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A VOC emissions survey at the SCANRAFF Refinery, Lysekil.

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1 Executive summary

1. In 1992 and again in 1995 SCANRAFF commissioned Spectrasyne Ltd to perform comprehensive VOC emission surveys of the refinery. The surveys were undertaken in co-operation with Lansstyrelsen the area environmental authority who had developed a policy requiring regular monitoring of VOC emissions applicable to large oil industry sites. The third in the series of surveys at SCANRAFF was due in 1999 and again Spectrasyne Ltd were selected to perform the survey using their Differential Absorption LIDAR (DIAL) system.

2. The survey was intended to provide information comparable with the earlier surveys and to this effect the site was similar areas for measurement as previously. Twenty refinery areas were addressed and each of these was visited by the DIAL on at least two occasions.

3. The speciated sorption tube concentrations reveal that there is evidence of significant levels of unsaturated species in the emissions. This along with the presence of ethylene and other unsaturated species may suggest the existence of methane in the emissions from the site.

4. The measured total refinery VOC (HC + toluene) amounted to 554 kg/h compared with a figure of 366 kg/h recorded during the 1995 DIAL survey of the refinery. This represents an increase of 51% on the 1995 total. However, 100 kg/h (27% increase on 1995 figure) came solely from Tank 1406 which is now used as a day tank and appears to have a sealing problem.

5. In addition to the increased emissions from Tank 1406 the other two crude oil tanks (1401 and 1402) in the South Tankage also showed increased emissions over the 1995 figures, suggesting a deterioration in the seals. However, because of the shorter survey duration in 1999 and the extended crude oil tank study in 1995 there were large differences between the two surveys in the quantity of data collected on the crude oil tanks.

6. The other refinery area to record significantly increased emissions over the 1995 survey was the Main Tankage where a total recorded VOC emission of 224 kg/h compared with 160 kg/h in 1995 represented a 40% increase. The Gasoline Component Tanks and the 5600 Tanks were the main contributors to the increased emissions but reductions in the emissions from the Middle Distillates (5200), the Gasoline and the Jet Tanks partially compensated for the increases.

7. The other two refinery areas, Process plant and Effluent Water Treatment gave slightly improved emission figures compared with those recorded in 1995. In the Effluent Treatment Plant an improvement in the API section as a result of the covers seemed to be at the expense of increased emissions from the Flocculation Plant but differences in operator activity may have had a bearing on the differences.

2 Introduction

2.1 Background

In 1992 and again in 1995 Spectrasyne Ltd were commissioned by SCANRAFF refinery to undertake a VOC emission survey of the refinery. These surveys were carried out under the auspices of Lansstyrelsen, the environmental authority responsible for the area. Lansstyrelsen had developed a policy requiring regular monitoring of VOC emissions at major oil installations. This came about as a result of Differential Absorption LIDAR (DIAL) surveys undertaken at the PREEM (formerly BP and subsequently OK Petroleum) Refinery in Gothenburg which clearly demonstrated the environmental and economic benefits to be gained from an accurate knowledge of the quantities and sources of VOC emissions on the site.

The first survey at SCANRAFF in 1992 identified a number of key areas in the refinery where investment could be focused to maximise environmental and loss control benefits. As a result of these investments VOC emission levels in 1995 improved by over 50% on the 1992 emissions.

The third in the series of DIAL VOC surveys at SCANRAFF was due in 1998 but a one year deferment was agreed with Lannstyrelsen so that the survey could be done at the same time as surveys at the other major oil installations in the Gothenburg region which had in turn sought deferment to provide time for remediation work. The two earlier surveys at SCANRAFF had occupied a duration of three and a half weeks and had involved three separate measurement visits to each of 20 designated refinery areas, but the 1995 survey also included a detailed study of the crude oil tanks over a large part of the filling and emptying cycle. The refinery specified a reduced duration of approximately two weeks for the 1999 survey, each of the 20 areas to be visited on two separate occasions.

The survey took place between 23rd August and 3rd September 1999 and the refinery areas visited and number of measurement visits made to each area are shown in the following table.

Operational Area	Sub-Area	No. of measurement visits
Process	FCCU / Polymerisation/ Merox Distillation / Utilities Platfomer / Visbreaker / Hydrogen Unit Synsat	2 2 2 2
Main tankage	Gasoline tanks Jet tanks Gasoline component tanks Heavy residue / Gas Oil, 5100 tanks Middle distillate 5200 tanks Vacuum gas oil & gas oil 5600 tanks	3* 2 3* 2 2 2

Operational Area	Sub-Area	No. of measurement visits
Water treatment	API	3
	Flocculation	3
	Bio plant	3
	Sludge thickening	3
	Ballast tanks	2*
South tankage	Crude oil tanks 1401 and 1402	3*
	Crude oil tank 1406	3*
	Slops tanks	3*
	Naphtha tanks	2
	Spheres	2

Historical spectral and sorption tube data from many refineries have shown refinery non-methane, non-aromatic, hydrocarbon (NMNAHC) fugitive emissions to be a cocktail of mainly alkane species with a mean carbon number of ~4.5. In recent years, as the technology for assessing the make up of this hydrocarbon cocktail has progressed, it has become apparent that the cocktail emitted from some areas of refineries has a mean carbon number which is rather greater than 4.5. Over the last 3 years Spectrasyne has made detailed assessment of the cocktails emitted a standard part of a Spectrasyne DIAL survey. Details of the methods used to achieve these assessments are given in the Section 2 and Appendix B of this report.

During the survey measurements of these non aromatic refinery cocktail hydrocarbons were complimented by simultaneous toluene measurements. Toluene is normally the most abundant aromatic in refinery fugitive emissions and is, therefore, a good indicator for total aromatics. Throughout this report the non aromatic hydrocarbon cocktails have been referred to as HC and the HCs have been quoted with a mean carbon number of ~4.5 to allow direct comparison with previous survey results. However, time weighted mean HC (TWM) data have also been given corrected to the 1999 Spectrasyne standard which is considered to be more representative of the “true” cocktails emitted from the site. The 1999 standard HC cocktail is described as a mixture of non-methane, non-ethylene, non-cyclic, non-aromatic hydrocarbons.

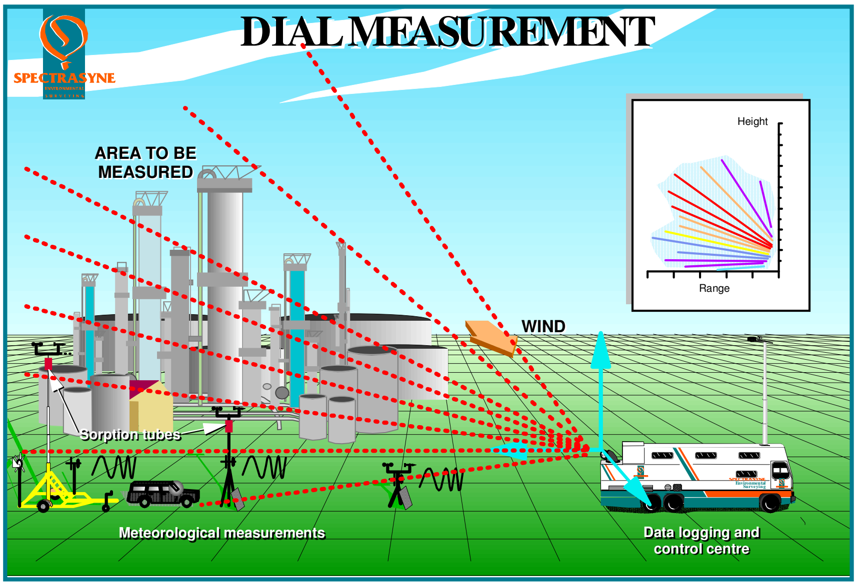
3 Survey Programme

The 1999 survey was intended to provide emission data which were comparable with the earlier surveys. To this end the survey programme essentially followed those of previous surveys. DIAL measurement of a mass emission of VOC relies upon the wind borne transfer of the hydrocarbon emission through a vertical plane downwind of the target area. Measurements of specific areas of a refinery or other site depend not only upon wind flow but, for simplicity, rely upon wind directions which provide substantially uncontaminated upwind regions. For this reason, the choice of area for measurement, on a daily basis, is chosen according to the wind direction prevailing and forecast at the start of the day. The most appropriate area for that wind direction can then be selected, thus largely obviating the need for extensive upwind measurement and subtraction. In the case of a survey lasting two weeks or more, it has been found that day to day wind direction variations usually allow most areas to be addressed in the most favourable wind regime. In some cases, of course, even the most favourable wind direction requires some account of upwind source The need to make upwind subtractions necessarily increases the measurement uncertainties but this can be limited by addressing these areas when the upwind sources are minimised by the wind direction. Fortunately, the Scanraff site has very few areas which are severely upwind constrained and for those that are, opportunities occurred to allow at least some of the measurements to be made with the best wind direction conditions.

3.1 DIAL measurements.

The measurement protocols adopted for the DIAL measurements comprised locating the DIAL truck in a position, optimally about 50 metres from the closest area to be measured and approximately orthogonal to the wind direction. The laser beams were then directed along a plane downwind of the target areas and scanned upwards to encompass completely the emission plume from the target area. Information relating to the measured gas concentrations throughout the plume and the plume area was combined with wind speed and direction information, relayed from meteorological stations on the scan plane, to give a mass emission figure for the scan. The meteorological measurements made on the scan plane are achieved through the deployment of portable met stations which operate at 6 or 8 metres height and a trailer mounted mast which extends up to 21.3 metres. These masts were also used on occasions to carry the sorption tube samplers, which otherwise were mounted on separate extendible tripods (see figure below). The DIAL truck itself is equipped with a telescopic met mast which normally operates at a height of 14.5m and measures the free air wind speed. It is the measurements made on the truck mast that are quoted in the data tables.

The uncertainties associated with the measurement of mass emissions using the Spectrasyne DIAL system have been quantified as -18% to +5%. The methods used to validate the DIAL system are discussed in Appendix A. When measurements are made downwind of structurally complex areas wind shadows can be created within the areas which are periodically purged as the wind speed and/or direction changes. Scan to scan variations in emission can



therefore occur as a result of hold-up or purging processes within the target areas. Overlaid upon this, of course, are any real changes in the source emission rates due to operational influences or direct wind effects. The measurements of benzene emissions may on occasions be subject to greater scan to scan variations simply because the emission figures are much smaller than the HC emissions and closer to the detection limit. Because of the natural variations which occur from scan to scan, time weighted mean (TWM) figures are calculated for each series of measurements which provide a better perspective on the emissions from a particular area than individual scan results.

To address the question of the mean molecular weight/speciation of the HC cocktails (for the 1999 standard) and to give some further aromatic characterisation, pumped sorption tubes analyses were made. Sorbant tubes with packing materials of Carbosieve and Tenax in series, were used to ensure capture of all gaseous hydrocarbon species from C2 to C15 (see Appendix B). All species up to C22 are actually determined, but the current thinking seems to be that most species caught on sorption tubes with carbon numbers of C16 or heavier, have been derived from atmospheric aerosol. They may be “force” evaporated from the silica glass filter put on the front end of the tube set to prevent entrainment of dust and aerosol. These are, therefore, not included in the mean gaseous carbon number determinations. As mentioned above, in order to ensure a direct relationship between the sorption tube concentration/speciation data and the DIAL mass emission measurements the samplers were placed on the meteorological masts or on tripods, which were located immediately adjacent to the DIAL measurement plane. Using the DIAL toluene mass emission measurements along with the sorption tube toluene:benzene ratio and ethylene, the mass emissions of these two species have been estimated and are given in the summary table.

The speciated sorption tube data sets from each individual area have also been given in Table 15. Although this data is useful to provide information on the relative abundance of various species at the sample positions the concentrations themselves are not very meaningful, except when taken together with the DIAL data to generate a inferred mass emission.

Since the 1995 VOC survey the only environmentally significant changes reported by the refinery concerned the effluent water treatment area where a second ballast tank had been equipped with an internal floating deck and the API separator had been substantially covered. No abnormal operational conditions were reported during the survey period.

4 Discussion

In the discussion the remarks will be addressed to the Time Weighted Mean (TWM) figures for each series of measurements except where individual measurements warrant comment. In general the comments will refer to both HC and toluene emissions although in a few instances for simplicity HC emissions only have been referred to, in these cases the remarks are also generally applicable to the toluene emissions

4.1 Process Area (Table 11)

The process area is densely constructed with only limited space between the blocks, making separate measurement particularly difficult. The separations were achieved by measurement downwind of the whole plant area and through the middle of the plant, by subtraction of two scan range measurements on the middle scan line from the downwind scan line measurements the area was divided into four blocks. The measurement uncertainties applying to the upwind subtracted blocks are likely to be larger than is normal because of the restricted space and consequently complex wind patterns.

As some maintenance activities were planned for parts of the process area towards the end of the scheduled survey period the area was addressed early in the survey programme. The measurements were made in the process area on 25th and 26th August, the former with a south-westerly wind requiring upwind subtraction of parts of the South Tankage and the latter in a south easterly wind which was substantially free of upwind sources. The plant blocks referred to above and separated on both occasions were the Distillation/Utilities, Visbreaker/Reformer/Hydrogen Finger, FCCU and Synsat. During the measurements the process plant was operating normally, with a crude oil throughput of 27000 tonnes/day.

4.1.1 Area 1 - Distillation/Utilities.

On the 25th August the TWM figures recorded for the Distillation/Utilities were 53.8 kg/h for HC and 2.59 kg/h for toluene, whilst on the 26th the TWM emissions were 47.8 and 3.0 kg/h for HC and toluene respectively. Despite having orthogonal wind directions for these two series of measurements with consequent different upwind areas the TWM figures were very similar, furthermore the individual measurement scans for the area were reasonably stable. The overall emission figures for the two measurement series together (means of the TWMs) were 50.8 and 2.5 kg/h for HC and toluene respectively. This compares with figures of 54.8 and 1.6 kg/h recorded on the 1995 survey. The slightly higher toluene ratio for the 1999 survey may be an indication that slightly more of the emission was from liquid rather than gaseous streams. The measurements gave no indications of high concentrations which would be indicative of large sources. It might therefore be concluded that Leak Detection and Remediation (LDAR) programmes in this area have been effective in eliminating large sources and in containing emissions from the area to a level slightly less than the 1995 emissions.

4.1.2 Area 2 - Visbreaker, Platforrner, Hydrogen Finger

The measurements made in this area on 25th August returned TWM figures of 41.0 and 3.65 kg/h for HC and toluene respectively. Those performed on 26th August resulted in TWMs of 45.8 and 2.73 kg/h for HC and toluene. The overall mean emission figures were thus 42.8 kg/h of HC and 3.2 kg/h of toluene. Once again the two data sets providing very similar emission figures. In 1995 the overall emission figures for this block of plant were 34.6 and 3.7 kg/h for HC and toluene. This area thus showed a small increase in emission over that seen in 1995, but once again no high concentration areas were observed, the sources being apparently well distributed and generally small individually.

4.1.3 Area 3 - FCCU / Merox

This part of the process plant is less wind constrained than the other two main blocks thus lending itself more easily to DIAL measurement. The TWM figures recorded for the block on 25th August were 9.0 and 0.39 kg/h for HC and toluene respectively. A more limited series of measurements on 26th August gave TWMs of 9.1 and 0.53 kg/h for HC and toluene. The overall means from those two measurement series of 9.0 kg/h for HC and 0.46 kg/h for toluene represent a significant improvement over the emission figures of 17.7 and 1.9 kg/h recorded in the 1995 measurement survey. The principal difference between the emissions recorded in the two surveys was that emission levels in 1999 were apparently more stable than those observed in 1995 when one series of measurements gave higher emissions and within this series a wider range of emissions were seen, these naturally were reflected in the overall emission figures. It would appear, therefore that these intermittent peaks have been eliminated by plant LDAR activities in the interim although this is not absolutely certain in view of the limited number of measurement visits possible in the survey.

4.1.4 Synsat.

The two series of measurements covering this small section of plant also returned consistent TWMs of 2.4 and 1.2 kg/h for HC and 0.67 and “bdl” kg/h for toluene, giving overall figures of 1.8 and 0.34 kg/h These very low emission figures were in fact higher than the close-to-detection-limit levels recorded in 1995 when the plant was new. As plant ages small leaks inevitably appear which individually may be too small for detection by conventional equipment.

4.1.5 Non DIAL Measurements

The sorption tube data collected downwind of the FCCU, not surprisingly, shows evidence of unsaturated species and other light hydrocarbons with relatively low levels of aromatic species. Somewhat incredibly even the benzene concentration measured downwind of the FCCU, the second lowest measured on the site, is still above the proposed Swedish Air Quality limit of 1.3 to 2.5 ug/m^3. It is, however, below the proposed EU limit of 5 ug/m^3 and well below (some 360 times) the Swedish occupational exposure limit of 1.5 mg/m^3.

Sorption tube data from the other main section of the Process Area, Distillation, Utilities, Platformer, Visbreaker and Hydrogen Plant also shows evidence of unsaturated species, but a smaller proportion of these and of light hydrocarbons. It contained double the benzene concentration for more or less the same total hydrocarbon concentration, but this is still very low, only 8 ug/m^3.

4.1.6 Process Area - Overview

The overall emission budget for the process area amounted to 96.9 kg/h for HC and 6.24 kg/h for toluene. This, compared with the respective emission figures from the 1995 survey of 107 and 7 kg/h represents a combined species improvement of 9%.

Expressed on a throughput basis the combined VOC emission amounts to 0.0092% of the refinery crude oil throughput compared with 0.016% calculated for the previous survey. This emission figure maintains SCANRAFF as having the lowest throughput based process plant emission of any conventional refinery surveyed by Spectrasyne.

4.2 Main Tankage (Table 12)

This consists of six separate tankage areas containing all refinery products except naphtha and gases which are stored in the South Tankage. No major emission control measures were reported for the main tankage area since the previous survey in 1995.

4.2.1 Residue Tanks 5100

This group of eleven fixed roof tanks contain mixed heavy products, mainly atmospheric and vacuum residues, heavy fuel oil and vacuum gasoil. The tanks were visited on 30th August when the area was free from upwind contamination and again on 2nd September when background subtractions were required. On both occasions the tanks were split into two groups of five (north-west) tanks and six (south-east) tanks both containing a mix of products, the blending area was split between the two tankage sections on 30th August but was included with the NW tanks on 2nd September.

For the first visit the total TWM emissions recorded were 29.5 and 2.57 kg/h for HC and toluene respectively. The HC emissions split between the six tanks in the south-easterly part of the area and the five in the north westerly section was 17.4 and 12.1 kg/h respectively. Two tanks recorded significant upward movement in the SE section and one in the NW section which is consistent with the emission balance. A significant portion (about 25%) of the emission was, however, at low elevation, mainly in the blending area region.

On 2nd September the TWM figures for the whole area amounted to 43.1 and 3.62 kg/h for HC and toluene, the HC emission split being 17.7 kg/h for the six SE tanks and 25.4 kg/h for the five NW tanks including the blending area. The recorded upward tank movements for the two areas was similar to the day of the first visit as far as the number of rising level tanks was concerned but the rate of the level increases were considerably greater for this day. On 30th August the combined hourly rising levels during the measurements were 309 mm/h for the SE tanks and 31 mm/h for the NW tanks, whereas on 2nd September the combined level increases were 471 mm/h for the SE tanks and 212 mm/h for the NW tanks. The large difference in emissions from the NW tanks on the two days would be largely accounted for by the much higher rising roof rates but the different location of the blending area emissions in the scan plane would also have contributed. The modest increase in emissions from the SE tanks may be accounted for by the fact that different tanks containing different products were rising and that the emissions from the blending area were lost to this section.

Compared with the 1995 survey the overall TWMs for this tankage area were higher. In 1995 the overall emissions were 15.3 and 1.6 kg/h for HC and toluene compared with 36.3 and 3.10 kg/h in 1999. In 1995 the overall figures were derived from three data sets, one in which the upward tank movements were similar to those recorded on 2nd September 1999 and two when recorded upward tank movements were more similar to those on 30th August 1999. Thus the 1995 data would have been biased towards the lower level increase condition whether or not this was the more typical operation. The apparently increased emission from the blending area might also be a factor in the higher overall emissions seen in 1999.

4.2.2 Middle Distillate Tanks - 5200

This group of eight tanks includes five fixed roof tanks containing gasoils and three external floating roof tanks, two with primary seals, containing kerosene and one with a secondary seal containing environmental diesel. The area was quantified on 24th August and 1st September.

During the first series of measurements the wind speeds were very light and TWMs of 5.1 and 0.01 kg/h were recorded for HC and toluene respectively. With the wind direction prevailing on that day it was not possible to segregate the floating roof tanks from the fixed roof tanks but clearly neither was contributing significant levels of emission. The highest roof level in any of the floating roof tanks was 9.3m, in the double seal tank, with the light wind speeds low emissions from these tanks might be anticipated. As far as the fixed roof tanks are concerned the only upward movement recorded was in Tk 5205 right at the end of the measurement sequence when, in fact higher emission levels of 7 to 9 kg/h were seen. This tank contained heavy gasoil at a temperature of 48°C. With the exception of this short period low emission levels from the fixed roof tanks would also be anticipated.

For the second series of measurements on 1st September the wind speed was only marginally higher at around 2.2 - 3.5 m/s. The wind direction was more conducive to splitting the floating roof and fixed roof tanks, although because of wind direction variations the splits cannot be considered to be definitive. The TWMs derived for the three floating roof tanks were 8.4 and 0.78 kg/h for HC and toluene and for the five fixed roof tanks the respective TWMs were 12.2 and 1.1 kg/h. During these measurements kerosene tank Tk 5201 was standing at top dip, the other two tanks being at 7.2 and 6.1m. Tank 5201 was probably mainly responsible for the increased emissions from these tanks. In the case of the fixed roof tanks, gasoil Tanks 4705 and 5202 were rising throughout the measurements and were the likely causes of the raised emissions from this section of the tanks.

During the 1995 survey this group of tanks was measured in much higher wind speed conditions and thus the floating roof tanks (all with single seals at this time) had a greater impact on the emissions, indeed the range of wind speeds encountered enabled a graph of wind speed versus emissions to be drawn. The wind speeds on the graph ranged from 6 to 12 m/s whereas the highest wind speed encountered in the 1999 measurements was only 3.5 m/s. In view of this the overall emission levels recorded in 1995 at 36.4 and 3.4 kg/h for HC and toluene were considerably higher than the 1999 overall emission figures of 12.9 and 1.02 kg/h. The apparent improvement in VOC emissions of 65% from this area thus needs to be seen in the context of the different meteorological conditions.

4.2.3 Gasoline Component Tanks

This tankage group was visited on three occasions; 24th and 27th August and 1st September. The group consists of four spheres, one of which was out of commission during the survey, and six external floating roof tanks, all fitted with secondary seals. On 24th August and again on 1st September the wind direction was conducive to the separation of the tanks into smaller groups. The first series of measurements on 24th August returned TWMs for the total tank group of 62.9 and 2.6 kg/h for HC and toluene. The scans were split into three sections which changed slightly with wind direction, but were for instance made up of two pairs of floating roof tanks; 4703 and 5303; 4704 and 5302 and finally two floating roof tanks; 4702 and 5308 together with the four spheres (one O/C). These splits indicated that at least one tank in each of the floating roof tank pairings was emitting significant emission levels, the three splits giving roughly equal emissions.

The second measurement visit to these tanks on 27th August gave total TWMs of 73.3 and 3.11 kg/h for HC and toluene, which were slightly higher than the figures from 24th August. Wind speeds were higher on 27th August by about 3 m/s but tank levels were lower by a combined 9m which would to some extent have mitigated the effect of the increased wind speed.

The final series of measurements on 1st September gave total TWM emission levels of 72.2 and 7.01 kg/h, which were consistent with those on 27th August. Wind speeds were similar on this day to the 27th August but floating roof tank levels were fractionally lower. The range splits indicated that on this occasion Tanks 4704 and/or 5302 were contributing more than on 24th August.

Overall the TWM emissions from the gasoline component tanks were 69 and 4.21 kg/h for HC and toluene, this compares an overall figures of 23.6 and 2.1 kg/h for HC and toluene seen in 1995. Unlike most of the other tankage areas the wind speeds prevailing during the 1995 measurements on the Gasoline component tanks were lower than those encountered during the 1999 measurements. This and the fact that combined floating roof tank levels during the 1995 measurements were significantly lower than for the 1999 survey would account for the higher emission levels seen in 1999. Also in 1995 four of the floating roof tanks had only recently been equipped with secondary roof seals which should thus have been in pristine condition.

4.2.4 Gasoline Tanks

Three of the four external floating roof tanks in the group were in commission during the survey, the fourth was undergoing refurbishment. The group was addressed on 24th August, 1st September and again on 2nd September. The measurements made on 24th August resulted in TWMs of 12.0 and 1.04 kg/h of HC and toluene, whilst the measurements on 1st September, also with a tank-aligned wind direction, gave much higher levels of 34.8 and 2.61 kg/h. The wind speed was only marginally higher on the second of these two days and although wind speed was seen in 1995 to be critical to emissions from these tanks, is unlikely to account wholly for the difference. On the second of the two days the tank levels overall were higher by about 5.5m, the main upward change being in Tk 5404 which had risen to 13.3m from 2.3m. The increased levels would have made the tanks somewhat more susceptible to wind speed and this combined with the slightly higher wind speed may explain the difference. It is also possible that Tank 5404 which had risen in level on the second day is in worse condition than Tank 5401 which had fallen in level.

On 2nd September measurements made primarily as upwinds for the Jet tanks gave HC TWM figures of 7.3 kg/h for each of Tanks 5403 and 5404. The measurement downwind of Tk 5401 is considered unreliable because of interference from the kerosene tanks. Wind speeds were significantly higher on this occasion but no information is to hand on the tank conditions.

During the 1995 survey a wide range of wind speed conditions were encountered under broadly equivalent overall tank level conditions. This enabled emissions from these tanks to be plotted against wind speed, showing how important this factor is in determining emissions. In the shorter 1999 survey only a limited range of wind speeds were encountered, almost all at the extreme low speed end of the range. Comparison with this graph is made even more difficult because only three of the four tanks were in commission in 1999. Allowing for this it might be said that the 1999 figures are reasonably in keeping with the 1995 figures. Because of the wide range of wind speed seen in 1995 the overall emissions from 1995 (38.9 and 3.6 kg/h for HC and toluene) appear higher than the overall figures derived for 1999 of 26.1 and 1.83 kg/h.

4.2.5 Jet Tanks

Two of these three internal floating deck tanks contain environmental diesel fuel and the third contains MTBE. MTBE has no differential absorption on the HC measurement wavelengths and thus any emission from this tank would not have been seen in the DIAL measurements. The measurements on these tanks were made on 24th August and 2nd September. Ideally the tanks would be measured with a north or north-easterly wind direction, but unfortunately no opportunity occurred to capture these tanks with such a wind direction. The two measurement visits to this area were with wind directions just north of west facilitating measurement of the tanks in line and just west of south which enabled the tanks to be split but provided the additional complication of significant upwind sources. On 24th August the TWM emissions for the two tanks combined were 12.8 and 1.15 kg/h for HC and toluene respectively whilst the measurements on 2nd September returned combined TWM emissions of 10.0 and 1.18 kg/h. The wind direction on 2nd September enabled the two tanks to be separated giving TWM figures of 2.8 and 0.42 kg/h for HC and toluene emissions from Tk 4405 and 7.2 and 0.76 kg/h for Tk 4406. The major differences between the two measurement days were firstly that on 24th August the wind speed was lower than on 2nd September, but this would have had an opposing effect on the emissions than that observed. Secondly and perhaps more importantly, on 24th August one tank (Tk 4405) was filling and the other running down whilst on 2nd September the level in Tk 4405 dropped slightly (100 mm) whilst Tk 4406 was static. The level in Tk 4405 on 24th August rose from 9.1m by about 380 mm during the measurement period whilst the level in Tk 4406 dropped by 1200 mm. Moving roof levels in internal floating deck tanks would not be expected to influence emissions to the extent that rising levels in fixed roof tanks do but the combination of the displacement of any vapour in the roof space and the evaporation from the wet walls in the falling level tank could explain the differences between the two days. This may indicate damaged seals in these tanks.

The overall mean emissions recorded on the Jet tanks from the two measurement visits were 11.4 and 1.17 kg/h for HC and toluene, this compares with 21.4 and 1.6 kg/h seen in 1995. The high emission levels seen in 1995 were then and still remain unexplained, one possibility is that some contamination by a volatile product had occurred. In any event and despite the tank level movements, which did not occur in 1995, the emission levels from these tanks were significantly better (45%) than in 1995.

4.2.6 Gas Oil Tanks - 5600

Two of these four fixed roof tanks contain vacuum gasoil (Tks 5603 and 5604) and are equipped with nitrogen blanketing and the other two contain gasoil (Tks 5601 and 5602). The whole area was addressed on 26th August and on 2nd and 3rd of September respectively two (Tks 5603 and 5604) and three (Tks 5601, 5602 and 5604) were quantified.

On 26th August the TWMs were 83.3 and 6.03 kg/h for HC and toluene. The wind direction permitted these measurements to segregate Tank 5602 (gasoil) from the other three. These splits gave 28.9 kg/h of HC for Tank 5602 and 54.4 kg/h of HC for the other three tanks, the corresponding toluene figures were 2.18 and 3.85 kg/h. Tank 5602 (gasoil) and 5603 (vacuum gasoil) were both rising in level during the measurements, the other two tanks were running down, it is therefore probable that a large proportion of the combined tank emission measured was derived from Tank 5603.

On the 2nd September the measurements covering Tks 5603 and 5604 gave total HC TWMs of 15.0 and 9.4 kg/h respectively with corresponding toluene figures of 0.99 and 0.71 kg/h. Tank 5604 was rising during these measurements but from bottom dip which may explain why the emissions from this tank were lower than Tk 5603 which was falling but was clearly breathing, possibly because the nitrogen blanketing system was overfilling the tank.

The measurements covering three tanks (5601, 5602 and 5604) on 3rd September showed very much lower emission figures of 3.8 and 0.13 kg/h for HC and toluene from Tanks 5602 (falling level) and 5604 (rising level), whilst Tank 5601 (falling level) recorded TWMs of 2.0 and 0.29 kg/h for HC and toluene. It is perhaps surprising that the emissions were so low from the filling tank (5604) but, like 2nd September, the tank was at very low level. A low level in such a large tank provides a big vapour space buffer and thus significant emissions may not arise until later in the filling cycle. This phenomenon may also be associated with the operation of the nitrogen blanketing system. That Tks 5601 and 5602 should have had low emissions on this day is not surprising as both tanks were recording falling levels (this may not be a typical condition).

The reason for the significant differences in emissions from these tanks between the first and second two measurement days would appear to be associated with the movement differences in the gasoil tanks and the very low liquid levels present in the rising vacuum gasoil tank on the final two days.

Combining the data for the two days on which only parts of the tank group were addressed gives figures for the whole group of 23.2 and 1.63 kg/h for HC and toluene respectively.

The overall emissions deduced from the first measurement visit and the combined second visit to these tanks were 53.2 and 3.83 kg/h for HC and toluene which compares with 1995 survey figures of 11.6 and 0.9 kg/h. The VOC emissions in 1999 were, therefore, higher than in 1995 by some 356%.

4.2.7 Main Tankage Overview

The combined emission figures for the whole of the main tankage area amounted to 209 and 15.2 kg/h for HC and toluene. In 1995 the respective figures recorded for the main tankage were 147 and 13 kg/h. The 1999 survey emission levels thus represent a VOC emission increase of 40% over the previous survey. The rise in emission from the main tankage was due to increased levels in three areas:- gasoline components, gasoils tanks (5600) and the heavy products (5100) tanks, the other three areas showing reduced levels. Wind speeds were an important factor in those areas containing floating roof tanks. Although the emissions from the Gasoline Component Tanks were higher in 1999 due to the higher wind speed conditions being experienced it would appear that these wind speeds were more than compensated for by the lower wind speeds encountered during measurements on the Gasoline tanks and the Middle Distillate tanks.

All of the sorption tube samples taken in this Main Tankage Area (Table 15) show significant levels of alkene and cyclic species. With the gas chromatography set up used to analyse the sorption tubes it is not possible to separate n-butane from its butene relatives. However, pentene-1 can be separated and the levels seen of this specie suggest that the butenes may also be present in significant quantities. These alkene species along with the ethylene probably originate in the cracking process. Even amongst the cyclic compounds more unsaturated than saturated species were seen (e.g. cyclohexane/cyclohexene comparison).

The benzene mass emission levels, calculated from the DIAL measured toluene mass emissions and sorption tube ratios for the tankage show the benzene emission to be about half the toluene emission (Summary Table). The concentrations of benzene measured downwind of each area of tankage (Table 15) are all well below the Swedish occupational 8 hour LEL of 1.5 $mg.m^{-3}$, but are all above the maximum air quality levels proposed for Sweden (1.3 to 2.5 $ug.m^{-3}$). They are also all above the proposed EU environmental limit of 5 $ug.m^{-3}$. It should be noted however that further downwind from the sorption tube measurement point the concentration is likely to be lower because of dispersion. By a similar argument, closer to the tanks it is likely to be higher.

The ethylene mass emission levels, calculated from the DIAL measured toluene mass emissions and sorption tube ratios for the tankage have been given for information.

4.3 South Tankage (Table 13)

The South Tankage area was split for measurement primarily into four sub sections according to the products stored. These sub sections were in some cases further split into individual or smaller groups of tanks.

4.3.1 Spheres

The emissions from the spheres, including associated control and refrigeration equipment were quantified on 23rd August and 2nd September. Although toluene measurements were carried out simultaneously with the HC measurements the levels of toluene were, as expected, below the detection limit of the system.

On 23rd August the wind direction allowed the three spheres to be quantified individually. The measurements giving a total HC emission TWM of 2.2 kg/h comprising 0.9 kg/h from Tk 4708, 0.8 kg/h from Tk 4707 and 0.5 kg/h from Tk 5511. On 2nd September the spheres were measured as a combined group with a HC TWM of 2.9 kg/h. On this second occasion, particularly, it was noticed that at least half of the emission was at low elevation which might suggest that the source for this part was the control/refrigeration equipment rather than the spheres themselves. The overall HC emission from the two series of measurements was 2.6 kg/h which compares with a figure of only 1.0 kg/h observed in the 1995 survey. Although this represents a large percentage increase in emission the figures are so low as to be insignificant in relation to the whole refinery.

4.3.2 Naphtha Tanks

The three tanks in this group all have internal floating decks with free ventilation of the roof spaces. The naphtha tanks were addressed briefly on 25th August and more comprehensively on 28th and 31st August.

On 25th August the TWM emission levels were 11.9 and 1.84 kg/h for HC and toluene. Tank deck levels and movements in internal deck tanks should not play such an important part in determining emissions as they do respectively in external floating roof tanks and fixed roof tanks but some evidence of their effects have been seen previously. During this series of measurements one of the three tanks (5503) was at top dip, the second was at 15.5m (both static) with the other one (Tk 5502) filling from process at a level of about 11m. The temperature in this tank was also rather high at over 30°C. Any or all of these factors could have had an influence on the relatively high emission levels observed.

On 28th August the measurements on the naphtha tanks was complicated by the wind direction which placed the crude oil tanks and slops tanks in the upwind region. Upwind subtractions can, of course, be made but in the case of Tank 5503 the upwind source (Tk 1406) at this time was very large in relation to the emission from Tk 5503 and with natural wind directional variations the upwind subtractions at any given time could not be considered reliable. It was, however, possible to make reliable upwind subtractions for the other two tanks. The TWM emissions from Tanks 5502 and 5504 in combination were 7.5 and 1.34 kg/h for HC and toluene. The tank conditions were very similar to those on 25th August with Tank 5504 at 15.5m and Tank 5502 at 11.5m and rising.

On 31st August the measurements again split Tanks 5503 and Tanks 5502/4. The tank levels and movements in all three tanks were again very similar to the two previous measurement days, the only slight difference being that Tank 5502 was at 12.3m and filling from process. These measurements returned TWMs for Tank 5503 of 6.6 and 0.92 kg/h for HC and toluene whilst the other two tanks combined were responsible for 10.6 and 1.3 kg/h for HC and toluene. The combined emissions for all three tanks were comparable with the levels recorded on 25th August.

The overall TWMs for the naphtha tank measurements were 14.3 kg/h for HC and 1.23 kg/h for toluene, this compares with 6.4 and 0.7 kg/h recorded in

1995. The main differences between the two surveys were that in 1995 the combined tank levels were lower by about 6m and overall the wind speeds were slightly lower. Neither of these marginal differences would be anticipated to have significant influences on the emission levels, although in might be noted that in 1995 the measurements returned two rather different emission levels of 11.3 and 4.6 kg/h HC under different wind speed conditions. It may be therefore that wind speed is a factor in the emission levels which probably indicates some deficiencies in the roof seals, the tanks are now four years older than when the previous survey was carried out, during which time seal deterioration would have continued.

4.3.3 Slops Tanks

One of the four tanks in this group (Tk 1405 previously used for cavern leak water) was out of commission during the survey period and was being ventilated, latterly by a compressor. This of course gave rise to emissions which were ‘abnormal’ and efforts were made to separate this tank from the other three in the measurements. The measurements on the slops tanks were made on 28th and 31st August and on 2nd September.

On 28th August Tk 1405 was open to natural ventilation, measurements covering the group of four tanks returned TWMs of 9.4 and 3.05 kg/h for HC and toluene, the earlier emission levels being lower than the later ones. During these measurements, when the wind speeds were in the region of 3 m/s, the tank containing light slop oil (Tk 1403) was static at low level (2.4m), the fixed roof tank (Tk 1404), containing heavy slop oil, was falling in level and the heavy naphtha tank (Tk 4404), also with an external floating roof, was initially rising and then falling slightly, around a level of 12.6m. In view of these conditions reasonably low emissions might have been anticipated. From this measurement position separation of the ventilating tank was somewhat difficult but a scan in the downwind region of this tank indicated that it was the source of about half of the HC emission and three quarters of the toluene emission at that time. These proportions have been taken off the data from this day in the calculation of the overall emission for the site overview.

Tank operating conditions and wind speeds were very similar on 31st August to those on 28th August, the only significant difference being that Tk 4404 was close to top dip at 13.8m. The emission levels from the three operating tanks gave TWMs of 11.0 and 1.09 kg/h for HC and toluene respectively. Measurements made simultaneously on Tk 1405 gave TWMs of 12.7 and 0.89 kg/h for HC and toluene, this tank was being force ventilated at this time. The higher emission levels observed for the three tanks on 31st August would appear to be mainly due to the higher level in Tk 4404.

The third visit to these tanks on 2nd September gave rather variable emission levels which returned TWMs of 23.1 and 1.85 kg/h of HC and toluene for the three operational tanks. In terms of tank operating conditions Tks 1403 and 1404 were again similar to the previous measurement days whilst Tk 4404 was a little lower at 9m and falling. However, the wind speeds were almost double those on the previous days and this is probably the most important factor in determining emissions from the two floating roof tanks and more especially Tk 4404.

Overall the emission levels from the slops tanks, excluding Tk 1405, were 12.9 and 1.24 kg/h for HC and toluene. In 1995 the overall emission levels for all four tanks in the group were 23.6 and 1.7 kg/h. Direct comparisons between the two surveys are clearly difficult on account of the excluded tank and the fact that in 1995 some measurements were made under higher wind speed conditions. In the intervening period Tk 1403 has been fitted with a secondary seal but this tank was almost empty throughout the 1999 survey and probably would have had little impact on the emissions even without this.

4.3.4 Crude Oil Tanks

4.3.4.1 Tanks 1401 and 1402.

In both of the previous surveys emission levels from these two tanks were seen to be crucially dependent on operating condition and wind speed. The 1995 survey included a detailed study of the tanks over their operating cycles and the overall emission figures benefited from this extended study. For the 1999 survey the tanks were scheduled to be visited on just two occasions, as were the other site areas, in fact measurement data were acquired on three different days. The operating and meteorological conditions experienced during the, necessarily limited, visit periods were therefore uncontrolled and possibly not typical of the conditions which might give rise to average emission levels.

These two tanks were addressed on 23rd and 31st August and again on 1st September. On 23rd August and 1st September it was possible to quantify the emissions from the two tanks separately, but on 31st August the wind direction was so unstable that Tank 1401 could only be quantified in one scan and this at the extreme of the measurement range. Although more data relating to Tank 1402 was acquired on 31st August, on occasions the wind direction made separation of its emission from that of Tank 1406 problematical, it is possible therefore that some cross contamination occurred.

Considering firstly Tank 1401 the TWM emissions recorded on 23rd August were 42 and 2.59 kg/h for HC and toluene whilst on 31st August the single HC emission scan gave a figure of 1.7 kg/h. The measurements made on 1st September provided TWM figures of 11.2 and 0.94 kg/h for HC and toluene. The wind speeds on the first two days were similar at 2.5 to 3.0 m/s whilst on the third day it was more variable, between 2 and 5 m/s. As far as tank conditions were concerned, the tank was at about top dip and static during the measurements on 23rd August and at bottom dip and static on the other two occasions. In view of these tank levels and wind conditions it would have been anticipated that the emissions on 23rd would be higher than the other two days, this would be reinforced by the fact that the vapour pressure of the tank contents was, in fact, higher on 23rd (6.4 psi) than on the other days (6.1 psi). The emission levels were in fact significantly higher on the 23rd August than the other days whilst the higher wind speeds on 1st September probably account for the higher emission level on that day compared with the single measurement on 31st August. In this context it is perhaps interesting to note that the highest emission recorded on 1st September coincided with a sudden drop in the wind speed and a slight swing in direction. Speculatively, this may be associated with the topography in the upwind region of the tank, Tanks 1401 and 1402 are located immediately beneath a rock cliff, the wind flow over this cliff is thus likely to affect the flow over the tanks. With a tank at low level it is possible that hydrocarbon vapour builds up in the tank which is periodically purged when wind speed and direction is conducive to a circulation into the tank.

In 1995 a significant emission was seen from the drainage sump on Tk 1401, at that time this sump was covered with an open grating. In the intervening period this grating has been replaced with checker plate as a result of which no significant low elevation emissions were observed during these measurements.

Tank 1402 gave respective HC and toluene TWM figures of 9.0 and 0.33 kg/h on 23rd August, 59.4 and 1.68 kg/h on 31st August and 6.1 and 0.47 kg/h on 1st September. On the 23rd August the tank was running down to process, the level at the start of the measurements being 11.1m, on 31st August the tank was again running down from 6.4m and on 1st September it was rising from 8.0m. Insofar as content vapour pressure is concerned there also appears to be some correlation with emissions. The highest emissions on 31st August coincided with a crude vapour pressure of 6.7 psi and the lowest emissions on 1st September related to a vapour pressure of 5.7 psi. On 23rd August the crude vapour pressure was 6.4 psi. Whilst vapour pressure is undoubtedly a very important factor in emissions from floating roof tanks it is not so in isolation, other factors also have a bearing. The wind speed and roof level on 31st August would not appear to be particularly conducive to the high emission levels seen on 31st August. It may be recalled that in 1995 during the tank study the emissions from Tank 1402 appeared to increase quite dramatically, to a level similar to that recorded on 31st August, with a falling tank roof about the 5-6m level (similar conditions to 31st August). The reason for this was not apparent at the time, the only operational change recorded at the time was an increase in flow from the tank. The vapour pressure of the crude oil in the tank during this event in the 1995 study was very high at 9.6 psi but this was so throughout the measurement sequence and so could not be the reason for the sudden increase. Increased wind speed was, however, recorded and this no doubt would have contributed but a question remains about whether there is a peculiarity in this tank which becomes evident in the emissions at a roof height of about 5 - 6m or some event which occurs at this level of run down.

4.3.4.2 Tank 1406

This tank had only recently been commissioned during the 1995 survey and was at that time use to store condensate but was not used as a day tank like the two crude oil tank. The operational mode of this tank has now changed and it is used in the same way as the other two tanks i.e. as crude oil supply tanks to process. The measurements covering this tank were made on 23rd and 31st August and 2nd September. On all three occasions the tank was captured it was being filled from the caverns but all at different roof levels. Tank 1406 has almost twice the capacity of the other two crude oil tanks and this fact might be expected to have a bearing on the relative emission levels.

The measurements on the 23rd August gave TWMs of 56.1 and 2.04 kg/h for HC and toluene, the tank level during these measurements began at about 7.3m and rose over the six hour measurement period to 14.5m. Over the measurement sequence there was no clear correlation between the level changes and the emissions. The wind speed was also reasonably constant for these measurements. On 31st August the TWM emission levels were 87.8 and 3.47 kg/h for HC and toluene with a starting tank level of 17.2 m and rising by about 350 mm but throughout most of the measurements on this tank the level was static. The final measurement visit on 2nd September resulted in TWM emissions of 153 and 6.65 kg/h at a starting roof level of 2.8 m and rising by about 1.4 m. The highest emission levels were thus at the lowest roof level, three factors are probably important in this context, the first being that the wind speed was rather higher at this time than during the other measurements with speeds of 5-6 m/s. Secondly filling of this tank had recently just begun when the measurements were in progress, this would cause considerable turbulence in such a large tank at low dip levels, added to which, of course, the mixers would also be in operation. Thirdly the vapour pressure of the crude mix on this day was higher at 7.9 psi compared with 6.1 and 6.7 psi on the other measurement days, indeed all three emission data sets on this tank are very much in line with the crude vapour pressures (see Figure 1).

The measurements made on 31st August in combination with Tk 1402 gave a TWM HC emission of 111 kg/h. If an earlier TWM emission of 1402 alone is subtracted from the combined emission figure then the remaining HC emission from Tk 1406 is still 51.6 kg/h.

Unfortunately Tank 1406 was only captured under rising roof levels, although rising roofs have been implicated from time to time in high emissions it is believed that predominantly it is the roof level rather than the movement which is important. In view of the generally high emission levels seen from this tank the likelihood is that the rim seal is not performing well, probably because of damage, although tank distortion could be a factor. The apparently close relationship between emissions and crude vapour pressure reinforces the point concerning tank sealing.

The SCANRAFF Refinery processes several different source crude oils and condensate, the blended crudes for processing therefore have a range of vapour pressures. A clear indication from the measurements on the crude oil tanks was the relationship between emissions and the vapour pressure of the crude oils. Figure 1 is a plot of emissions from the three crude oil tanks versus crude oil vapour pressure. The reason for the correlation being so marked is that the wind speeds encountered throughout almost all of the measurements were very low and relatively similar. When a wider range of wind speeds are encountered then wind speed itself usually appears to be the predominating factor. The actuality seems to be that emissions from floating roof tanks vary as exponents of wind speed, volatility and rim seal gap thus any one of these may appear to have an overriding influence when the other two are minimised. The indications from the crude oil tanks and in particular Tank 1406, is that seal gaps are reasonably large thus multiplying the effect of volatility and or wind speed.

4.3.5 South Tankage Overview

Taking the south tankage as a whole the overall VOC emission level (excluding Tk 1405) amounted to 189 kg/h. This represents a 294% increase over the 48 kg/h figure recorded in 1995. The deterioration in emissions from the south tankage was due principally to the much higher emission levels recorded for tank 1406. Only the slops tanks (with one tank excluded) recorded improved emission levels over the previous survey. The only remediation activities reported for the South Tankage area was the installation of the double seal on TK 1403 and the sump cover on Tk 1401. Some deterioration in emission performance of the tanks in this area might therefore have been anticipated due simply to degeneration of seals, fittings etc. with time.

The sorption tube speciated data from the South Tanks (Table 15) shows a similar pattern of cyclic and alkene species to the Main Tankage. Surprisingly, there is even a significant alkene presence in the emissions from the Crude Tanks, so possibly the alkene species seen in other areas of the site cannot all be attributed to the cracking process. The amounts of pentene-1 (the alkene “marker”) relative to other species were, however, less in the emission from the Crude tanks than for the other tanks in the area.

The 1406 Crude Tank sorption tube data shows much higher concentrations than the other Crude tank data collected earlier in the survey. The sampler positioning downwind of the tank was similar in both cases although the wind conditions may have been slightly different. It is interesting that these higher concentrations correlate with vapour pressure, which was much higher during the final data set than earlier in the survey. This difference is, of course, also seen and quantified more appropriately in the DIAL mass emission measurements.

The benzene mass emissions are much more similar to the toluene emissions in this area (see Summary Table). This was not the case for the early Crude Tank measurements.

4.4 Effluent Water Treatment and Ballast Tanks (Table 14)

4.4.1 Effluent Water Treatment

Since the last survey visit the API section of the effluent treatment plant has been covered to limit atmospheric emissions. The effluent water treatment area was visited on three occasions during the survey, the visits were made on 27th and 30th August and on 3rd September.

On the first measurement day when the wind speed was mainly between 2.0 and 3.6 m/s the API, Flocculation and Bio plant gave HC TWMs of 9.4, 6.0 and 0.68 kg/h with corresponding toluene emissions of 2.35, 1.46 and 0.24 kg/h. The second series of measurements undertaken with wind speeds of between 4.0 and 5.4 m/s gave HC TWMs of 7.2, 16.3 and 4.6 kg/h with toluene figures of 1.65, 3.97 and 2.21 kg/h. On this second day the emissions from the Flocculation section in particular, but to a lesser extent the other two sections, showed two distinct levels; the earlier measurements on the Flocculation plant were in the region 22 to 25 kg/h of HC whilst later measurements were below 10 kg/h. These two distinct levels were not correlated with wind speed. Whilst the average plant throughput rates for the two days were very similar at about 150 m^3/h the emission changes may have reflected short term changes in rundown rate to the plant or quantity of oil in the water or, perhaps more likely, operator activity on the plant, skimming etc. Previous measurements on effluent treatment plants have shown that atmospheric emissions can be related to such activities. If plants are left unattended for long periods emissions do tend to rise. This may be implicated in the rather large difference in emissions between the two days but the higher wind speeds on the second day may also have contributed, especially in the uncovered Flocculation and Bio sections.

Because of the two rather different emission levels recorded for the plant on the two measurement days a third visit was made in an effort to identify whether one was more typical. On 3rd September the wind speed was similar to that seen on the 27th August at around 2.5 - 3.0 m/s and rain was falling throughout the measurements. The rundown rate to the plant was higher on this day at 176 m^3/h. The HC emissions recorded were 3.6, 7.2 and 2.1 kg/h respectively for the API, Flocculation and Bio plants. No corresponding toluene figures were recorded. Taking the three measurement days together the overall HC measurements for the three sections were 6.7 kg/h for the API, 9.9 kg/h for the Flocculation and 2.46 kg/h for the Bio plants with respective toluene figures of 2.0, 2.72 and 1.23 kg/h.

In 1995 the HC emissions recorded were 14.7, 6.9 and 2.3 kg/h for the API, Flocculation and Bio. Wind speeds for two of the three measurement days in 1995 were higher than those encountered in 1999. It is apparent that the 1999 levels of emission from the API have improved as a result of the plant being covered. Conversely, the Flocculation section had slightly higher emissions overall due to the high levels seen initially on 30th August. The emissions from the Bio plant were substantially similar to those in 1995. There is some suggestion in the figures that the improvements seen in the API might have moved some of the emission further downstream. Even if this is so the overall effect appears to have been positive in that the improvement in the API more than outweighs the observed increases in the other two sections.

The measurements on the Effluent Treatment Plant also included the sludge thickening area. In all cases this was measured with some part (usually the Bio Plant) in the upwind. Because the upwind was large in comparison with the Sludge Thickening Plant this made upwind subtractions problematical. Wind direction and variations prevented reliable upwind subtractions except on the first measurement day. This gave TWMs of 0.3kg/h for HC with a corresponding toluene figure of 0.07 kg/h. These very low emission levels were in keeping with those seen on previous surveys.

In the course of the measurements made from the north-western side of the lagoon it was possible to quantify emissions from areas upwind of the scan lines crossing the south-eastern end of the lagoon. This essentially was the south western half of the primary lagoon and any emission from the ponds which collect storm drain water before feeding it to the primary lagoon. These sources had not been quantified in previous surveys. The TWM HC levels identified to be associated with these areas on the three measurement days were 3.2, 2.9 and 0.28 kg/h, the toluene emissions were more variable from at 0.14 and 1.1 kg/h for the first two measurement days.

The overall emissions from the Effluent Treatment Plant, excluding the lagoon area, amounted to 33.6 and 8.27 kg/h for HC and toluene respectively compared with 37 and 7 kg/h observed in 1995. It should however be stated that previous experience of effluent treatment plant would indicate that the relatively small changes in emission level between the 1995 and 1999 surveys might easily be explained by differences in operator activities on the plant.

4.4.2 Ballast Tanks

Two of the three ballast tanks are fitted with internal floating decks and are used as balance tanks for the water treatment plant. The third tank is a fixed roof tank but this is now rarely used, during the survey period the tank was virtually empty with a level of only 0.7m of water, no movement in this tank was recorded during the measurements. The measurements covering the Ballast Tanks were made on 27th August and 1st September.

On 27th August the HC emission levels recorded for the ballast tanks ranged from 6.9 to 20.8 kg/h, the wind speeds were reasonably stable in the region of 6 m/s. Initially the emissions were at the high end of the range between 16.2 and 20.8 kg/h, these then suddenly reduced to around 7 to 8 kg/h, the final measurement giving 11.1 kg/h. Tank movement data show that during the first hour of measurements the level in Tank 6203 dropped by 46 mm whilst the level in 6304 rose by 54 mm. The tanks were at roughly equivalent levels of around 9 and 10m. It was during the second hour of measurements that the major emission level change occurred and during this hour the tanks were switched. The level change recorded for Tank 6203 was an increase of 246 mm whilst Tank 6304 dropped by 147 mm. During the third hour Tank 6203 rose by a further 283 mm whilst Tank 6304 dropped by 225 mm. It would appear therefore that following the tank switch there was a respite, possibly temporary, in the emissions. The reason for this is not clear, one possibility is that there is simply a delay between the initiation of an upward roof movement and the attainment of stabilised emission levels. It may also be that Tank 6304 (initially rising) has worse condition seals, it was the first tank to be converted. This assumes of course that rising roof levels represent the worst condition for emissions in this type of tank. There is some evidence to support this, but the effect should be much less pronounced than with a fixed roof tank. Another possibility is that Tk 6203 had more and/or lighter oil on the surface at the time. The TWM emissions from this series of measurements were 12.4 and 2.18 kg/h for HC and toluene respectively.

On the second day of measurements the recorded emission levels were much lower than on the first visit. The HC levels recorded ranged from 1.7 to 4.5 kg/h with a TWM of 3.1 kg/h (0.6 kg/h of toluene). During these measurements the tank level movements were much less than on 27th August. Tank 6203 was running down, 25 mm being recorded during the first hour of measurements and 22 mm during the second. Tank 6304 was showing increases in level but only of 8 mm in the first hour and 6 mm in the second hour. The indications are that these very small movements, and particularly the small upward movements in Tank 6304 resulted in lower emissions than those seen on 27th August.

Overall the emissions recorded for the Ballast tanks amounted to 7.8 and 1.39 kg/h for HC and toluene. These compare reasonably well with the 13.0 and 0.7 kg/h recorded during the 1995 visit.

4.4.3 Non DIAL Measurements

Sorption tube measurements downwind of the flocculation area also revealed significant quantities of saturated species. This is not surprising as all areas of the site contribute to the mixture treated on this plant.

The benzene concentrations measured on the sorption tubes, some 10m downwind of the Flocculation system, were quite high, 238 ug/m^3. These were measured approximately 4m above ground on the roadway. Wind speeds were quite low during the sampling period on the 27th August, around 2-3 m/s. Nevertheless, the concentrations close to and above the Flocculation area would be higher and could conceivably be of concern compared with the Swedish occupational health limit of 1.5 mg/m^3 for benzene. Proposed Swedish ambient air limits for benzene of 1.3 to 2.5 ug/m^3 are exceeded 100x or more 10m downwind of the flocculation, it is therefore, possible that levels at the site boundary fences close to the Water Treatment could be of concern.

Benzene concentrations around the Ballast tanks were very much lower than in the Water Treatment Area. Significant amounts of light alkene and other unsaturated species were also seen in the Ballast Tank emission plume.

4.5 Site overview

An overview of the emissions for all the measured areas of the SCANRAFF Refinery site is given in Table 16 which also includes data from the 1995 survey for comparison. Figure 2 shows the relative contributions made by each refinery area to the site total and Figure 3 compares the four main site areas VOC emissions with those from the previous surveys. Overall the VOC emissions from the refinery were 554 kg/h which represented a 51% increase over the 1995 survey emission figure. The main area summary clearly shows that in 1999 emissions from two of the four main areas had marginally improved but that emissions from the other two areas had deteriorated. The 1995 levels were maintained in the Process and Effluent Water Treatment areas where LDAR programmes in the former and emission control measures in the latter had been effective in containing the emission levels. The two tankage areas returned increased emission levels compared with 1995. Only very limited emission control measures had been applied to the tankage areas since the last survey. As seals and fittings on tanks tend to deteriorate with time some increases in emissions might be anticipated over a four year period. On tank in particular was responsible for a large part (100 kg/h) of the site increase, this was the largest crude oil tank, Tk 1406, which was operating on a different duty compared with 1995. The large increased emission, however, suggests that the tank seals are not in good condition.

With regard to comparisons between surveys one caveat should be raised concerning the differences in meteorological and operational conditions existent during the survey. Overall, wind speeds were lower during the 1999 (4.0 m/s) survey than during the 1995 survey (~6.1 m/s), this would have been expected to reduce the emission levels in the 1999 survey although the reduction might have been partially mitigated by the Gasoline Components Tanks area where higher wind speed were experienced compared with the 1995 survey. In one or two areas operational conditions were noted to be more severe but as the refinery was operating at normal capacity such effects might be expected to even out over the whole survey duration, even though this was shorter than in 1995.

The total refinery emission budget expressed as a percentage of the throughput during the survey period amounted to 0.0493%. Even with the increased emissions seen in the 1999 survey this specific emission is still at the lower end of the range of throughput based emissions seen by Spectrasyne at European refineries.

Mass emission levels of both benzene and ethylene are also shown in the overview table; calculated from the sorption tube data. Benzene has been given as it is a genotoxic carcinogen and, therefore of importance in health issues and ethylene has been specifically detailed as recent evidence has shown that it may also be considered to be an indirect carcinogen. As no previous data exists for these species from the Scanraff site, these have been given for information purposes.

The speciated sorption tube concentrations reveal evidence of significant levels of unsaturated species in the emissions, these probably originate from the FCCU although there is also some evidence of unsaturated compounds in the crude oil itself.

5 Conclusions

1. The total refinery VOC (HC + toluene) emission budget amounted to 554 kg/h which is 51% higher than the total VOC emissions recorded in the 1995 survey.

2. The largest single contribution to the increased emission was Tank 1406 which alone was responsible for an additional 100 kg/h to the site total (27% of the total site increase).

3. Of the four main refinery plant areas the Main Tankage was responsible for the largest proportion, accounting for 41% of the total refinery VOC emission whilst the South Tankage accounted for 34%.

4. Compared with the 1995 survey measurements two of the main plant areas; Main and South Tankage, recorded increased emission levels. The principal individual section contributors to the overall increase were the three crude oil tanks in the South Tankage and the Gasoline Component Tanks and 5600 Tanks in the Main Tankage.

5. Differences between the 1995 and 1999 surveys in VOC emissions from some sections of tankage containing floating roof tanks could be largely attributable to differences in meteorological conditions between the two surveys.

6. The other two main refinery areas; Process and Effluent Water Treatment showed slight improvements between the 1995 and 1999 surveys in terms of their total emissions although there was some redistribution of emissions from individual sections.

7. The benzene sorption tube concentrations recorded were all well below the Swedish 8 hour occupational limit, but all were above the proposed Swedish Air Quality limit.

8. As percentages of the refinery throughput at the time of the survey the measured VOC emissions from the Process Area was 0.0092% and from the whole refinery was 0.0493%. These figures compare favourably with the specific emission ranges recorded by Spectrasyne at other European refineries.

6 Tables.

Main Tankage Operational Data

Date & Time	Tank	Level (mm)	Movement (mm)	Temperature (°C)
30/8/99 09:00 - 11:00	5101	6889	+52	81
	5102	10571	0	84
	5103	4798	+506	84
	5104	1373	0	78
	5105	1251	0	45
	5106	10391	+2	75
	5107	10244	+59	61
	5108	11624	-466	82
	5109	9398	0	63
	5110	3724	0	41
	4701	12035	+2	78
2/9/99 09:00 - 11:00	5101	8601	+43	81
	5102	10585	+414	80
	5103	1798	-1	80
	5104	12080	+13	82
	5105	1266	0	45
	5106	10372	+1	72
	5107	16227	+424	58
	5108	18699	-220	80
	5109	9585	+473	60
	5110	17524	-1	67
	4701	16383	-69	81

Table 1. Residue (Heavy) tank movements

Date & Time	Tank	Level (mm)	Movement (mm)	Temperature (°C)
24/8/99 11:00 - 14:00	4705	5825	-39	32
	5201	6350	0	24
	5202	17888	+30	37
	5204	16235	-482	32
	5205	7988	-324	48
	5208	9384	-119	27
	5210	1286	+1	30
	5211	4104	+27	31
1/9/99 11:00 - 14:00	4705	7339	+162	38
	5201	18194	0	27
	5202	14356	+176	39
	5204	10328	0	26
	5205	9500	-2	47
	5208	7224	+108	23
	5210	10927	+2	30
	5211	6098	-39	43

Table 2. Middle distllate / Gasoil tank movements

Date & Time	Tank	Level (mm)	Movement (mm)	Temperature (°C)
24/8/99 15:00 - 16:00	4702	7000	+146	32
	4703	16400	-58	26
	4704	12300	-202	25
	5302	9400	+1	26
	5303	14000	-274	34
	5304	12606	+91	24
	5305	11961	-443	27
	5306	-	-	-
	5307	12168	-339	34
	5308	3731	+3	18
27/8/99 15:00 - 17:00	4702	4700	-763	31
	4703	13900	-189	24
	4704	11600	-1	23
	5302	8000	+1	23
	5303	12000	-768	35
	5304	13357	+138	26
	5305	11365	-415	25
	5306	-	-	-
	5307	12146	-698	34
	5308	10985	+380	24
1/9/99 14:00 - 16:00	4702	7100	+199	31
	4703	11300	+128	32
	4704	4700	+129	25
	5302	4200	-143	19
	5303	14900	+408	34
	5304	13667	+1	22
	5305	13074	+531	26
	5306	165	0	11
	5307	14053	-214	34
	5308	14400	+9	19

Table 3. Gasoline component tank movements

Date & Time	Tank	Level (mm)	Movement (mm)	Temperature (°C)
24/8/99 11:00 - 14:00	5401	7100	0	25
	5403	9700	+35	22
	5404	2300	0	25
1/9/99 11:00 - 14:00	5401	1900	+1	23
	5403	11400	+2	20
	5404	13300	+101	26
2/9/99 13:00 - 15:00	5401	5382	-1	22
	5403	10633	0	20
	5404	13552	-965	25

Table 4. Gasoline tank movements

Date & Time	Tank	Level (mm)	Movement (mm)	Temperature (°C)
24/8/99 11:00 - 14:00	4405	9100	+3834	39
	4406	3500	-1198	37
	4407	4394	-3	20
1/9/99 12:00 - 13:00	4405	13682	+311	40
	4406	9570	0	34
	4407	3964	+1	19
2/9/99 12:00 - 15:00	4405	12989	-109	38
	4406	13220	-3	35
	4407	3963	-1	19

Table 5. Jet tank movements

Date & Time	Tank	Level (mm)	Movement (mm)	Temperature (°C)
26/8/99 10:00 - 13:00	5601	2700	-333	30
	5602	6458	+317	50
	5603	9572	+518	75
	5604	5691	-511	78
2/9/99 09:00 - 12:00	5601	2800	-143	32
	5602	6400	+355	43
	5603	10600	-676	68
	5604	1300	+638	80
3/9/99 09:00 - 10:00	5601	1709	-48	48
	5602	8056	-149	42
	5603	9969	-1	67
	5604	2610	+204	84

Table 6. Vacuum gasoil tank movements

South Tankage Operational Data

Date & Time	Tank	Level (mm)	Movement (mm)	Temperature (°C)
25/8/99 13:00 - 14:00	5502	10808	+12	30
	5503	18180	+1	18
	5504	15478	0	15
28/8/99 12:00 - 15:00	5502	11502	+46	30
	5503	18172	+3	17
	5504	15473	+1	15
31/8/99 09:00 - 12:00	5502	12327	+48	32
	5503	18171	0	17
	5504	15472	0	15

Table 7. Naphtha tank movements

Date & Time	Tank	Level (mm)	Movement (mm)	Temperature (°C)
28/8/99 09:00 - 12:00	1403	2494	+1	17
	1404	12021	-205	39
	1405	-	-	-
	4404	12662	+24	27
31/8/99 18:00 - 19:00	1403	2499	+2	17
	1404	11192	-3	38
	1405	-	-	-
	4404	13806	-7	27
2/9/99 16:00 - 18:00	1403	2495	±2	17
	1404	12324	-118	39
	1405	-	-	-
	4404	9046	-156	27

Table 8. Slops tank movements

Date & Time	Tank	Level (mm)	Movement (mm)	Temp. (°C)
23/8/99 11:00 - 17:00	1401	18313	+1	24
	1402	11190	-4054	25
	1406	7349	+7284	28
28/8/99 14:00 - 15:00	1401	18382	-1	23
	1402	7413	+1903	24
	1406	14830	-438	26
31/8/99 12:00 - 17:00	1401	2011	+1	21
	1402	6405	-3269	26
	1406	17222	+343	26
1/9/99 16:00 - 18:00	1401	2007	0	20
	1402	8034	+530	24
	1406	8423	-870	26
2/9/99 16:00 - 18:00	1401	18259	0	29
	1402	-	-	-
	1406	2786	+1402	24

Table 9. Crude tank operational data

Ballast Tanks Operational Data

Date & Time	Tank	Level (mm)	Movement (mm)	Temperature (°C)
24/8/99 15:00 - 16:00	6203			
	6204			
	6304			
27/8/99 14:00 - 17:00	6203	9203	+483	42
	6204	699	0	40
	6304	10374	-318	43
1/9/99 14:00 - 16:00	6203	10921	-47	34
	6204	699	0	40
	6304	12705	+14	37

Table 10. Ballast tank movements

	Scan No	Scan time	Mean Wind Speed (m/s)	Mean Wind Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 11. Process area							
Table 11a. Area 1 - Distillation & Utilities							
	6.1 2-3	25-Aug-99 09:56 - 10:12	1.8	206	72.4	C4.5	3.40
	6.2 2-3	25-Aug-99 10:15 - 10:29	2.3	219	73.7	C4.5	3.09
	6.3 2-3	25-Aug-99 10:36 - 10:53	2.0	222	38.6	C4.5	1.75
	6.4 2-3	25-Aug-99 11:01 - 11:19	2.3	195	47.2	C4.5	2.69
	6.5 2-3	25-Aug-99 11:24 - 11:42	2.5	233	49.0	C4.5	2.66
	6.6 2-3	25-Aug-99 11:47 - 12:01	2.1	230	50.3	C4.5	2.42
	6.7 2-3	25-Aug-99 12:07 - 12:22	2.8	242	59.4	C4.5	2.45
	6.8 2-3	25-Aug-99 12:27 - 12:41	2.6	230	43.5	C4.5	2.31
	TWM [1999 basis]				**53.8**	**[117.2]**	**2.59**
	10.1 -1	26-Aug-99 13:51 - 14:11	6.8	155	53.8	C4.5	3.42
	10.2 -1	26-Aug-99 14:19 - 14:36	6.2	158	46.0	C4.5	2.69
	10.3 -1	26-Aug-99 14:41 - 14:59	5.7	152	41.5	C4.5	3.01
	10.4 -1	26-Aug-99 15:04 - 15:20	6.1	155	51.6	C4.5	-
	10.5 -1	26-Aug-99 15:30 - 15:47	5.1	149	45.8	C4.5	2.92
	TWM [1999 basis]				**47.8**	**[99.0]**	**3.02**
Table 11b. Area 2 - Platformer / H2/ Visbreaker							
(Incld Dist. & Utils.)	8.1 2-3	25-Aug-99 14:26 - 14:43	6.5	213	136.4	C4.5	6.10
(Incld Dist. & Utils.)	8.2 2-3	25-Aug-99 14:46 - 15:00	5.8	209	84.1	C4.5	3.64
(Incld Dist. & Utils.)	8.3 2-3	25-Aug-99 15:30 - 15:44	6.5	210	119.1	C4.5	7.41
(Incld Dist. & Utils.)	8.4 2-3	25-Aug-99 15:47 - 16:02	6.0	208	69.4	C4.5	5.54
(Incld Dist. & Utils.)	8.5 2-3	25-Aug-99 16:07 - 16:19	5.4	205	43.1	C4.5	-
(Incld Dist. & Utils.)	8.6 2-3	25-Aug-99 16:25 - 16:41	4.9	204	61.7	C4.5	-
(Dist & Utils subtracted)	**TWM [1999 basis]**				**41.0**	**[89.3]**	**3.65**
	10.1 -2	26-Aug-99 13:51 - 14:11	6.9	155	49.6	C4.5	3.00
	10.2 -2	26-Aug-99 14:19 - 14:36	6.2	159	39.9	C4.5	2.23
	10.3 -2	26-Aug-99 14:41 - 14:59	5.3	151	46.1	C4.5	3.09
	10.4 -2	26-Aug-99 15:04 - 15:20	6.2	155	50.8	C4.5	-
	10.5 -2	26-Aug-99 15:30 - 15:47	5.1	149	42.7	C4.5	2.57
	TWM [1999 basis]				**45.8**	**[99.9]**	**2.73**

	Scan No	Scan time	Mean Wind Speed (m/s)	Mean Wind Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 11c. Area 3 - FCCU							
	6.1 -1	25-Aug-99 09:56 - 10:12	1.9	204	2.5	C4.5	0.93
	6.2 -1	25-Aug-99 10:15 - 10:29	2.3	218	13.3	C4.5	0.26
	6.3 -1	25-Aug-99 10:36 - 10:53	2.0	218	8.1	C4.5	0.26
	6.4 -1	25-Aug-99 11:01 - 11:19	2.4	201	13.8	C4.5	0.23
	6.5 -1	25-Aug-99 11:24 - 11:42	2.5	234	10.7	C4.5	0.25
	6.6 -1	25-Aug-99 11:47 - 12:01	2.3	234	8.3	C4.5	0.47
	6.7 -1	25-Aug-99 12:07 - 12:22	2.7	241	4.2	C4.5	0.17
	6.8 -1	25-Aug-99 12:27 - 12:41	2.4	225	10.5	C4.5	0.58
	TWM [1999 basis]				**9.0**	**[17.7]**	**0.39**
	11.1 -1	26-Aug-99 16:21 - 16:35	7.0	127	9.6	C4.5	0.39
	11.2 -1	26-Aug-99 16:42 - 16:55	6.9	127	8.8	C4.5	-
	11.3 -1	26-Aug-99 17:00 - 17:09	6.0	126	8.6	C4.5	0.75
	11.4 -1	26-Aug-99 17:12 - 17:21	5.9	125	9.0		0.50
	TWM [1999 basis]				**9.1**	**[17.8]**	**0.53**
	Overall TWM				**9.0**		**0.46**
Table 11d. Synsat							
	8.1 -1	25-Aug-99 14:26 - 14:43	6.5	213	2.9	C4.5	0.79
	8.2 -1	25-Aug-99 14:46 - 15:00	5.8	209	2.4	C4.5	0.57
	8.3 -1	25-Aug-99 15:30 - 15:44	6.5	210	2.5	C4.5	0.98
	8.4 -1	25-Aug-99 15:47 - 16:02	6.2	210	3.6	C4.5	0.32
	8.5 -1	25-Aug-99 16:07 - 16:19	5.3	206	2.0	C4.5	-
	8.6 -1	25-Aug-99 16:25 - 16:41	4.9	203	1.2	C4.5	-
	TWM [1999 basis]				**2.4**	**[2.4]**	**0.67**
	11.1 -2	26-Aug-99 16:21 - 16:35	7.1	126	1.0	C4.5	bdl
	11.2 -2	26-Aug-99 16:42 - 16:55	6.9	127	1.4	C4.5	bdl
	11.3 -2	26-Aug-99 17:00 - 17:09	6.1	126	1.3	C4.5	bdl
	TWM [1999 basis]				**1.2**	**[1.2]**	**bdl**
	Overall TWM				**1.8**	**[1.8]**	**0.34**

	Scan No	Scan time		Mean Wind Speed (m/s)	Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 12. Main Tankage								
Table 12a. Heavy Residue tanks (5100)								
Tanks 5101-04,08,09	18.1 -1	30-Aug-99 08:45	- 9:11	4.0	215	12.1	C4.5	1.35
	18.2 -1	30-Aug-99 09:13	- 9:32	4.5	211	16.0	C4.5	-
	18.3 -1	30-Aug-99 09:34	- 9:46	3.7	210	9.6	C4.5	0.75
	18.4 -1	30-Aug-99 09:53	- 10:10	4.6	209	15.6	C4.5	1.42
	18.5 -1	30-Aug-99 10:12	- 10:29	4.7	209	16.2	C4.5	1.41
	18.6 -1	30-Aug-99 10:32	- 10:46	5.0	208	22.6	C4.5	1.84
	18.7 -1	30-Aug-99 10:49	- 11:06	5.7	210	23.6	C4.5	1.71
	18.8 -1	30-Aug-99 11:12	- 11:29	5.0	205	17.1	C4.5	-
	TWM [1999 basis]					**17.4**	**[29.5]**	**1.45**
Tanks 5105-07, 4701, 511(	18.1 -2	30-Aug-99 08:45	- 9:11	4.2	216	16.3	C4.5	1.64
	18.2 -2	30-Aug-99 09:13	- 9:32	4.4	211	9.7	C4.5	-
	18.3 -2	30-Aug-99 09:34	- 9:46	3.7	211	6.8	C4.5	0.53
	18.4 -2	30-Aug-99 09:53	- 10:10	4.6	211	16.4	C4.5	1.69
	18.5 -2	30-Aug-99 10:12	- 10:29	4.7	208	14.9	C4.5	1.43
	18.6 -2	30-Aug-99 10:32	- 10:46	4.8	207	10.9	C4.5	0.62
	18.7 -2	30-Aug-99 10:49	- 11:06	5.7	210	8.5	C4.5	0.34
	18.8 -2	30-Aug-99 11:12	- 11:29	5.0	207	10.3	C4.5	-
	TWM [1999 basis]					**12.1**	**[20.6]**	**1.12**
	Total position 18					**29.5**	**[50.2]**	**2.57**
Tanks 5105-07, 4701, 511(	27.1 -1	2-Sep-99 08:48	- 9:02	5.5	229	27.1	C4.5	2.47
	27.2 -1	2-Sep-99 09:07	- 9:20	5.6	229	30.5	C4.5	1.95
	27.5 -1	2-Sep-99 10:17	- 10:35	5.7	229	22.0	C4.5	1.60
	27.6 -1	2-Sep-99 10:40	- 10:51	6.3	234	22.8	C4.5	3.58
	TWM [1999 basis]					**25.4**	**[43.2]**	**2.28**
Tanks 5101-04,08,09	27.1 -2	2-Sep-99 08:48	- 9:02	5.3	228	21.5	C4.5	1.56
	27.2 -2	2-Sep-99 09:07	- 9:20	5.4	229	23.4	C4.5	1.15
	27.5 -2	2-Sep-99 10:17	- 10:35	5.8	230	11.4	C4.5	1.23
	27.6 -2	2-Sep-99 10:40	- 10:51	6.4	234	16.6	C4.5	1.46
	TWM [1999 basis]					**17.7**	**[30.1]**	**1.34**
	Total position 27					**43.1**	**[73.2]**	**3.62**
	Overall TWM 5100 tanks					**36.3**	**[61.7]**	**3.10**

	Scan No	Scan time	Mean Wind Speed (m/s)	Mean Wind Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 12b. Middle distillate/Gasoil tanks (5200)							
All tanks	4.1 -1	24-Aug-99 11:41 - 11:58	2.4	286	1.9	C4.5	bdl
	4.2 -1	24-Aug-99 12:03 - 12:22	2.4	286	5.5	C4.5	0.04
	4.3 -1	24-Aug-99 12:27 - 12:47	1.9	288	2.8	C4.5	bdl
	4.4 -1	24-Aug-99 12:49 - 13:07	2.4	258	3.7	C4.5	bdl
	4.5 -1	24-Aug-99 13:15 - 13:30	2.0	242	4.6	C4.5	0.14
	4.6 -1	24-Aug-99 13:37 - 13:55	2.7	255	7.0	C4.5	0.44
	4.7 -1	24-Aug-99 13:58 - 14:15	2.7	244	9.0	C4.5	0.27
	4.8 -1	24-Aug-99 14:20 - 14:34	3.3	263	7.2	C4.5	0.55
	TWM [1999 basis]				**5.1**	**[10.4]**	**0.17**
Gas oil tanks	23.1 -2	1-Sep-99 10:57 - 11:10	2.2	238	12.8	C4.5	1.15
	23.2 -2	1-Sep-99 11:13 - 11:24	2.8	267	9.6	C4.5	0.79
	23.3 -2	1-Sep-99 11:30 - 11:46	2.8	247	13.2	C4.5	1.08
	23.5 -2	1-Sep-99 12:42 - 13:03	2.8	236	12.4	C4.5	1.52
	23.7 -2	1-Sep-99 13:48 - 13:59	3.5	236	11.9	C4.5	0.59
	TWM [1999 basis]				**12.2**	**[24.8]**	**1.10**
Kerosine tanks	23.1 -1	1-Sep-99 10:57 - 11:10	2.2	244	10.2	C4.5	0.95
	23.2 -1	1-Sep-99 11:13 - 11:24	2.8	265	7.7	C4.5	1.00
	23.3 -1	1-Sep-99 11:30 - 11:46	2.9	250	9.7	C4.5	0.86
	23.5 -1	1-Sep-99 12:42 - 13:03	3.0	236	9.7	C4.5	0.70
	23.7 -1	1-Sep-99 13:48 - 13:59	3.5	236	3.0	C4.5	0.40
	TWM [1999 basis]				**8.4**	**[17.2]**	**0.78**
	Overall TWM 5200 tanks				**12.9**	**[26.2]**	**1.02**

	Scan No	Scan time	Mean Wind Speed (m/s)	Mean Wind Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 12c. Gasoline component tanks							
Tanks 4703, 5303	5.1 -1	24-Aug-99 15:05 - 15:19	2.7	267	19.8	C4.5	-
	5.2 -1	24-Aug-99 15:23 - 15:35	3.8	266	11.7	C4.5	0.45
	5.3 -1	24-Aug-99 15:40 - 15:55	3.6	277	11.2	C4.5	0.64
	5.4 -1	24-Aug-99 16:02 - 16:17	3.7	283	13.0	C4.5	0.76
	5.5 -1	24-Aug-99 16:30 - 16:41	3.2	287	13.0	C4.5	1.16
	5.6 -1	24-Aug-99 16:45 - 16:56	3.1	283	12.1	C4.5	1.34
	5.7 -1	24-Aug-99 17:01 - 17:12	3.0	291	12.8	C4.5	1.25
	TWM [1999 basis]				**13.4**	**[25.7]**	**0.91**
Tanks 4704, 5302	5.1 -2	24-Aug-99 15:05 - 15:19	2.7	266	8.2	C4.5	0.36
	5.2 -2	24-Aug-99 15:23 - 15:35	3.8	265	11.6	C4.5	0.45
	5.3 -2	24-Aug-99 15:40 - 15:55	3.6	278	10.7	C4.5	0.50
	5.4 -2	24-Aug-99 16:02 - 16:17	3.7	283	21.6	C4.5	0.73
	TWM [1999 basis]				**13.3**	**[25.4]**	**0.52**
Tank 5302	5.5 -2	24-Aug-99 16:30 - 16:41	3.2	287	12.7	C4.5	0.43
	5.6 -2	24-Aug-99 16:45 - 16:56	3.1	284	7.7	C4.5	0.55
	5.7 -2	24-Aug-99 17:01 - 17:12	3.1	291	12.2	C4.5	0.69
	TWM [1999 basis]				**10.8**	**[20.7]**	**0.56**
Tanks 4702, 5304-08	5.1 -3	24-Aug-99 15:05 - 15:19	2.6	267	21.6	C4.5	0.61
	5.2 -3	24-Aug-99 15:23 - 15:35	3.8	265	42.1	C4.5	0.95
	5.3 -3	24-Aug-99 15:40 - 15:55	3.7	279	49.7	C4.5	-
	5.4 -3	24-Aug-99 16:02 - 16:17	3.7	283	27.0	C4.5	1.61
	TWM [1999 basis]				**34.8**	**[66.5]**	**1.08**
Tanks 4702/04, 5304-08	5.5 -3	24-Aug-99 16:30 - 16:41	3.0	285	-	C4.5	-
	5.6 -3	24-Aug-99 16:45 - 16:56	3.1	285	52.4	C4.5	1.49
	5.7 -3	24-Aug-99 17:01 - 17:12	3.2	291	27.4	C4.5	0.95
	TWM [1999 basis]				**39.9**	**[76.3]**	**1.22**
	Overall TWM position 5				**62.9**	**[120.1]**	**2.60**
All tanks	15.1 -2	27-Aug-99 15:29 - 15:43	5.4	255	78.4	C4.5	3.91
	15.2 -2	27-Aug-99 15:45 - 16:00	6.6	251	75.4	C4.5	3.55
	15.3 -2	27-Aug-99 16:02 - 16:18	6.9	257	77.1	C4.5	-
	15.5 -2	27-Aug-99 16:37 - 16:53	6.4	255	79.8	C4.5	3.03
	15.6 -2	27-Aug-99 16:55 - 17:09	6.6	251	54.4	C4.5	1.89
	TWM [1999 basis]				**73.3**	**[140.1]**	**3.11**
Tanks 4702, 5304-08	24.1 -2	1-Sep-99 14:20 - 14:39	5.4	255	27.9	C4.5	3.30
	24.2 -2	1-Sep-99 14:43 - 14:58	5.6	249	28.6	C4.5	3.15
	24.3 -2	1-Sep-99 15:00 - 15:16	6.0	249	26.0	C4.5	2.81
	24.5 -2	1-Sep-99 15:36 - 15:49	5.6	255	19.4	C4.5	2.49
	TWM [1999 basis]				**25.8**	**[49.2]**	**2.97**
Tanks 4704, 5302	24.1 -3	1-Sep-99 14:20 - 14:39	5.5	256	29.2	C4.5	-
	24.2 -3	1-Sep-99 14:43 - 14:58	5.6	249	24.6	C4.5	-
	24.3 -3	1-Sep-99 15:00 - 15:16	6.0	249	17.9	C4.5	-
	24.5 -3	1-Sep-99 15:36 - 15:49	5.6	255	25.8	C4.5	2.10
	TWM [1999 basis]				**24.6**	**[46.9]**	**2.10**
Tanks 4703, 5303	24.1 -4	1-Sep-99 14:20 - 14:39	5.6	257	28.2	C4.5	2.15
	24.2 -4	1-Sep-99 14:43 - 14:58	5.5	248	15.2	C4.5	1.65
	24.3 -4	1-Sep-99 15:00 - 15:16	6.0	249	25.6	C4.5	2.25
	24.5 -4	1-Sep-99 15:36 - 15:49	6.0	254	15.7	C4.5	1.62
	TWM [1999 basis]				**21.8**	**[41.6]**	**1.94**
	Overall TWM Gasoline Comp. Tanks				**69.0**	**[131.8]**	**4.21**

	Scan No	Scan time	Mean Wind Speed (m/s)	Mean Wind Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 12d. Gasoline tanks							
All tanks	4.1 -2	24-Aug-99 11:41 - 11:58	2.3	285	13.7	C4.5	1.02
	4.2 -2	24-Aug-99 12:03 - 12:22	2.4	287	18.6	C4.5	0.95
	4.3 -2	24-Aug-99 12:27 - 12:47	1.9	288	13.0	C4.5	1.12
	4.4 -2	24-Aug-99 12:49 - 13:07	2.3	260	11.0	C4.5	0.74
	4.5 -2	24-Aug-99 13:15 - 13:30	1.9	243	9.9	C4.5	1.64
	4.6 -2	24-Aug-99 13:37 - 13:55	2.8	257	9.9	C4.5	-
	4.7 -2	24-Aug-99 13:58 - 14:15	2.8	242	9.2	C4.5	0.96
	4.8 -2	24-Aug-99 14:20 - 14:34	3.2	264	9.0	C4.5	0.90
	TWM [1999 basis]				**12.0 [21.5]**		**1.04**
	23.1 -3	1-Sep-99 10:57 - 11:09	2.1	237	-	C4.5	2.36
	23.3 -3	1-Sep-99 11:30 - 11:46	2.7	244	-	C4.5	3.17
	23.5 -3	1-Sep-99 12:42 - 13:03	2.8	233	33.4	C4.5	2.68
	23.7 -3	1-Sep-99 13:48 - 13:59	3.6	235	37.3	C4.5	1.97
	TWM [1999 basis]				**34.8 [62.6]**		**2.61**
Tank 5401	28.4 -5	2-Sep-99 13:34 - 13:48	5.2	208	16.5	C4.5	-
	28.5 -5	2-Sep-99 13:50 - 14:08	5.0	217	18.3	C4.5	-
	28.8 -5	2-Sep-99 14:50 - 14:58	4.8	196	14.9	C4.5	1.00
	TWM [1999 basis]				**17.0 [30.6]**		**1.00**
Tank 5403	28.4 -4	2-Sep-99 13:34 - 13:48	5.3	208	6.6	C4.5	-
	28.5 -4	2-Sep-99 13:50 - 14:08	4.9	216	8.7	C4.5	-
	28.8 -4	2-Sep-99 14:50 - 14:58	4.7	199	5.8	C4.5	-
	TWM [1999 basis]				**7.3 [13.2]**		**-**
Tank 5404	28.4 -3	2-Sep-99 13:34 - 13:48	5.2	208	7.7	C4.5	-
	28.5 -3	2-Sep-99 13:50 - 14:08	4.8	215	9.1	C4.5	-
	28.8 -3	2-Sep-99 14:50 - 14:58	4.7	199	2.5	C4.5	0.74
	TWM [1999 basis]				**7.3 [13.1]**		**0.74**
	Overall TWM Gasoline tanks				**26.1 [47.0]**		**1.83**
Table 12e. Jet tanks							
All tanks	4.1 -3	24-Aug-99 11:41 - 11:58	2.3	285	14.6	C4.5	1.31
	4.2 -3	24-Aug-99 12:03 - 12:22	2.4	289	14.6	C4.5	1.35
	4.3 -3	24-Aug-99 12:27 - 12:47	1.9	289	12.5	C4.5	1.06
	4.4 -3	24-Aug-99 12:49 - 13:07	2.2	264	9.8	C4.5	0.90
	TWM [1999 basis]				**12.8 [26.2]**		**1.15**
	23.5 -4	1-Sep-99 12:42 - 13:00	2.5	229	-	C4.5	2.79
Tank 4405	28.1 -1	2-Sep-99 12:36 - 12:51	5.3	220	2.6	C4.5	0.17
	28.2 -1	2-Sep-99 12:54 - 13:09	4.9	201	1.1	C4.5	-
	28.3 -1	2-Sep-99 13:12 - 13:31	5.1	204	2.6	C4.5	0.30
	28.6 -1	2-Sep-99 14:13 - 14:30	5.3	215	3.5	C4.5	0.61
	28.7 -1	2-Sep-99 14:33 - 14:44	5.0	213	5.0	C4.5	0.70
	TWM [1999 basis]				**2.8 [5.7]**		**0.42**
Tank 4406	28.1 -2	2-Sep-99 12:36 - 12:51	5.3	220	10.5	C4.5	1.36
	28.2 -2	2-Sep-99 12:54 - 13:09	5.0	202	11.6	C4.5	-
	28.3 -2	2-Sep-99 13:12 - 13:31	5.2	203	4.0	C4.5	0.41
	28.6 -2	2-Sep-99 14:13 - 14:30	5.3	216	4.4	C4.5	0.57
	28.7 -2	2-Sep-99 14:33 - 14:44	5.0	214	6.8	C4.5	0.90
	TWM [1999 basis]				**7.2 [14.7]**		**0.76**
	Total position 28				**10.0 [20.4]**		**1.19**
	Overall TWM				**11.4 [23.3]**		**1.17**

	Scan No	Scan time	Mean Wind Speed (m/s)	Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 12f. Vacuum gasoil tanks							
Tank 5602	9.3 -1	26-Aug-99 10:17 - 10:24	4.6	104	46.2	C4.5	4.40
	9.3 -1	26-Aug-99 10:17 - 10:24	4.6	104	46.2	C4.5	-
	9.4 -1	26-Aug-99 10:31 - 10:42	3.9	103	24.9	C4.5	2.47
	9.5 -1	26-Aug-99 10:45 - 10:55	5.1	106	15.3	C4.5	1.77
	9.6 -1	26-Aug-99 11:00 - 11:17	5.6	105	28.4	C4.5	-
	9.7 -1	26-Aug-99 11:28 - 11:41	5.3	107	29.8	C4.5	1.92
	9.8 -1	26-Aug-99 11:46 - 11:57	5.9	110	26.6	C4.5	1.77
	9.9 -1	26-Aug-99 12:03 - 12:18	5.9	110	25.2	C4.5	2.02
	9.10 -1	26-Aug-99 12:32 - 12:45	5.8	111	26.7	C4.5	1.67
	TWM [1999 basis]				**28.9**	**[54.0]**	**2.18**
Tanks 5601/03/04	9.3 -2	26-Aug-99 10:17 - 10:24	4.6	104	54.7	C4.5	4.53
	9.3 -2	26-Aug-99 10:17 - 10:24	4.6	104	54.7	C4.5	-
	9.4 -2	26-Aug-99 10:31 - 10:42	3.9	102	48.7	C4.5	3.81
	9.5 -2	26-Aug-99 10:45 - 10:55	5.1	106	66.9	C4.5	6.12
	9.6 -2	26-Aug-99 11:00 - 11:17	5.5	105	52.7	C4.5	-
	9.7 -2	26-Aug-99 11:28 - 11:41	5.3	107	49.4	C4.5	-
	9.8 -2	26-Aug-99 11:46 - 11:57	6.0	110	48.9	C4.5	3.08
	9.9 -2	26-Aug-99 12:03 - 12:18	6.0	110	60.5	C4.5	3.28
	9.10 -2	26-Aug-99 12:32 - 12:45	5.9	111	54.4	C4.5	3.04
	TWM [1999 basis]				**54.4**	**[101.7]**	**3.85**
Tanks 5603/04	9.11 1-2	26-Aug-99 13:03 - 13:13	4.9	110	68.9	C4.5	4.28
Tanks 5601/02	27.7 -3	2-Sep-99 10:56 - 11:07	5.9	232	1.85	C4.5	0.15
	27.8 -3	2-Sep-99 11:13 - 11:24	4.9	218	0.71	C4.5	-
	27.9 -3	2-Sep-99 11:28 - 11:39	5.3	216	0.42	C4.5	-
	TWM [1999 basis]				**1.0**	**[1.9]**	**0.15**
Tank 5603	27.3 -5	2-Sep-99 09:29 - 9:43	5.5	226	11.7	C4.5	-
	27.4 -5	2-Sep-99 09:53 - 10:08	5.6	229	18.5	C4.5	-
	27.7 -5	2-Sep-99 10:56 - 11:07	6.0	230	19.6	C4.5	0.99
	27.8 -5	2-Sep-99 11:13 - 11:24	4.8	215	12.9	C4.5	-
	27.9 -5	2-Sep-99 11:28 - 11:39	5.4	218	12.0	C4.5	-
	TWM [1999 basis]				**15.0**	**[28.1]**	**0.99**
Tank 5604	27.3 -4	2-Sep-99 09:29 - 9:43	5.5	227	11.1	C4.5	-
	27.4 -4	2-Sep-99 09:53 - 10:08	5.9	230	14.0	C4.5	-
	27.7 -4	2-Sep-99 10:56 - 11:07	5.9	231	7.1	C4.5	0.71
	27.8 -4	2-Sep-99 11:13 - 11:24	4.9	216	5.6	C4.5	-
	27.9 -4	2-Sep-99 11:28 - 11:39	5.6	221	7.8	C4.5	-
	TWM [1999 basis]				**9.4**	**[17.6]**	**0.71**
Tanks 5602/04	31.1 -1	3-Sep-99 09:00 - 9:19	5.6	183	3.6	C4.5	0.15
	31.2 -1	3-Sep-99 09:25 - 9:42	5.6	179	1.9	C4.5	0.20
	31.3 -1	3-Sep-99 09:48 - 10:03	5.9	196	5.0	C4.5	0.03
	31.3 -1	3-Sep-99 09:48 - 10:03	5.9	196	5.0	C4.5	-
	TWM [1999 basis]				**3.8**	**[7.2]**	**0.13**
Tank 5601	31.1 -2	3-Sep-99 09:00 - 9:19	5.8	181	1.7	C4.5	0.11
	31.2 -2	3-Sep-99 09:25 - 9:42	5.6	179	2.4	C4.5	0.21
	31.3 -2	3-Sep-99 09:48 - 10:03	5.8	196	2.0	C4.5	0.60
	31.3 -2	3-Sep-99 09:48 - 10:03	5.8	196	2.0	C4.5	-
	TWM [1999 basis]				**2.0**	**[3.7]**	**0.29**
	Overall TWM positions 27 & 31				**23.2**	**[43.3]**	**1.63**
	Overall TWM Vacuum GO tanks				**53.2**	**[99.5]**	**3.83**

	Scan No	Scan time	Mean Wind Speed (m/s)	Mean Wind Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 13. South Tankage							
Table 13a. Spheres							
Tank 4708	3.5 -1	23-Aug-99 17:24 - 17:35	3.5	263	1.28	as C3	0.02
	3.6 -1	23-Aug-99 17:40 - 17:51	3.1	262	0.62	as C3	-
	3.7 -1	23-Aug-99 18:02 - 18:06	3.4	262	0.39	as C3	-
	TWM [1999 basis]				**0.85 [0.58]**		**0.02**
Tank 4707	3.5 -2	23-Aug-99 17:24 - 17:35	3.6	266	0.33	as C3	0.01
	3.6 -2	23-Aug-99 17:40 - 17:51	3.1	262	1.16	as C3	-
	3.7 -2	23-Aug-99 18:02 - 18:06	3.7	257	1.21	as C3	-
	TWM [1999 basis]				**0.83 [0.56]**		**0.01**
Tank 5511	3.5 -3	23-Aug-99 17:24 - 17:35	3.6	268	0.77	as C3	0.00
	3.6 -3	23-Aug-99 17:40 - 17:51	2.8	261	0.39	as C3	-
	3.7 -3	23-Aug-99 18:02 - 18:06	3.7	260	bdl	as C3	-
	TWM [1999 basis]				**0.49 [0.33]**		**0.00**
Tanks 4707/08	30.4 -2	2-Sep-99 17:30 - 17:40	5.4	205	2.86	as C3	bdl
	30.4 -2	2-Sep-99 17:30 - 17:40	5.4	205	2.86	as C3	bdl
	30.5 -2	2-Sep-99 17:41 - 17:49	5.3	204	3.10	as C3	bdl
	TWM [1999 basis]				**2.93 [1.99]**		**0.01**
Tank 5511	30.4 -1	2-Sep-99 17:30 - 17:40	5.4	205	bdl	as C3	bdl
	30.4 -1	2-Sep-99 17:30 - 17:40	5.4	205	bdl	as C3	bdl
	30.5 -1	2-Sep-99 17:41 - 17:49	5.2	205	bdl	as C3	bdl
	TWM				**bdl**		**bdl**
Table 13b. Naphtha tanks							
All tanks	7.1 -3	25-Aug-99 13:11 - 13:21	2.5	210	12.0	C4.5	1.62
	7.3 -3	25-Aug-99 13:45 - 14:00	3.1	212	11.9	C4.5	2.00
	TWM [1999 basis]				**11.9 [23.2]**		**1.84**
Tanks 5502/04	17.1 -2	28-Aug-99 12:10 - 12:24	3.3	301	-	C4.5	0.97
	17.2 -2	28-Aug-99 12:28 - 12:38	4.6	284	6.4	C4.5	-
	17.3 -2	28-Aug-99 12:58 - 13:06	3.9	279	6.3	C4.5	-
	17.6 -2	28-Aug-99 14:12 - 14:28	3.5	278	8.0	C4.5	1.68
	17.7 -2	28-Aug-99 14:30 - 14:40	3.7	284	8.6	C4.5	1.34
	17.8 -2	28-Aug-99 14:54 - 15:02	3.3	280	7.8	C4.5	1.32
	TWM [1999 basis]				**7.5 [14.6]**		**1.34**
Tanks 5502/04	20.2 -2	31-Aug-99 09:26 - 9:40	2.1	316	12.1	C4.5	1.47
	20.3 -2	31-Aug-99 09:45 - 10:00	2.4	340	10.7	C4.5	1.13
	20.4 -2	31-Aug-99 10:04 - 10:15	2.5	322	9.4	C4.5	1.31
	20.7 -2	31-Aug-99 10:56 - 11:04	2.3	310	9.4	C4.5	1.32
	TWM [1999 basis]				**10.6 [20.6]**		**1.30**
Tank 5503	20.2 -1	31-Aug-99 09:26 - 9:40	2.2	317	7.0	C4.5	1.17
	20.3 -1	31-Aug-99 09:45 - 10:00	2.7	336	6.5	C4.5	-
	20.4 -1	31-Aug-99 10:04 - 10:15	2.6	322	6.3	C4.5	0.90
	20.7 -1	31-Aug-99 10:56 - 11:04	2.2	309	6.6	C4.5	0.55
	TWM [1999 basis]				**6.6 [12.8]**		**0.92**
Tank 5504	20.13 -2	31-Aug-99 13:24 - 13:35	1.6	287	13.3	C4.5	1.76
	Overall TWM Naphtha Tanks				**14.3 [27.9]**		**1.23**

	Scan No	Scan time	Mean Wind Speed (m/s)	Mean Wind Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 13c. Slops tanks							
All tanks	16.1 -1	28-Aug-99 09:09 - 9:24	3.9	289	7.1	C4.5	2.74
	16.2 -1	28-Aug-99 09:29 - 9:43	3.6	290	3.1	C4.5	2.62
	16.3 -1	28-Aug-99 09:46 - 10:00	3.4	299	6.4	C4.5	2.11
	16.5 -1	28-Aug-99 10:23 - 10:37	3.0	298	15.2	C4.5	3.04
	16.7 -1	28-Aug-99 11:04 - 11:17	2.6	295	12.4	C4.5	2.82
	16.8 -1	28-Aug-99 11:20 - 11:34	3.1	315	12.7	C4.5	4.99
	TWM [1999 basis]				**9.4**	**[15.9]**	**3.05**
Tanks 1403/04/05	16.4 -1	28-Aug-99 10:05 - 10:21	3.8	307	27.1	C4.5	5.53
Tank 1405	16.6 -1	28-Aug-99 10:44 - 10:56	2.7	298	7.2	C4.5	2.36
Tanks 1403/04, 4404	22.1 -1	31-Aug-99 17:53 - 18:03	3.8	343	14.5	C4.5	1.91
	22.2 -1	31-Aug-99 18:06 - 18:15	3.7	341	9.7	C4.5	1.04
	22.3 -1	31-Aug-99 18:16 - 18:22	3.7	330	9.3	C4.5	0.58
	22.4 -1	31-Aug-99 18:27 - 18:36	1.7	350	9.7	C4.5	0.57
	TWM [1999 basis]				**11.0**	**[18.8]**	**1.09**
Tank 1405	22.1 -2	31-Aug-99 17:53 - 18:03	3.8	342	13.2	C4.5	1.10
	22.2 -2	31-Aug-99 18:06 - 18:15	3.7	341	12.2	C4.5	0.64
	22.3 -2	31-Aug-99 18:16 - 18:22	3.7	330	11.2	C4.5	0.65
	22.4 -2	31-Aug-99 18:27 - 18:36	1.8	346	13.5	C4.5	1.08
	TWM [1999 basis]				**12.7**	**[21.6]**	**0.89**
Tanks 1403/04, 4404	30.1 -2	2-Sep-99 16:31 - 16:51	6.3	204	28.7	C4.5	1.46
	30.2 -2	2-Sep-99 16:54 - 17:09	5.7	204	10.2	C4.5	0.71
	30.3 -2	2-Sep-99 17:12 - 17:25	5.2	204	29.3	C4.5	3.68
	TWM [1999 basis]				**23.1**	**[39.3]**	**1.85**
	Overall TWM (ex. 1405)				**12.9**	**[22.0]**	**1.24**

	Scan No	Scan time	Mean Wind Speed (m/s)	Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 13d. Crude tanks							
Tank 1406	1.1 -1	23-Aug-99 11:05 - 11:20	3.5	198	62.9	C4.5	1.87
	1.2 -1	23-Aug-99 11:23 - 11:45	3.6	207	69.4	C4.5	2.50
	1.3 -1	23-Aug-99 11:50 - 12:05	3.6	205	66.1	C4.5	2.18
	3.1 -1	23-Aug-99 16:01 - 16:18	3.4	258	41.0	C4.5	2.42
	3.2 -1	23-Aug-99 16:20 - 16:35	3.3	254	45.3	C4.5	1.04
	3.3 -1	23-Aug-99 16:42 - 16:59	3.2	250	40.8	C4.5	2.03
	3.4 -1	23-Aug-99 17:02 - 17:15	3.6	264	66.3	C4.5	2.00
	TWM [1999 basis]				**56.1 [148.2]**		**2.04**
	21.1 -1	31-Aug-99 15:05 - 15:20	2.8	238	74.6	C4.5	-
	21.2 -1	31-Aug-99 15:25 - 15:37	3.3	244	109	C4.5	4.69
	21.3 -1	31-Aug-99 15:39 - 15:49	3.4	257	102	C4.5	4.29
	21.5 -1	31-Aug-99 16:57 - 17:12	1.1	199	74.6	C4.5	1.95
	TWM [1999 basis]				**87.8 [139.6]**		**3.47**
	29.2 -1	2-Sep-99 15:53 - 16:16	4.8	203	156	C4.5	7.86
	30.1 -1	2-Sep-99 16:31 - 16:51	6.1	203	163	C4.5	6.80
	30.2 -1	2-Sep-99 16:54 - 17:09	5.8	204	134	C4.5	4.78
	30.3 -1	2-Sep-99 17:12 - 17:25	5.4	204	153	C4.5	6.54
	TWM [1999 basis]				**153 [174.1]**		**6.65**
Tank 1401	2.1 -2	23-Aug-99 13:03 - 13:18	2.8	236	41.4	C4.5	2.36
	2.2 -2	23-Aug-99 13:26 - 13:45	2.5	251	48.1	C4.5	2.96
	2.3 -2	23-Aug-99 14:01 - 14:19	2.5	256	42.7	C4.5	2.85
	2.4 -2	23-Aug-99 14:24 - 14:35	2.7	251	44.9	C4.5	2.59
	2.5 -2	23-Aug-99 14:50 - 15:07	2.2	255	41.0	C4.5	2.38
	2.6 -2	23-Aug-99 15:22 - 15:41	2.5	245	34.9	C4.5	2.38
	TWM [1999 basis]				**42.0 [85.6]**		**2.59**
	21.3 -3	31-Aug-99 15:39 - 15:49	3.5	254	1.7	C4.5	-
	25.1 -2	1-Sep-99 16:27 - 16:47	5.0	231	8.4	C4.5	0.54
	25.2 -2	1-Sep-99 16:49 - 17:04	5.1	240	5.5	C4.5	0.88
	26.1 -2	1-Sep-99 17:23 - 17:35	2.2	251	26.3	C4.5	1.71
	26.2 -2	1-Sep-99 17:38 - 17:49	3.9	225	9.5	C4.5	-
	26.3 -2	1-Sep-99 17:50 - 18:04	3.5	229	10.5		0.98
	TWM [1999 basis]				**11.2 [22.9]**		**0.94**
Tank 1402	2.1 -1	23-Aug-99 13:03 - 13:18	2.5	241	10.6	C4.5	0.47
	2.2 -1	23-Aug-99 13:26 - 13:45	2.4	250	19.6	C4.5	0.41
	2.3 -1	23-Aug-99 14:01 - 14:19	2.6	254	6.8	C4.5	-
	2.4 -1	23-Aug-99 14:24 - 14:35	2.5	249	7.1	C4.5	0.34
	2.5 -1	23-Aug-99 14:50 - 15:07	2.4	250	4.5	C4.5	0.11
	2.6 -1	23-Aug-99 15:22 - 15:41	2.5	247	4.9	C4.5	0.35
	TWM [1999 basis]				**9.0 [18.4]**		**0.33**
	21.1 -2	31-Aug-99 15:05 - 15:20	2.8	234	57.2	C4.5	1.49
	21.2 -2	31-Aug-99 15:25 - 15:37	3.2	244	46.1	C4.5	2.73
	21.3 -2	31-Aug-99 15:39 - 15:49	3.4	257	77.8	C4.5	0.76
	TWM [1999 basis]				**59.4 [121.2]**		**1.68**
	25.1 -1	1-Sep-99 16:27 - 16:47	4.4	229	6.9	C4.5	0.50
	25.2 -1	1-Sep-99 16:49 - 17:04	5.1	240	4.6	C4.5	0.56
	26.1 -1	1-Sep-99 17:23 - 17:35	2.2	253	6.6	C4.5	0.42
	26.2 -1	1-Sep-99 17:38 - 17:49	3.8	225	5.8	C4.5	0.40
	26.3 -1	1-Sep-99 17:50 - 18:04	3.5	229	6.3	C4.5	0.43
	TWM [1999 basis]				**6.1 [12.4]**		**0.47**
All tanks	17.5 -1	28-Aug-99 13:52 - 14:09	4.2	282	18.3	C4.5	-
Tanks 1402/6	20.11 -1	31-Aug-99 12:27 - 12:47	2.6	275	119	C4.5	7.95
	20.12 -1	31-Aug-99 13:00 - 13:18	2.3	299	101	C4.5	0.60
	TWM [1999 basis]				**111 [225.5]**		**4.40**
Tanks 1401/02/06	20.13 -1	31-Aug-99 13:24 - 13:35	1.7	295	42.3	C4.5	-

Table 14. Water treatment

Table 14a. API, Bio plant

	Scan No	Scan time	Mean Wind Speed (m/s)	Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
API	12.1 -4	27-Aug-99 09:30 - 9:42	2.2	197	7.2	C4.5	1.89
	12.2 -4	27-Aug-99 09:48 - 10:01	2.0	190	11.6	C4.5	2.31
	12.3 -4	27-Aug-99 10:06 - 10:21	1.9	193	8.9	C4.5	2.02
	12.6 -4	27-Aug-99 11:09 - 11:21	2.7	235	11.5	C4.5	2.88
	12.7 -4	27-Aug-99 11:26 - 11:39	2.4	230	11.1	C4.5	2.65
	12.10 -4	27-Aug-99 12:18 - 12:29	2.6	255	9.6	C4.5	2.09
	12.11 -4	27-Aug-99 12:35 - 12:48	3.6	255	9.0	C4.5	2.62
	12.12 -4	27-Aug-99 12:52 - 13:03	2.5	256	8.3	C4.5	2.73
	12.13 -3	27-Aug-99 13:06 - 13:15	3.1	251	6.2	C4.5	1.98
	TWM [1999 basis]				**9.4**	**[9.4]**	**2.35**
	19.1 -4	30-Aug-99 12:16 - 12:31	5.7	178	-	C4.5	1.27
	19.2 -4	30-Aug-99 12:42 - 12:48	4.8	177	7.6	C4.5	1.41
	19.3 -4	30-Aug-99 13:09 - 13:22	4.1	182	10.5	C4.5	2.03
	19.6 -4	30-Aug-99 14:11 - 14:20	5.1	207	6.0	C4.5	1.88
	19.7 -4	30-Aug-99 14:52 - 15:02	4.0	189	6.7	C4.5	1.67
	19.10 -4	30-Aug-99 15:46 - 15:56	4.5	196	4.2	C4.5	-
	TWM [1999 basis]				**7.2**	**[7.2]**	**1.65**
	32.3 -4	3-Sep-99 11:38 - 11:43	2.8	195	4.1	C4.5	-
	32.5 -4	3-Sep-99 12:15 - 12:23	2.4	189	3.6	C4.5	-
	32.6 -4	3-Sep-99 12:40 - 12:46	3.5	188	4.6	C4.5	-
	32.8 -4	3-Sep-99 13:14 - 13:24	2.4	192	2.8	C4.5	-
	TWM [1999 basis]				**3.6**	**[3.6]**	**-**
Bio plant	12.1 -2	27-Aug-99 09:30 - 9:42	2.2	194	1.15	C4.5	0.33
	12.2 -2	27-Aug-99 09:48 - 10:01	2.0	193	0.83	C4.5	0.38
	12.3 -2	27-Aug-99 10:06 - 10:21	1.8	196	0.45	C4.5	0.22
	12.6 -2	27-Aug-99 11:09 - 11:21	2.7	233	0.19	C4.5	0.10
	12.7 -2	27-Aug-99 11:26 - 11:39	2.4	232	0.15	C4.5	0.07
	12.10 -2	27-Aug-99 12:18 - 12:29	2.6	254	0.28	C4.5	0.02
	12.11 -2	27-Aug-99 12:35 - 12:48	3.3	258	0.83	C4.5	0.34
	12.12 -2	27-Aug-99 12:52 - 13:03	3.0	258	0.67	C4.5	0.29
	12.13 -1	27-Aug-99 13:06 - 13:15	2.7	253	1.84	C4.5	0.49
	TWM [1999 basis]				**0.68**	**[0.68]**	**0.24**
	19.1 -2	30-Aug-99 12:16 - 12:31	5.4	179	-	C4.5	3.87
	19.2 -2	30-Aug-99 12:42 - 12:48	5.0	177	3.5	C4.5	1.26
	19.3 -2	30-Aug-99 13:09 - 13:22	4.3	180	7.5	C4.5	2.54
	19.6 -2	30-Aug-99 14:11 - 14:20	5.3	207	5.6	C4.5	1.28
	19.7 -2	30-Aug-99 14:52 - 15:02	4.0	191	3.2	C4.5	0.72
	19.10 -2	30-Aug-99 15:46 - 15:56	4.3	195	2.5	C4.5	-
	TWM [1999 basis]				**4.6**	**[4.6]**	**2.21**
	32.3 -2	3-Sep-99 11:38 - 11:43	3.0	192	1.5	C4.5	-
	32.5 -2	3-Sep-99 12:15 - 12:23	2.7	191	3.2	C4.5	-
	32.6 -2	3-Sep-99 12:40 - 12:46	3.4	189	1.3	C4.5	-
	32.8 -2	3-Sep-99 13:14 - 13:24	2.5	192	2.0	C4.5	-
	TWM [1999 basis]				**2.1**	**[2.1]**	**-**

	Scan No	Scan time	Mean Wind Speed (m/s)	Mean Wind Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 14b. Flocculation, Lagoon, Sludge Thickener							
Flocculation	12.1 -3	27-Aug-99 09:30 - 9:42	2.2	196	3.1	C4.5	1.59
	12.2 -3	27-Aug-99 09:48 - 10:01	1.9	191	5.4	C4.5	1.93
	12.3 -3	27-Aug-99 10:06 - 10:21	1.8	195	5.5	C4.5	1.67
	12.6 -3	27-Aug-99 11:09 - 11:21	2.7	234	7.0	C4.5	1.31
	12.7 -3	27-Aug-99 11:26 - 11:39	2.4	230	7.3	C4.5	1.05
	12.10 -3	27-Aug-99 12:18 - 12:29	2.6	255	7.3	C4.5	1.27
	12.11 -3	27-Aug-99 12:35 - 12:48	3.4	254	7.3	C4.5	1.36
	12.12 -3	27-Aug-99 12:52 - 13:03	3.0	258	5.1	C4.5	1.41
	12.13 -2	27-Aug-99 13:06 - 13:15	2.9	252	6.3	C4.5	-
	TWM [1999 basis]				**6.0 [8.0]**		**1.46**
	19.1 -3	30-Aug-99 12:16 - 12:31	5.5	178	24.0	C4.5	4.57
	19.2 -3	30-Aug-99 12:42 - 12:48	4.9	177	22.1	C4.5	4.67
	19.3 -3	30-Aug-99 13:09 - 13:22	4.3	181	24.9	C4.5	5.34
	19.6 -3	30-Aug-99 14:11 - 14:20	5.2	206	9.3	C4.5	3.04
	19.7 -3	30-Aug-99 14:52 - 15:02	4.0	189	9.9	C4.5	1.60
	19.10 -3	30-Aug-99 15:46 - 15:56	4.3	195	3.1	C4.5	-
	TWM [1999 basis]				**16.3 [21.9]**		**3.97**
	32.3 -3	3-Sep-99 11:38 - 11:43	2.7	195	5.6	C4.5	-
	32.5 -3	3-Sep-99 12:15 - 12:23	2.4	190	7.5	C4.5	-
	32.6 -3	3-Sep-99 12:40 - 12:46	3.4	190	5.0	C4.5	-
	32.8 -3	3-Sep-99 13:14 - 13:24	2.5	192	9.3	C4.5	-
	TWM [1999 basis]				**7.2 [9.7]**		**-**
Lagoon	12.1 -1	27-Aug-99 09:30 - 9:42	2.1	194	3.8	C4.5	0.19
	12.2 -1	27-Aug-99 09:48 - 10:01	2.1	193	3.5	C4.5	0.18
	12.3 -1	27-Aug-99 10:06 - 10:21	1.8	195	3.3	C4.5	0.06
	12.6 -1	27-Aug-99 11:09 - 11:21	2.7	233	2.4	C4.5	0.06
	12.7 -1	27-Aug-99 11:26 - 11:39	2.4	232	2.8	C4.5	0.20
	TWM [1999 basis]				**3.2 [3.2]**		**0.14**
	19.1 -1	30-Aug-99 12:16 - 12:31	5.4	179	3.4	C4.5	0.21
	19.2 -1	30-Aug-99 12:42 - 12:48	5.0	178	4.8	C4.5	0.16
	19.3 -1	30-Aug-99 13:09 - 13:22	4.3	180	4.7	C4.5	2.17
	19.6 -1	30-Aug-99 14:11 - 14:20	5.3	207	2.7	C4.5	1.69
	19.7 -1	30-Aug-99 14:52 - 15:02	4.1	192	0.9	C4.5	-
	19.10 -1	30-Aug-99 15:46 - 15:56	4.3	193	0.8	C4.5	-
	TWM [1999 basis]				**2.9 [2.9]**		**1.10**
	32.3 -1	3-Sep-99 11:38 - 11:43	3.1	192	0.12	C4.5	-
	32.5 -1	3-Sep-99 12:15 - 12:23	2.5	195	0.51	C4.5	-
	32.6 -1	3-Sep-99 12:40 - 12:46	3.4	187	0.19	C4.5	-
	32.8 -1	3-Sep-99 13:14 - 13:24	2.6	192	0.25	C4.5	-
	TWM [1999 basis]				**0.28 [0.3]**		**-**
Sludge thickener	12.4 -1	27-Aug-99 10:32 - 10:46	3.1	212	0.5	C4.5	0.09
	12.5 -1	27-Aug-99 10:53 - 11:06	1.9	209	0.1	C4.5	0.03
	12.8 -1	27-Aug-99 11:46 - 11:56	2.4	259	bdl	C4.5	0.01
	12.9 -1	27-Aug-99 11:59 - 12:15	3.0	256	0.5	C4.5	0.11
	TWM [1999 basis]				**0.3 [0.3]**		**0.07**
Sludge thickener + bio	19.4 -1	30-Aug-99 13:36 - 13:47	6.1	202	13.3	C4.5	2.01
	19.5 -1	30-Aug-99 13:54 - 14:03	7.0	201	2.5	C4.5	0.60
	19.8 -1	30-Aug-99 15:11 - 15:18	5.8	199	6.9	C4.5	1.33
	19.9 -1	30-Aug-99 15:30 - 15:38	5.4	190	1.9	C4.5	0.47
	TWM [1999 basis]				**6.6 [6.6]**		**1.16**
	32.4 -1	3-Sep-99 11:57 - 12:09	3.3	188	2.8	C4.5	-
	32.7 -1	3-Sep-99 12:57 - 13:07	3.0	189	5.9	C4.5	-
	TWM [1999 basis]				**4.2 [4.2]**		**-**

	Scan No	Scan time	Mean Wind Speed (m/s)	Mean Wind Dir'n (deg)	IR Flux (kg/h)	Species	UV Flux (kg/h)
Table 14c. Ballast Tanks							
All tanks	13.1 -1	27-Aug-99 13:59 - 14:19	4.8	251	16.2	C4.5	1.45
	13.2 -1	27-Aug-99 14:24 - 14:35	5.7	245	17.2	C4.5	1.76
	14.1 -2	27-Aug-99 14:50 - 15:03	5.6	252	16.7	C4.5	1.37
	14.2 -2	27-Aug-99 15:07 - 15:20	5.7	247	20.8	C4.5	2.70
	15.1 -1	27-Aug-99 15:29 - 15:43	5.5	254	8.7	C4.5	2.55
	15.2 -1	27-Aug-99 15:45 - 16:00	6.5	253	8.7	C4.5	2.53
	15.3 -1	27-Aug-99 16:02 - 16:18	6.9	257	7.1	C4.5	2.68
	15.5 -1	27-Aug-99 16:37 - 16:53	6.2	255	6.9	C4.5	2.44
	15.6 -1	27-Aug-99 16:55 - 17:09	6.4	252	11.1	C4.5	-
	TWM [1999 basis]				**12.4**	**[19.5]**	**2.18**
Tank 6204	14.1 -1	27-Aug-99 14:50 - 15:03	5.8	251	12.4	C4.5	1.41
	14.2 -1	27-Aug-99 15:07 - 15:20	5.8	247	32.4	C4.5	2.51
	TWM [1999 basis]				**22.6**	**[35.5]**	**1.97**
Tank 6203	5.1 -4	24-Aug-99 15:05 - 15:19	2.6	269	16.9	C4.5	0.79
	5.2 -4	24-Aug-99 15:23 - 15:35	3.9	265	12.8	C4.5	0.36
	TWM [1999 basis]				**15.0**	**[23.5]**	**0.59**
Tanks 6204, 6304	15.4 -1	27-Aug-99 16:22 - 16:35	6.7	257	5.5	C4.5	1.65
Tank 6203	15.4 -2	27-Aug-99 16:22 - 16:35	6.8	258	2.5	C4.5	1.27
All tanks	24.1 -1	1-Sep-99 14:20 - 14:39	5.4	253	4.0	C4.5	0.41
	24.2 -1	1-Sep-99 14:43 - 14:58	5.7	252	2.3	C4.5	0.35
	24.3 -1	1-Sep-99 15:00 - 15:16	6.0	250	1.7	C4.5	0.34
	24.5 -1	1-Sep-99 15:36 - 15:49	5.1	256	4.5	C4.5	1.48
	TWM [1999 basis]				**3.1**	**[4.9]**	**0.60**
	Overall TWM				**7.8**	**[12.2]**	**1.39**

Table 15. Sorption Tube Data

Area Covered	Crude Tks ug/m3	5200 Middle Dist Tks ug/m3	Gaso Comp Tks ug/m3	FCCU ug/m3	Dist/Utils Plat/Vis/H2 ug/m3	Flocc ug/m3	Ballast Tks ug/m3	Slops Tks ug/m3	5100 Heavy Tks ug/m3	Naphtha Tks ug/m3	Gaso Tks ug/m3	1406 Crude Tk ug/m3
Ethylene	0.6	1.8	1.8	1.0	0.9	2.4	1.2	1.4	1.3	1.2	0.6	1.3
Ethane	18.8	2.8	1.4	22.9	5.1	29.0	6.0	8.1	10.6	2.9	1.7	286.5
Propane	19.5	23.1	9.3	19.2	9.6	20.5	9.9	15.5	8.6	10.4	16.7	113.3
i-Butane	24.3	28.3	36.8	27.4	11.7	106.0	18.6	27.5	19.2	28.1	26.7	215.5
Butene-1/n-Butane/Isobutylene	56.2	42.7	35.6	40.9	17.6	204.8	27.4	70.3	29.9	26.3	37.3	415.6
c-Butene-2/i-Pentane			2.1	5.0		6.0	15.7	3.8	7.3	3.0	3.1	
Pentene-1	18.5	42.0	65.3	24.7	23.7	103.2	91.2	100.3	42.2	24.9	25.9	151.9
n-Pentane/2-Methyl-butene-2	14.5	18.3	37.6	11.3	2.1	62.8	38.2	54.9	20.3	7.0	13.8	145.6
Pentene-2						11.4	10.8	10.9	7.1		6.7	
Cyclopentene		4.2		1.9		97.1	5.5	3.5				12.3
2-Methylpentane	9.5	27.1	54.4	16.8	18.1		52.2	42.6	27.6	17.5	18.7	91.2
3-Methylpentane	9.2	14.2	15.9	10.9		29.1	22.9	19.2	9.1	9.6	8.8	34.7
n-Hexane	7.2	9.7	3.1	9.7	2.6	29.9	16.5	20.9	15.9	7.7	7.6	43.7
Benzene	3.4	12.0	5.6	4.1	8.4	238.0	18.1	20.3	9.9	7.3	7.8	16.6
2-Methylhexane	1.9	8.0	2.7	3.2		27.1	7.6	7.4	4.9	8.2	5.8	26.9
Cyclohexane	1.5	4.0	2.1			13.1	6.8	7.3	7.7	4.3	3.5	12.0
Cyclohexene	7.9	27.9	10.5	11.8	8.8	23.9	22.0	26.2	27.5	17.0	9.8	48.9
3-Methylhexane												4.2
n-Heptane	3.0	7.0	3.2	3.3		21.6	9.1	8.2	12.2	8.6	6.3	19.5
Methylcyclohexane	3.5	20.9	5.8	3.7	4.0	30.3	8.6	11.5	9.4	19.0	6.2	25.9
2,3,4-Trimethylpentane						2.5						
Toluene	6.0	22.0	16.7	5.2	7.3	370.4	21.8	24.8	13.6	11.1	26.0	14.6
n-Octane	1.9	5.8	2.3	2.9	2.1	12.4	4.4	5.7	10.1	7.7	4.8	23.9
Ethylbenzene	1.8	4.7	3.1		2.1	31.4	3.5	3.3	4.0	2.6	3.0	8.0
m/p-Xylene	3.0	11.2	9.4	5.0	6.5	88.6	13.4	9.1	14.2	6.9	11.2	11.6
o-Xylene	4.8	24.4	6.6	7.0	6.8	41.2	19.3	22.9	30.5	22.1	6.8	47.4
Cyclooctene	2.1	6.2	2.7	3.4	2.9	6.2	5.9	6.1	8.9	5.7	3.4	16.0
n-Nonane						5.7	2.3	3.9	6.5	6.1	4.2	20.4
i-Propylbenzene						2.3						
n-Propylbenzene						5.1	2.9	3.5	6.0	2.9		11.6
1,3,5-Trimethylbenzene	7.3	18.6	8.9	7.9	10.4	16.7	9.8	10.8	12.6	10.5	7.4	12.1
1,2,4-Trimethylbenzene	5.8	30.9	8.8	9.2	9.1	22.1	20.1	3.9	37.8	31.0	9.1	56.2
1,2,3-Trimethylbenzene	6.4	7.7	5.1	5.5	4.3	6.0	3.6	4.6	4.7	3.4	3.7	3.9
n-Decane	3.3	4.7	3.0	2.6	2.7	5.4	2.4	2.7	3.6	2.7	3.5	3.6
n-Butylbenzene	2.0	12.1	3.2		2.0	5.1	5.7	9.9	10.0	7.7	3.3	11.0
n-Unedecane	2.5	5.6	4.1	3.6	4.1	4.4	2.4		5.1	4.8	3.1	4.7
Naphthalene	2.3	2.7						37.7	2.3	2.4		3.3
n-Dodecane												47.2
n-Tridecane	6.1	9.4	4.1	3.7	3.4	3.2	3.4	2.4				
n-Tetradecane	11.0	22.0	22.4	17.1	20.5	10.5	10.4	12.0	6.3	8.3	7.8	6.7
n-Pentadecane	21.6	63.6	25.8	19.9	32.6	28.5	11.3	2.2	19.1	66.6		15.2
n-Hexadecane					2.0			2.3				
Total Hydrocarbons	**968**	**1997**	**1097**	**886**	**1005**	**2524**	**1035**	**1683**	**1074**	**1328**	**754**	**2741**

Area	Sub area	Meas. HC (kg/h)	*1999 basis (kg/h)*	Mean Toluene (kg/h)	Ethylene (kg/h) *	Benzene (kg/h) *	Meas. Total (kg/h)	1995 total	1992 total	% Change 1995-1999
South Tankage	Tank 1401	26.6	*54.2*	1.77	0.18	1.00	28	10	145	
	Tank 1402	24.8	*50.7*	0.83	0.08	0.47	26	7		
	Tank 1406	98.9	*154*	4.05	0.36	4.56	103	3		
	Naphtha tanks	14.3	*27.9*	1.23	0.26	1.53	16	7	5	
	Spheres	2.55	*1.73*	bdl	-	-	3	1	2	
	Slops (excld. 1405)	12.9	*22.0*	1.24	0.15	2.07	14	25	31	
South Tankage Total		**180**	***311***	**9.1**	**1.03**	**9.6**	**189**	**48**	**183**	**294%**
Main Tankage	5200s (mid-dist/gasoil)	12.9	*26.2*	1.02	0.08	0.56	14	40	47	
	5100s (heavies)	36.3	*61.7*	3.10	0.24	1.74	39	17	44	
	Gasoline tanks	26.1	*47.0*	1.83	0.04	0.55	28	43	57	
	Jet Tanks	11.4	*23.3*	1.17	0.09	0.63	13	23	10	
	Gasoline component tanks	69.0	*132*	4.21	0.46	1.43	73	26	60	
	Vacuum gasoil tanks	53.2	*100*	3.83	0.48	3.68	57	13	118	
Main Tankage Total		**209**	***390***	**15.2**	**1.39**	**8.6**	**224**	**160**	**335**	**40%**
Process plant	A1-Distillation & Utilities	42.7	*91.4*	2.26	0.27	2.56	45	56	71	
	A2-Reformer/H2/Visbreaker	43.4	*94.6*	3.19	0.38	3.67	47	38	65	
	A3-FCCU	9.0	*17.8*	0.46	0.09	0.36	9	20	29	
	Synsat	1.82	*1.82*	0.34	-	-	2	<0.3		
Process plant Total		**96.9**	***206***	**6.24**	**0.74**	**6.6**	**103**	**114**	**164**	**-9%**
Water treatment	API	6.7	*6.7*	2.00			9	18		
	Bio plant	2.46	*2.46*	1.23			4	3	41	
	Flocculation	9.9	*13.2*	2.71			13	10		
	Lagoon	3.16	*3.16*	0.14			3			
	Sludge thickener	0.31	*0.31*	0.07			0	1		
	Ballast tanks	7.8	*12.2*	1.39			9	14	38	
Water treatment Total (excld lagoon)		**27.1**	***34.9***	**7.40**	**0.29**	**6.12**	**35**	**44**	**80**	**-22%**
Site Total		**516**	***944***	**38.0**	**3.2**	**24.8**	**554**	**366**	**762**	**51%**

** calculated from sorption tubes*

Table 16. Summary table

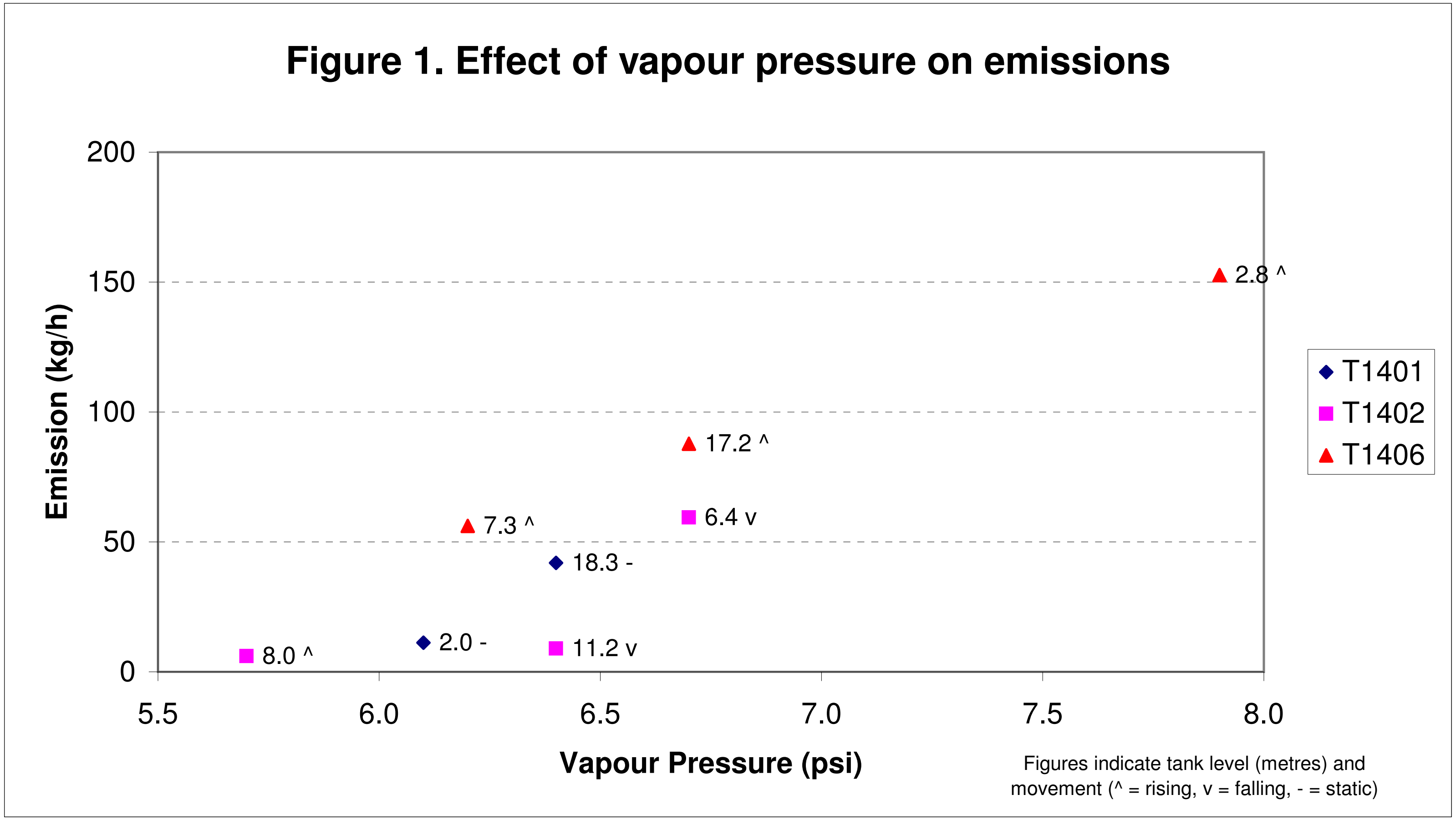


Figure 1. Effect of vapour pressure on emissions
Emission (kg/h)
200
150
100
50
0
5.5
6.0
6.5
7.0
7.5
8.0
Vapour Pressure (psi)
2.8 ^
17.2 ^
6.4 v
7.3 ^
18.3 -
2.0 -
8.0 ^
11.2 v
T1401
T1402
T1406
Figures indicate tank level (metres) and movement (^ = rising, v = falling, - = static)

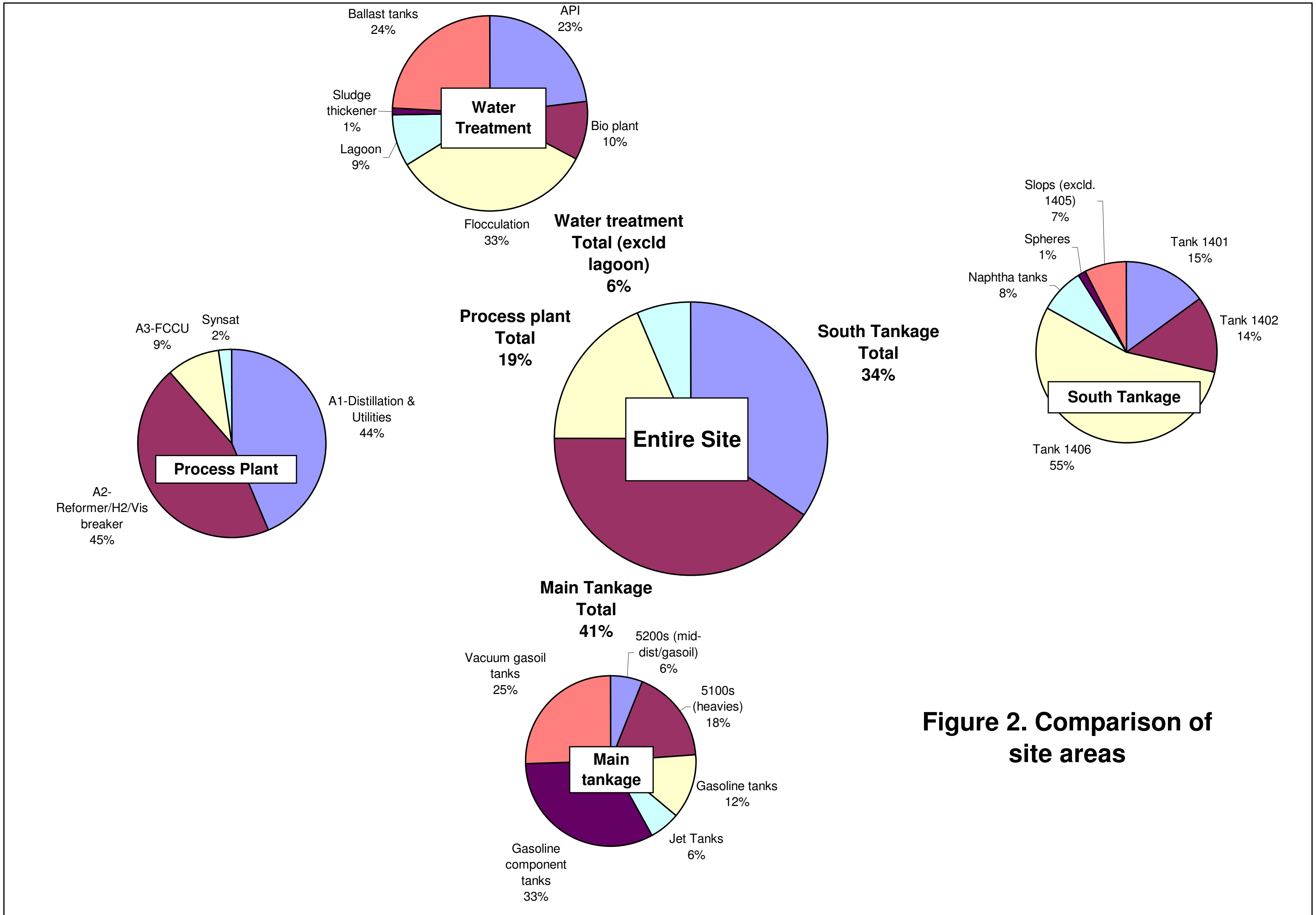
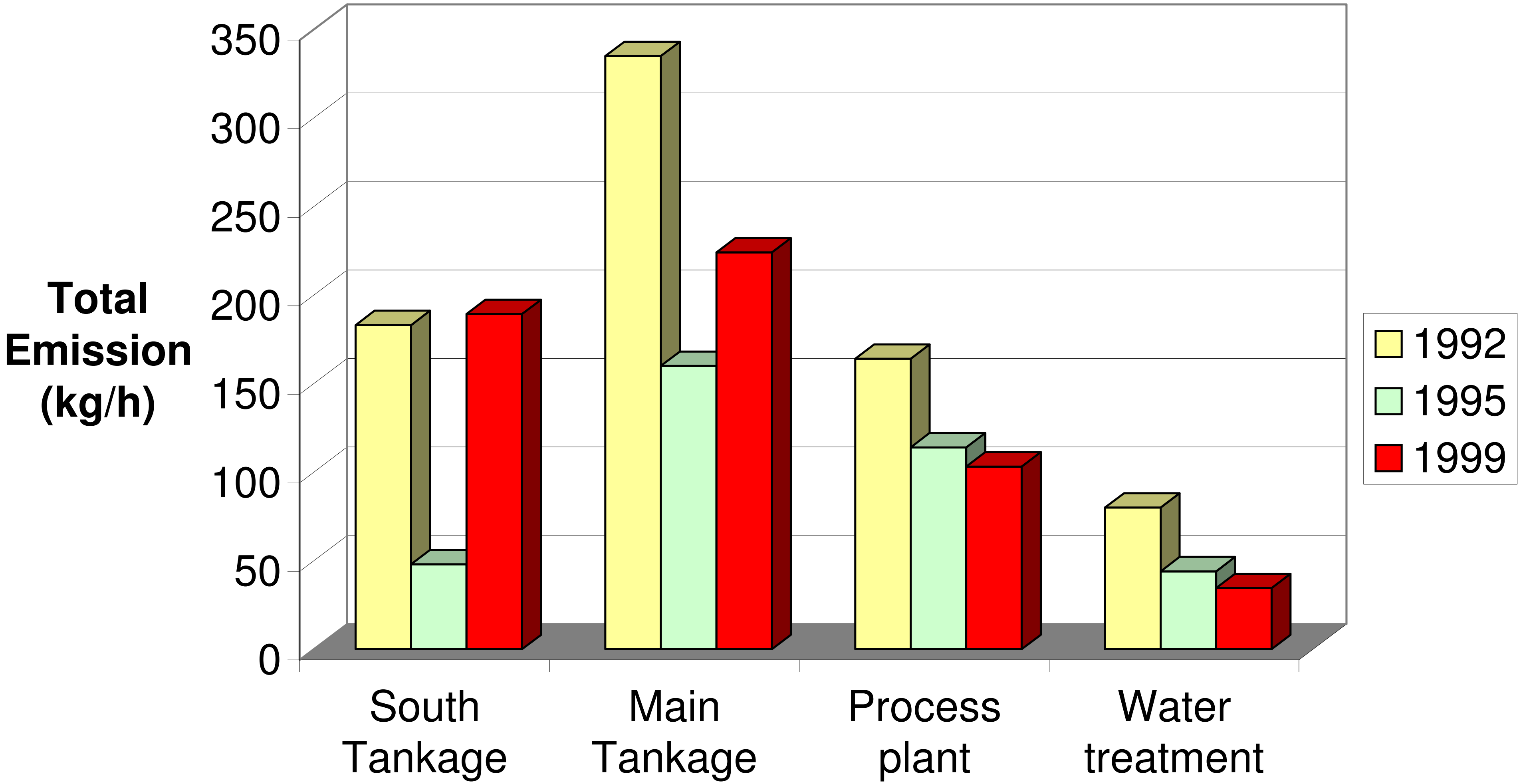
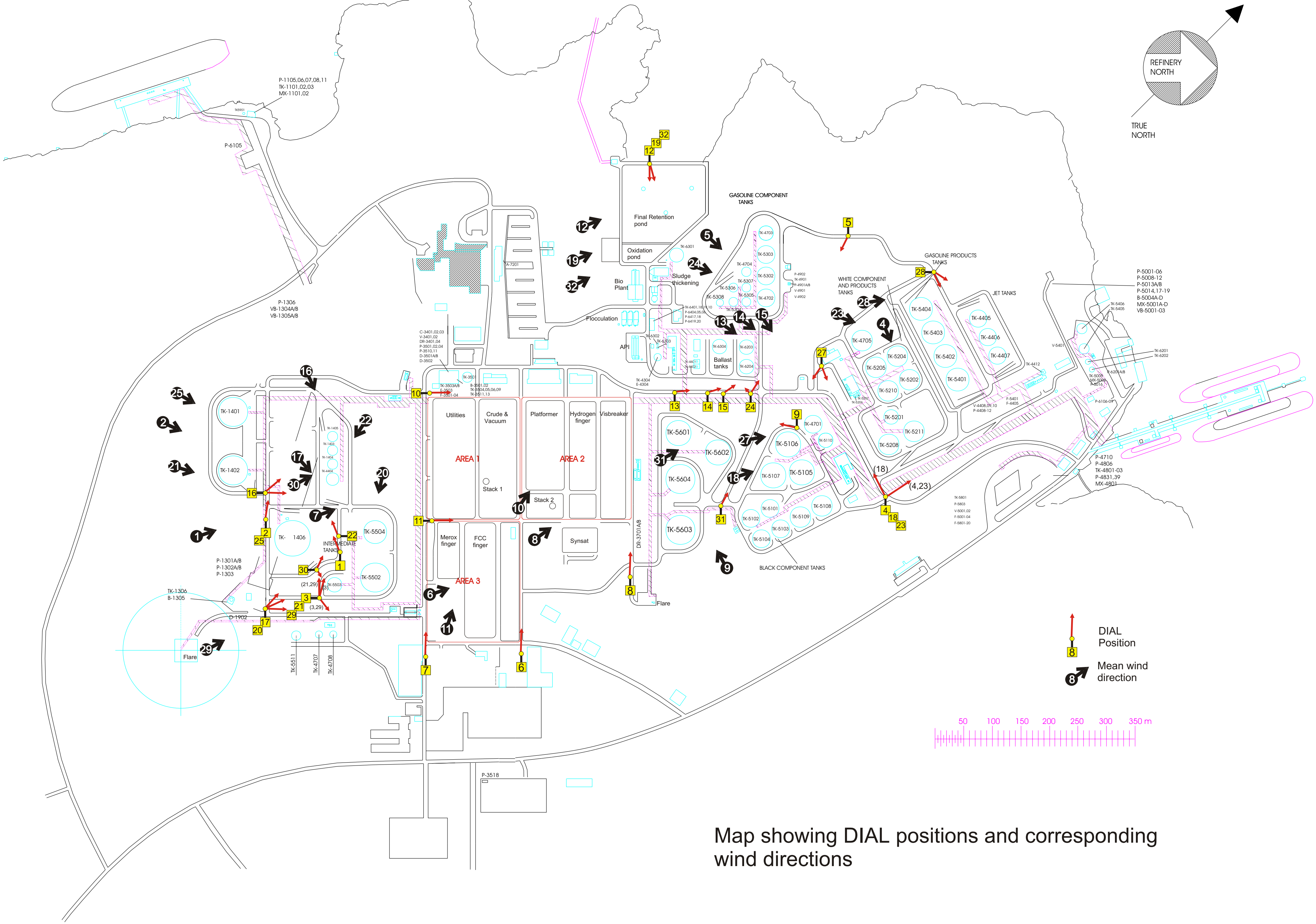


Figure 2. Comparison of site areas

Figure 3. Comparison of site emissions 1992 - 1999





Map showing DIAL positions and corresponding wind directions

Appendix A. Equipment

History

Light/laser based technology systems for the remote monitoring of gaseous species in the atmosphere has been under development for the past decade and a half. The flagship of these developments is a Differential Absorption LIDAR or DIAL system. DIAL is a development of LIDAR, a light based range finding system similar to RADAR. If a laser is used as the LIDAR light source, the collimated, coherent light emitted can be used to define the range of specific small objects with great precision. A tunable laser source can give LIDAR an additional spectroscopic capability as the source laser can alternately be tuned onto then off an absorption feature in the known ‘spectral fingerprint’ of a specific gas. Measurement of concentration in the path between the laser and the detector can then be made by comparing the energies in the two return signals.

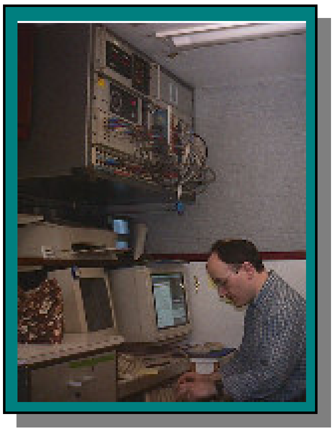
Until 1986 the DIAL development programme had concentrated on the UV and visible spectral regions where gases such as sulphur dioxide, nitric oxide, nitrogen dioxide and ozone have specific absorption features. Many other gases including the majority of the hydrocarbons have strong absorption features in the infrared region. The significance and potential of a system that could operate in the infrared was realised by all concerned and a further research programme was established to enable the technology development for DIAL hydrocarbon species monitoring. This programme involved a number of British companies, a laser manufacturer and the creation of a unique infrared source assembly which with the customised laser system, provided tunable infrared laser radiation. During the prototype testing phase, and subsequently, a more commercially orientated DIAL system was designed and constructed. This system was built on the experience of the prototype and incorporated many recent technological improvements in optics, laser equipment, fast data transfer and communications hardware. Two parallel laser systems were installed to enable simultaneous measurement in the UV, visible, and IR spectral regions. The acquisition software was improved, and fast data handling programs were designed to speed up the processing of the vast amount of data generated by the system. This data processing development is continuing to provide, ultimately, a real-time read-out capability.

The construction of the new, commercial DIAL was completed, installed in the 12 metre mobile Environmental Surveying System (ESS, Figure right), in September 1990, 6 months ahead of the original schedule. The ESS (which was the basis of a management buyout by Spectrasyne from BP Research in 1992) also houses a unique in-stack, emissions monitoring system, which along with its current Spectrasyne operating team has been engaged by a number of national authorities to make emission measurements from various refinery sources. Throughout the 1980s and early 90s, at various critical development stages, validation and correlation work was carried out with the DIAL. This work ranged from making measurements through gas cells which had been filled with gravimetric standard gas mixtures to correlation exercises between DIAL concentration measurements and stack gas analyses collected using conventional gas analysers and gas chromatography equipment. Concentration correlations at ambient / environmental levels against accredited thermal sorption tube data were also undertaken. In all cases the DIAL measured concentrations were within 10-15% of the standard or the data generated by the more conventional technologies. However, since 1988, DIAL concentration data has been used with wind speed and direction to produce mass emission fluxes ($kg.h^{-1}$) and some further validation work on the production of mass emission fluxes was considered necessary. A number of mass emission correlation exercises between the SPECTRASYNE DIAL and other measurement techniques have been carried out during recent years. The other methods include SF6, calibrated releases of methane from a point source and marine tanker vent measurements. In all of these exercises the maximum divergence from the DIAL measurements recorded was 15%.

The most recent of the correlation exercises was carried out in 1993 with personnel from the European oil industries association, CONCAWE. The correlation exercise was carried out during one complete loading schedule of a river barge loading motor spirit as this represented a discrete emission source. The CONCAWE team calculated the mass hydrocarbon emission levels throughout the loading from the tank vent measurements and knowledge of the loading rate and thus vapours displacement rate. The Spectrasyne DIAL measurements were made some distance downwind of the barge. The sequential measurement data derived from the two methods were integrated over the loading period to provide total mass emission figures for each measurement technique. The resultant correlation was within 12%.

DIAL Equipment

The Spectrasyne DIAL is based on two high energy (1.4J), 10Hz pulsed Nd:YAG pumped dye lasers. Tunable ultraviolet and visible radiation is generated in one of the laser sets by selective use of frequency doubling and tripling crystals. The second laser set, which has an injection seeded Nd:YAG, is used to generate tunable infrared radiation by means of the unique infrared source assembly. The DIAL is single ended and its output beam is directed by means of a mirror steering system which rotates in two planes. The backscattered light, which returns along the same path, is collected in a cassegrain-type receiving telescope and delivered to the appropriate detector through a multi-dichroic, beam splitting, collimating and focusing system. In order to collect, store, handle and process the DIAL signals a sophisticated, high speed data communication network has been developed in parallel with a unique MicroVax based software package. The MicroVax is also used to



perform a number of ancillary control functions and to store essential spectroscopic and other databases. The vehicle is also equipped with an extendible meteorological mast and a number of portable telemetric stations which are used along the DIAL scan lines to measure wind speed and direction, temperature and humidity. These data are displayed in real time and digitally logged for subsequent use with DIAL concentration data to produce mass emission fluxes. A sophisticated 3D computational fluid dynamics (CFD) model is also connected to the processing system; this is used to provide interpolation between measured wind speed data points for flux calculation and to assist in the definition of suitable measurement positions where the wind fields are complex. Telephoto and wide angle TV cameras are used on the steering system to facilitate beam pointing, the wide angle image is recorded on a time-lapse video recorder to be used if necessary to identify problems visually during subsequent data analysis.

Appendix B. Sorption Tube Analyses

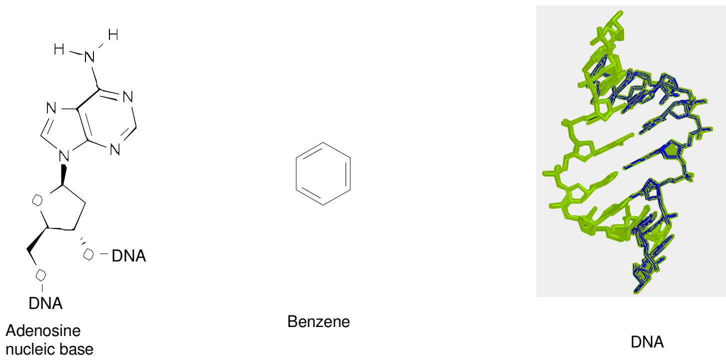
The sampling method consists of aspirating the atmosphere through solid sorbants contained in stainless steel tubes (~8 ml.min-1). For the majority of these measurements, three stainless steel tubes (89 mm x 6.4 mm ID) were used in series packed with tenax, Chromosorb-106 60/80 mesh and carbosieve respectively. For subsequent analyses of the hydrocarbon analytes retained on the sorbant materials, the tubes are purged with an inert gas, then heated. The analyses are carried out on gas chromatographic equipment (GC-FID) where a stream of carrier gas is passed through each tube to desorb the trapped species, which are cryofocused before being injected onto an OV-1701 capillary column for individual species separation. The identification of the individual species is achieved by retention time comparison. All species were grouped according to n-alkane equivalent carbon number up to C18+ Blank sample baseline levels are incorporated into each sample.

Data handling for the analysis system is by Digital MicroVAX with VG Multichrom software. The laboratory used by Spectrasyne for these analyses is NAMAS approved.

Appendix C. Benzene and other Aromatic Species

Benzene is a flat hydrocarbon specie which is carcinogenic by virtue of its structure. Its flat, hydrophobic shape makes it difficult to excrete from the body, but is "perfect" for insertion into DNA molecules (benzene is similar in structure to the component parts of the nucleic bases in DNA, see the figure below). DNA with benzene intercalated can travel through the body to the liver where the enzymes oxidise it (OH groups replacing some Hs); it can then react chemically with the DNA and become permanently attached to it. Once chemically bonded the benzene can interfere with the proper functioning of DNA and can lead to cancer.

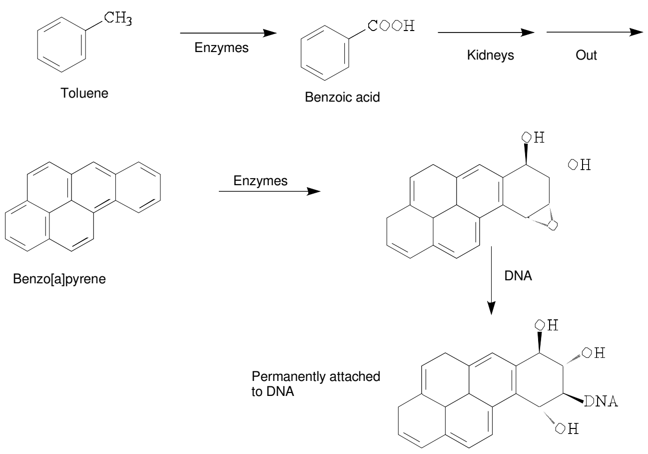
Benzene/Aromatics & Cancer



Similarity between nucleic bases and benzene

Other aromatic species, such as toluene and xylenes are much less toxic than benzene. They all have reactive alkyl groups attached to their benzene rings which allows them to be oxidised to carboxylic acids, e.g. benzoic acid in the liver (figure right). Such acids are readily soluble and, therefore easily passed through the kidneys and excreted.

The primary hazard associated with benzene is therefore a health one; it is genotoxic i.e. toxic and carcinogenic and although statistical maximum exposure limits can be derived for benzene, there is no safe level of exposure. This was recognised by the DoE Expert Panel on Air Quality Standards[1] who have set an environmental, statistical annual running average limit of 5 ppb of benzene reducing to 1 ppb.



Difference between actions of alkylated aromatics/benzene/PAHs/phenols in the liver

However, due to benzene's unreactive ring structure (with no alkyl groups) it does not have a high photochemical ozone production potential (POCPs). The benzene POCP is only 43% of the toluene figure and only 25% of the trimethyl benzenes' POCP figures. The reactive alkyl groups found in toluene, xylenes, methyl & ethyl benzenes etc., whilst

[1] Expert Panel on Air Quality Standards Benzene, HMSO 1994

making them more benign from a health point of view, unfortunately make them of more concern environmentally.

Appendix D. Glossary

DIAL Differential Absorption LIDAR.

HC Hydrocarbons – for the purposes of this report defined as all non-methane, non-aromatic, non-cyclic, non-ethylene hydrocarbons

IR Infrared

Nd:YAG Neodymium Yttrium Aluminium Garnet, a laser medium

TWM Time Weighted Mean = $\dfrac{\sum_{i=1}^{k}(t_i \times f_i)}{\sum_{i=1}^{k} t_i}$

where t_i is the length of scan in minutes and f_i is the corresponding flux calculated over the number of scans (k).

UV Ultraviolet

VOC Volatile Organic Compounds

VOC_D In this report defined as VOCs directly measured by DIAL (i.e. HC + ethane + benzene).

VOC(t) "Total" VOCs, i.e. the VOCs measured by DIAL plus those aromatics (toluene, xylene & ethyl-benzene) calculated by ratioing the acquired sorption tube samples to the measured benzene.