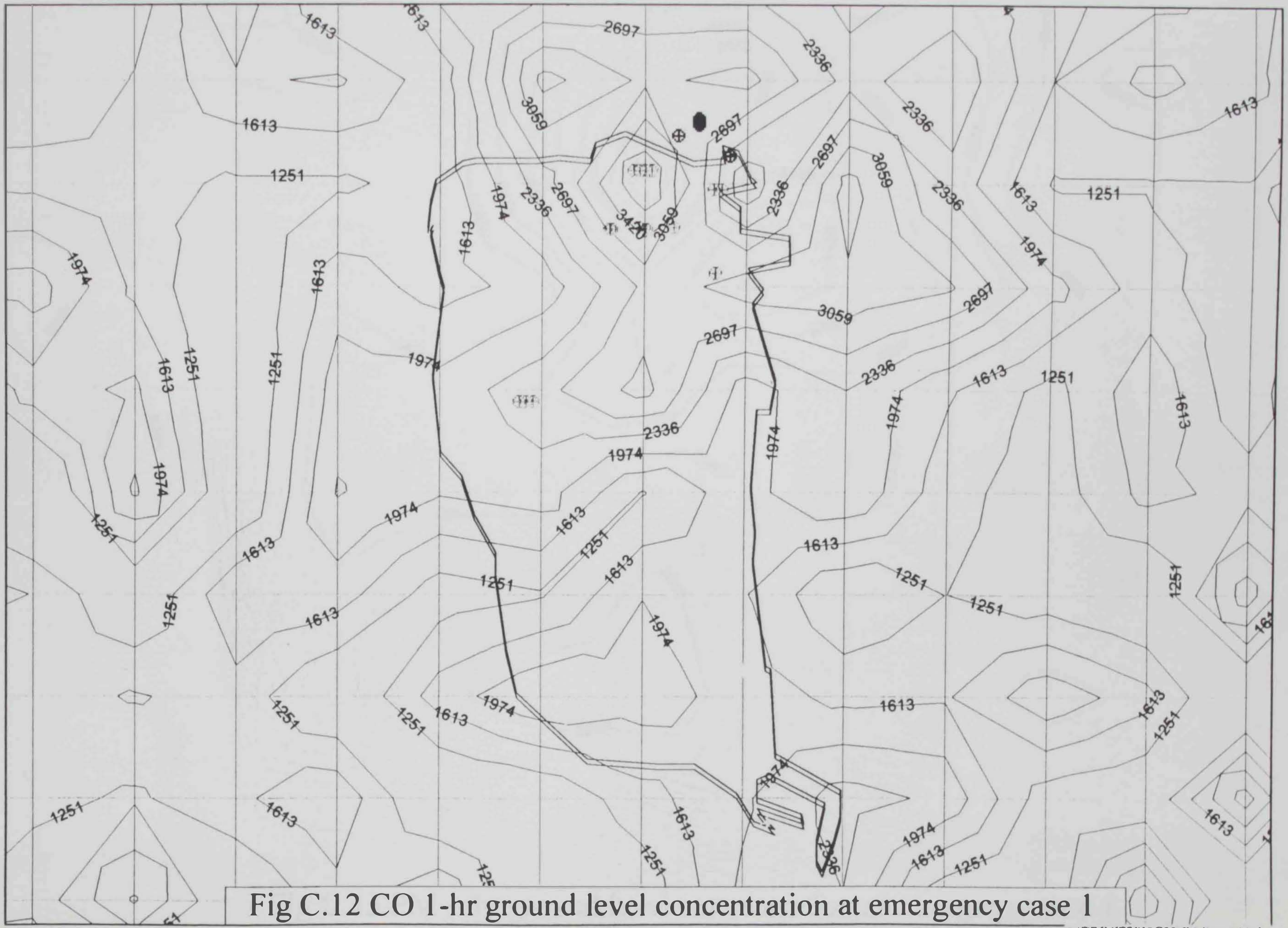

Fig C.12 CO 1-hr ground level concentration at emergency case 1

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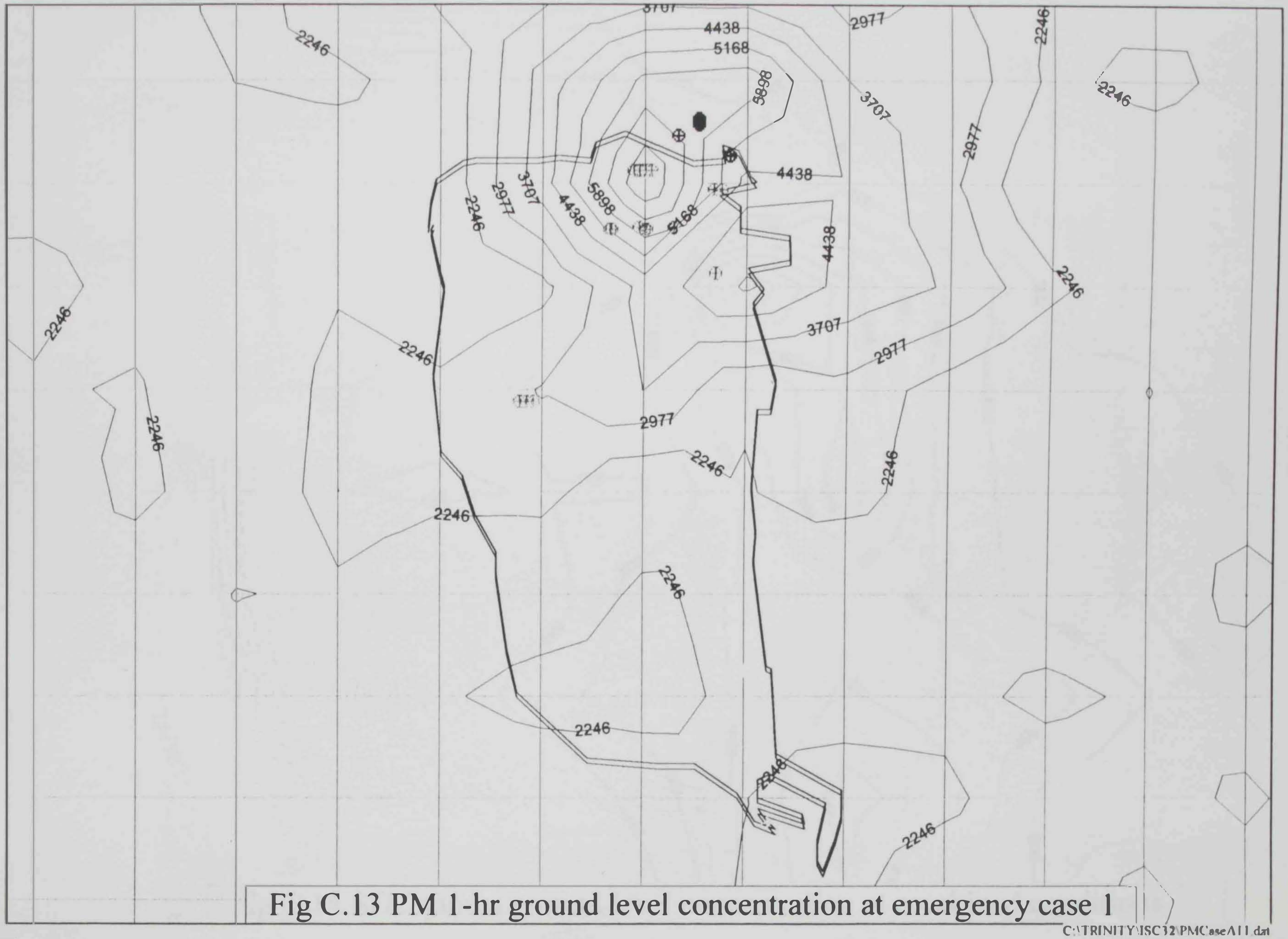

Fig C.13 PM 1-hr ground level concentration at emergency case 1

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Fig C.14 SO2 annual ground level concentration at combined conditions

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Fig C.15 PM annual ground level concentration at combined conditions

C:\TRINITY\ISC32\CCPM.dat

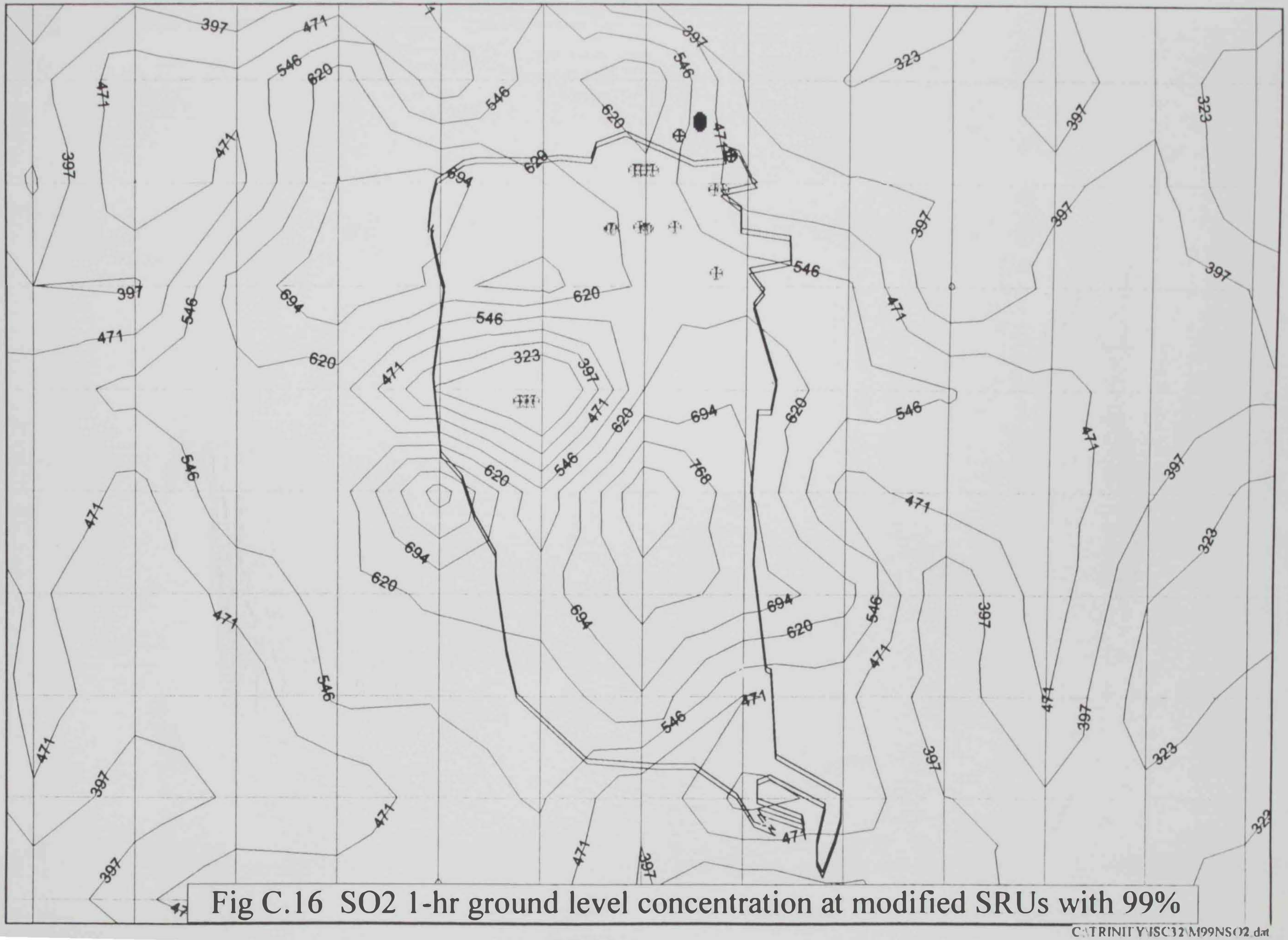


Fig C.16 SO2 1-hr ground level concentration at modified SRUs with 99%

C:\TRINITY\ISC32\M99NSO2.dat

وتعتبر توربينات الغاز والغلايات المصدر الرئيسي لانبعاث مركبات النيتروجين المؤكسدة وغاز أول أكسيد الكربون ، بينما تعتبر وحدات استرجاع الكبريت وتوربينات الغاز هما المصدران الرئيسيان لغاز ثاني أكسيد الكبريت المنبعث، وفي الوقت ذاته فإن زيادة كفاءة وحدات استرجاع الكبريت إلى ٩٧,٥٪ تؤدي إلى تخفيض تركيز غاز ثاني أكسيد الكبريت بنسبة ٣٠٪ كما أن إضافة ضواغط هوائية لاسترجاع بخار الغاز الطبيعي المسيل يؤدي كذلك إلى تقليل جذري في تركيز مركبات النيتروجين المؤكسدة ، وغاز أول أكسيد الكربون وكذلك الجزيئات المتطايرة.

ملخص الرسالة

تشهد صناعة الغاز في دولة الإمارات العربية المتحدة نمواً مطرداً يتناسب مع الطلب المتزايد لإنتاج الطاقة وكذلك مع الاستخدام الأمثل للغاز المصاحب للبترول الخام . وتستلزم المشاكل البيئية المصاحبة لاستخدام الغاز استنباط تقنية تؤدي إلى التحكم المناسب في الإنبعاثات الناتجة ، حيث أن بعض هذه الانبعاثات ضرورية لأسباب تتعلق بالصحة والأمان.

وتقدم الدراسة الحالية إطاراً لتقليل الإنبعاثات الناتجة من المرافق الصناعية التابعة لشركة أبو ظبي لتسييل الغاز المحدودة (أدجاز) بجزيرة داس والتي تمثل نموذجاً لشركات الغاز في المنطقة وذلك من خلال دراسة تأثير عمل تعديلات على وحدات العمليات التي تدخل في صناعة الغاز.

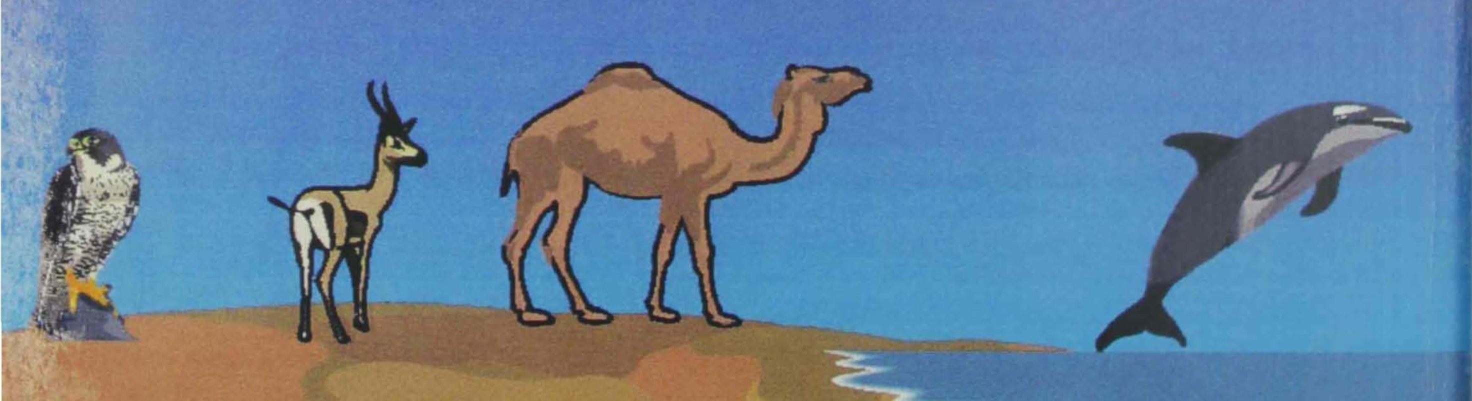
و من خلال هذه الدراسة تم تحديد كمية الغازات المنبعثة في الوقت الحالي من مصنع تسييل الغاز التابع لشركة أدجاز وكذلك تحديد التركيز الأرضي لأربعة ملوثات ناتجة عن الغازات المنبعثة وهي ثاني أكسيد الكبريت ومؤكسدات النيتروجين وأول أكسيد الكربون، والجزيئات المتطايرة . وقد استخدم نموذج تمثيل عددي لحساب تركيز الملوثات السابق ذكرها في الظروف الحالية وكذلك تم حساب التركيز بعد عمل تعديلات مقترحة لتقليل التركيز الأرضي للملوثات التي يزيد تركيزها حالياً عن الحد المسموح به.

وفي هذه الدراسة تم اعتبار وسيلتين لتقليل التركيز الأرضي : أولا : تقليل كميات الغاز المرسلة إلى المحارق عن طريق إضافة ضواغط هوائية لاسترجاع أية غازات زائدة، ثانياً: رفع كفاءة وحدات استرجاع الكبريت.

وخلاصة هذه الدراسة أن معدل انبعاث الغازات في ظل الظروف الحالية الطبيعية والطارئة من المرافق الصناعية التابعة للشركة يتجاوز الحدود التي وضعتها شركة أدنوك .

بسم الله الرحمن الرحيم

شكر و تقدير على جميع من ساهم في أنجاح
رسالة الماجستير في مجال علوم البيئة ، وهذا يدل
على الجهود التي بذلت لرفع مستوى الحياة
الراقية في دولة الإمارات تحت توجيهات
صاحب سمو رئيس الدولة الشيخ زايد بن
سلطان آل نهيان رجل اليئة



إدارة الانبعاثات في شركة أبوظبي لتسييل الغاز

رسالة مقدمة إيفاءً جزئياً لدرجة الماجستير في علوم البيئة

عبد العزيز علي راشد النعيمي

كلية العلوم

جامعة الإمارات العربية المتحدة

(يونيو ١٩٩٩)