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Air Monitoring Trials on HMAS OVENS (U)

M. Loncar, P.J. Hanhela,
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M. Loncar, P. J. Hanhela, T. H. Gan and W. Mazurek

Ship Structures and Materials Division
Aeronautical and Maritime Research Laboratory

DSTO-RR-0085

ABSTRACT (R)

(R) Three air monitoring trials were undertaken in an RAN Oberon class submarine, HMAS Ovens, using an instrument package consisting of commercially available monitors for hydrogen, hydrogen chloride, chlorine, oxygen, carbon monoxide, carbon dioxide, refrigerant R-12, volatile organic compounds (VOCs) and aerosols.

(R) During the trial periods, dive times were short so there was little opportunity for the build up of air contaminants. However, of the air contaminants measured, only the VOCs exceeded maximum permissible levels although aerosols concentrations were considered to be high by outdoor environmental standards.

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Air Monitoring Trials on HMAS OVENS (U)

Executive Summary (U)

The air quality in Royal Australian Navy Oberon class submarines has always been a matter of concern amongst submariners and particular attention has been paid to this problem in the design of the Collins class submarines. However, hitherto, no attempt has been made to survey the air quality in these submarines. Consequently, there has been no basis for comparison of the air quality on both classes of submarine and the effect of the air purification measures implemented on the Collins class submarines. This report describes the instrumentation and concentration levels of a number of air contaminants monitored on board HMAS Ovens while at sea.

Three air monitoring trials were conducted in HMAS Ovens, between March and July, 1995. They involved the installation of an instrument package consisting of commercially available monitors for hydrogen, hydrogen chloride, chlorine, oxygen, carbon monoxide, carbon dioxide, refrigerant R-12, volatile organic compounds (VOCs) and aerosols. Pressure, temperature and relative humidity were also monitored. These instruments were connected to a datalogger and left unattended for 1-2 week periods.

The results showed that during the trial periods, with the exception of the VOCs, these air contaminants were present in concentrations below the maximum permissible levels. However, the dives were short and consequently, there was little opportunity for the accumulation of air contaminants between snorting (snorkelling). As a result, the carbon dioxide removal units and oxygen candles were not used and hence the effectiveness of these air purification measures was not evaluated.

Aerosol and carbon monoxide concentrations were considerably lower than those reported for Royal Navy Oberon class submarines where smoking is permitted at most times. Although the aerosol concentrations were below maximum permissible levels, set by RAN, they were considered to be high by outdoor environmental standards.

Although the maximum refrigerant R-12 concentration detected was 170 volumes per million (vpm), there appeared to be a potential for the gas to reach unacceptable levels as indicated by the rate of increase in concentration during one event.

Thus even while operating with relatively short dive times and consequently frequent ventilation, the air quality in HMAS Ovens was relatively poor (particularly with regard to VOCs) by standards applied to the Collins class submarines but better than that of the Royal Navy Oberon class submarines. As a matter of comparison the VOC levels in HMAS Ovens are approximately 1000 times higher than urban levels.

Authors

M. Loncar

On attachment from FAO 58, Sweden

Mario Loncar graduated with an MSc in engineering physics from Chalmers University of Technology, Sweden, in 1991 and is currently a Research Engineer at the Naval Medicine Division of FOA (National Defence Research Establishment), Sweden. His main interests have been in the development of instrumentation for simulating and monitoring physiological processes in hyperbaric experiments. During 1995 he spent 3 months as a visiting scientist at AMRL, in the Submarine Air Quality Task.

P. J. Hanhela

Ship Structures and Materials Division

Peter J. Hanhela is a Senior Professional Officer Class B in the Ship, Structures and Materials Division at AMRL. Since joining AMRL in 1970 he has gained extensive experience in preparative organic and analytical chemistry and has worked with chemiluminescence and aircraft sealants. He has been engaged in air monitoring studies in submarines for the past 5 years during which time he has been involved with air analysis by GC-MS and dedicated sensors as well as carbon dioxide absorption studies on sodalime and lithium hydroxide.

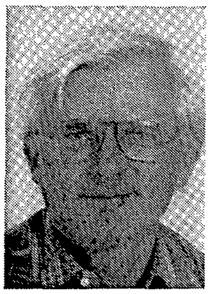
T. H. Gan

Ship Structures and Materials Division

Tiang-Hong Gan, PhD, BSc (Hons) is a Senior Research Scientist at AMRL, Maribyrnong. A graduate of La Trobe University, he undertook research in mass spectrometry and ultraviolet photoelectron spectroscopy with quantum chemistry. On joining the Australian Radiation Laboratory (ARL) in 1980, his research involved the applications of physics and surface chemistry to environmental radioactivity, including the development of standards for radon and radon progeny in an OECD/NEA intercomparison program. He lectured for one year at the Phillip Institute of Technology and returned to ARL prior to his transfer to AMRL in late 1989. Since then he has worked in the areas of chemical warfare disarmament, oxygen sensors and is currently researching aspects of chemical vapour detection and aerosol particles in submarines.

W. Mazurek

Ship Structures and Materials Division



Waldermar Mazurek has an MSc and a PhD degree in inorganic chemistry and is a Principal Research Scientist in the Ship Structure and Materials Division at AMRL. He joined AMRL in 1967 and has worked in various areas of applied chemistry including textiles, paints and polysulfide elastomers. Since 1991 he has directed research into air monitoring in submarines. During this period he spent 13 months on submarine air purification problems while attached to the Defence Research Agency, UK. In 1994 he organised the first international conference on submarine air monitoring (SAMAP 94).

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1. Introduction

The Oberon class submarines have been in service in the Royal Australian Navy since 1967 [1] and are now being replaced by the Collins class. Air purification on these submarines relies principally on the removal of carbon dioxide (CO_2) by absorption with sodalime [2] and replenishment of oxygen (O_2) through the burning of chlorate oxygen candles [3]. Carbon monoxide (CO) and hydrogen (H_2) are removed by catalytic oxidation on palladium coated alumina pellets contained in nickel wire sachets and electrically heated to 120°C [3]. Other air contaminants such as hydrocarbons, can only be removed from the submerged submarine by snorting. Filters are situated in the galley, above the stove to remove fat and oil vapours.

The air contaminants arise from a number of sources including respiration (CO_2), charging of the batteries (H_2), fugitive exhaust emissions, cooking (CO), bilge water (hydrogen sulfide, H_2S), diesel fuel, refrigerant leaks and oil and cooking (organic vapours). Smoking, a common source of air pollution, is restricted to snorting times in front of the air intakes to the engines.

Routine air monitoring on these submarines is carried out with a detector (Gastech GX91) located in the control room, which uses electrochemical sensors for O_2, CO, H_2S and a catalytic sensor for H_2 (combustibles). A separate infrared detector (Gastech RI-413) is used for refrigerant R-12. Colorimetric indicator (Drager) tubes are also used for these and other gases (including O_2, CO and CO_2). The readings are recorded in a log at 3 hourly intervals during a dive.

Aerosols are not monitored and these may consist of oil droplets from cooking, engines or hydraulics, salt particles from sea water or carbon particles from engine emissions and cooking.

On occasions, high concentrations of CO, CO_2 and freons have been recorded. In one instance a death occurred on HMAS *Onslow* [1] from CO poisoning as a result of the failure of an exhaust valve which allowed exhaust gases to enter the interior of the boat. During long dive times high CO_2 levels have been known to affect the concentration of the crew and freon levels have been known to exceed the maximum permissible concentrations. However, the most common complaint with regard to air quality on the Oberon class submarines is that of odour which is reputed to linger on the clothing of submariners long after leaving the boat.

In addition, anecdotal evidence suggests that submariners commonly suffer from headaches and skin complaints which generally appear to clear after leaving the submarine. Medical records from the sickbay at the submarine base, HMAS Platypus also indicate that respiratory and skin complaints are common [4]. Similar symptoms are generally associated with sick building syndrome [5].

In order to assess the extent of air contamination on the Oberon class submarines dedicated detectors were placed on board HMAS Ovens to monitor as many of the pollutants as possible at frequent intervals, using commercially available instruments. In addition, whole air samples were taken in canisters for retrospective analysis in the laboratory. In this way fluctuations in pollutant concentrations could be monitored in conjunction with a detailed analysis of organic vapours.

Due to the restrictions on space availability, the instrumentation was kept as compact as possible and the key contaminants targeted for monitoring were confined to H_2, O_2, CO, CO_2, Cl_2, HCl, refrigerant R-12 , volatile organic vapours (VOCs) and aerosols. The concentration levels were recorded on a data logger for subsequent examination.

Three trials were carried out on board HMAS Ovens over a period of 2.5 months in waters off the eastern coast of Australia. During the last trial only one of the diesel engines was operating and as a consequence the battery power was more likely to be reserved for emergencies and dives were restricted to short periods. Thus the diesel engine was run more frequently than usual during this period. Shortly after these trials HMAS Ovens was due to sail to HMAS Stirling where it would be used for training and later become part of the maritime museum.

2. Experimental

Carbon monoxide, carbon dioxide and refrigerant R-12 were monitored with an infrared detector, Uras model 10E (Hartmann and Braun, Germany). Oxygen levels were determined using a paramagnetic detector, Helox model 2 (MBE Electronic AG, Switzerland) containing a Servomex 500A paramagnetic sensor. Hydrogen, chlorine and hydrogen chloride concentrations were measured with electrochemical detectors, Oldham (France) TX-11(H_2) and TX-12 with an internal datalogger. Volatile organic vapours were determined using a photoionisation detector, HNU Systems, Inc., (USA) model PI-101 with a 9.5 eV light source calibrated against toluene. Humidity and temperature were recorded using the sensors from a humidity and temperature transmitter, Vaisala (Finland) HMD model 30 UB. Pressures were measured with a pressure transmitter, Transinstruments (UK) model 200B. Total aerosols were determined with a Casella (UK) model AMS 950 aerosol monitor in the particle size range of $0.3\mu m$ to $20\mu m$. These instruments were connected to a data logger with 15 bit resolution, Datataker (Australia) model 500 and programmed in Microsoft Quickbasic , version 4.5 (Appendix A) to allow for calibration factors and variable data sampling rates. Sampling intervals were set at 20 minutes for these trials with the above monitors.

As the amount of space on the submarines is limited, the instrumentation used for air monitoring was kept to a minimum volume. The sensors from the humidity/temperature transmitter were removed and mounted in a case containing the data logger, pressure transducer and electrochemical detectors. A schematic diagram and photograph of the instrument package is shown in Figs 1a and 1b respectively.

All instruments with the exception of the electrochemical detectors contained air sampling pumps. Air was drawn from the surroundings and introduced to the electrochemical detectors, using the sampling pumps in the Uras and the Helox instruments. The photoionisation detector was operated independent of this plumbing arrangement.

Aerosol size distribution (0.5μm, 0.7μm, 1μm, 3μm, 5μm and 10μm) was measured with a Met One (USA) model 237 particle counter connected to IBM compatible personal computer (note book type) for data logging and was mounted in a separate case together with the Casella AMS 950. Both instruments were calibrated with dioctyl phthalate in ethanol with 0.5μm, 3μm and 10μm particle sizes using a syringed pumped vibrating orifice generator (TSI-3450) with a diffusion dryer and aerosol neutraliser. Sampling intervals for this monitor were 10 minutes.

Aerosol samples were collected on 37 mm metricel membrane filters (Gelman GN-4) with a cut-off size of 0.8 μm. The air flow through the filters was maintained at 7.5 l/min using a carbon vane pump. Samples were collected over 24 h periods (27-30 June) in the motor room aft of the engine room. The samples were examined with a Cambridge Stereoscan S250 Mk2 (Oxford Instruments) scanning electron microscope with a Link AN-10000 energy dispersive spectrometer (EDS) with a Link LZ-5 detector. The filter samples were mounted onto aluminium stubs using Leit-C carbon conducting cement. One group was coated with carbon, the other with aluminium. Qualitative x-ray elemental analysis was carried out using the beryllium window for elements with atomic numbers above 11 and the ultra thin window for elements with atomic numbers from 5-11.

All gas and vapour monitors were calibrated with standard gas mixtures (BOC, Australia) within 2-3 days prior to installation. The instruments were placed in the rear compartment, at the stern end of the after bunk room, on HMAS Ovens.

Whole air samples were collected in electropassivated stainless steel canisters (Scientific Instruments Specialists, Graseby Andersen, USA). A 200 ml gas sample together with a metered d_8 toluene internal standard were trapped in a CO_2 cooled cold trap of a TD4 (Spantech, UK) thermal desorber, thermally desorbed and split in a 1:15 split ratio and chromatographed on a Fisons gas chromatograph, model 8000, using a 50m, 0.33mm I. D. capillary column with a 5μm film DB1 coating (SGE, Australia). The mass spectrum was obtained on a VG Trio 1000 mass spectrometer interfaced with a Carlo Erba GC 8000 series gas chromatograph.

3. Results

The first of the three trials was held during the period 19-30 April, 1995. During this trial the aerosol monitors were not installed. The Casella aerosol counter was installed during the second trial (10 - 17 June) and during the third trial (23 June - 4 July) both the Casella and the Met One (aerosol sizer) instruments were included.

Due to the limited availability of space air sampling was confined to the extreme rear of the boat. The air intake to the instrumentation was inserted in the air ducting so that the circulating air could be monitored. This arrangement is comparable with the central air monitoring system on some UK and US submarines where stainless steel tube sampling lines are used to deliver air samples, from a number of points in the boat, to a mass spectrometer and an infrared CO meter. While permanent gases and organic vapours would be expected to circulate freely and unattenuated in the ducting it may not be the case with aerosols.

The presence Cl_2 and HCl was not detected since oxygen candles were not used in the submarine due to the short dive periods (< 4 hours). It was suspected that small amounts of these gases may be produced from the thermal decomposition of the sodium chlorate in the candles.

During the course of the three trials temperatures from 15° - 32°C were recorded with humidities from 35% - 76% RH. The pressure varied from 621 - 787 mm Hg as a result of atmospheric pressure changes and the decrease in pressure due to snorting. The rapid pressure fluctuations caused by snorting were used to check the sensitivity and correct functioning of the gas monitoring instruments. Indeed, during the second trial the lack of correlation between pressure changes and the CO, CO_2 and R-12 readings together with a lack of correlation between the O_2 and CO_2 measurements was interpreted as being due to the pump failure on the Uras instrument. The pressure and temperature data were also used to normalise the gas concentrations to 760 mm, Hg and 20°C to avoid the effects of the substantial temperature and pressure fluctuations.

The pressure measurements were useful in determining snort times indicated by a drop in pressure (Fig. 2) and these coincided with the snort times recorded by the crew. However, it was not always possible to determine, from pressure measurements alone, whether the boat had dived or surfaced. This could only be resolved by referring to the boat's air monitoring log which recorded snorting times as well as air quality during dives. These operational states are important as air contamination is likely to increase during dive periods and the removal of these air contaminants will occur during snorting and while the boat is operating on the surface. During prolonged snorting charging of the batteries may occur resulting in the formation of hydrogen. Although most of the hydrogen would be expected to be discharged through the engine exhaust some increase in concentration within the boat can be expected.

3.1 Oxygen and Carbon Dioxide

Throughout the trials, the operation of the submarine was such that the dive times were short eliminating the need for the use of the carbon dioxide absorption units and oxygen candles. The maximum CO_2 concentration recorded was 1.4% while the minimum O_2 concentration was 18.9% during the same period (first trial). Because of the interdependent relationship between O_2 and CO_2, the two sets of data should anticorrelate as shown in Fig. 3 and every percent decrease in O_2 concentration should correspond to a numerically equal increase in CO_2 concentration (conservation of mass). This holds for data up 25 March after which there is little response by both the Uras (CO_2) and the Helox (O_2 meter) instruments to snorting and very little correlation between the readings of both instruments. As there was a measurable signal for both instruments, it appears that the most likely cause of this problem is the failure of the instrument sampling pumps probably due to a temporary power failure. This also affected the CO and R-12 data from the Uras.

A similar problem was encountered during the third trial with the Uras instrument. However, the Helox pump was unaffected. Both instruments functioned correctly during the second trial as indicated by the correlations of the O_2 and CO_2 data in Fig. 3b.

3.2 Carbon Monoxide

The maximum level of CO measured was 18 vpm during the first trial and occurred prior to the first snorting period for a relatively short duration (<20 min.). Levels of 10 vpm were reached on a number of occasions during the first 6 days of this trial (Fig. 4a). There were two periods of 3-4 hours duration during which there was a rapid rise in CO levels (11:40-16:40 and 00:40-03:40, 20 March) while the boat was submerged. These rapid increases were not repeated during subsequent dives (23-25 March) or during the second trial. A maximum of 7.5 vpm was recorded during the second trial with an average level of approximately 5vpm. Reliable CO data could not be obtained during the third trial due to the sampling pump failure.

3.3 Refrigerant

Refrigerant leaks usually occur during the operation of refrigerant equipment or from gas cylinders. The highest concentration of refrigerant R-12 measured was 178 vpm which occurred during the first trial (Fig. 5a) coinciding with the highest CO reading (Fig. 4a). There appeared to be no logical connection between the two events and subsequent tests on the Uras revealed no cross sensitivity between the two gases. In both cases a rapid decline in the concentration of these contaminants was observed on commencement of snorting. The ventilation rate during snorting appeared to be sufficient to clear the R-12. The initial rapid rise in R-12 suggests that much higher air concentrations could have been reached had snorting not commenced shortly after the occurrence of the leak. During the second trial period the concentration of R-12 did not exceed 30 vpm (Fig. 5b).

3.4 Hydrogen

The hydrogen concentrations were found to be below 0.15% even during a period prior to diving and when the batteries were probably being charged (Fig. 6). It is during battery charging that the greatest evolution of hydrogen can be expected. Although there is limited data it suggests that the hydrogen elimination from the boat is effective.

3.5 Volatile Organic Compounds

Organic vapours were detected with the photoionisation detector (PID) which is most responsive to unsaturated and aromatic hydrocarbons. As the detector does not respond to R-12 which can be the most concentrated organic vapour in the submarine air, it may be assumed that the detector is essentially indicating diesel vapour levels which contain a mixture of saturated, unsaturated and aromatic hydrocarbons. Vapours from cooking oils may also illicit a response but their concentrations are expected to be lower than that of diesel fuel.

The maximum concentration detected was 13 vpm during the second trial. A concentration of approximately 10 vpm or more was maintained for 15.5 hours during one period and 16.5 hours during another period (Fig. 7a). Both excursions occurred during snorting and the CO_2 data suggests that the submarine may have dived prior to the commencement of the first excursion. However, during the first trial maximum VOC levels did not exceed 1 vpm (Fig. 7b). The correlation between snorting and high VOC levels indicates that diesel is the most likely source of VOCs.

A whole air sample taken during the first trial (29 March) and analysed by gas chromatography - mass spectrometry (Fig. 8) resulted in a total integrated hydrocarbon level of 15 vpm consistent with the maximum PID readings (second trial). The chromatograms confirm that the major contributing source of organics is diesel fuel. This suggests that the PID readings were far too low during this trial and were inconsistent with those obtained during the second trial.

During both the first and second trials there is a generally good correlation between the VOC and CO readings (Fig. 9) despite erroneously low VOC readings recorded during the first trial. This is consistent with the major source for both pollutants being associated with the operation of the diesel engine.

3.6 Aerosols

Aerosol measurements made with the Casella were indicative of total aerosols (0.3μm-20μm particle sizes). Maximum aerosol levels of approximately 0.15 mg,m^{-3} were regularly recorded during the third trial with a particularly high reading (1.3 mg,m^{-3}) observed at 10:00, 3 July (Fig. 10). The event produced large particles (0.3μm to at least 10μm) which was due to the engine exhaust fumes entering the boat through the open hatches. The aerosol levels appeared to be significantly higher when the boat was submerged compared to surface operations. The regular snorting during this period indicated that the diesel engine was being turned on and off and this was a major contributor to the aerosols.

A similar pattern was observed during the second trial (Fig. 10b). During long snorting times, the aerosol levels were not particularly high but increased with more frequent snorting times. Overall, the levels were lower than those recorded during the third trial, rarely exceeding 0.1 mg m^{-3} with the exception of a value of 0.3 mg m^{-3} recorded at 1:20 and 0.15 mg m^{-3} at 7:20, 16 June which occurred during snorting and may have been due to the intake of engine exhaust fumes. However, these did not coincide with high CO readings (Fig. 4b) which may have been due to the rapid dispersion of CO compared with the aerosol particles.

A comparison of the particle size distribution of the aerosols with the total aerosol concentration showed that most of the aerosols were less than 1μm (Fig. 10c,10d).

Aerosols samples were taken in the motor room, aft of the engine room. These were collected on the filters and from gravimetric measurements corresponded to an average of 0.03 mg m^{-3} and 0.045 mg m^{-3} over a 24 h period, in reasonable agreement with measurements obtained from the Casella AMS 950 instrument (0.033-0.037 mg m^{-3}). The residues were examined by scanning electron microscopy and x-ray elemental analysis. They were shown to be principally carbon particles less than 1 μm in size containing only trace quantities of inorganic salts.

This contrasts with the average aerosol levels which have been reported in Royal Navy Oberon class submarines (0.2-0.5 mg m^{-3}) when sampled under similar conditions [7]. In addition, substantial amounts of water soluble inorganic salts were found to be present in the aerosols with an organic component of 27-44%.

4. Discussion

Due to the short dive times, there was little opportunity for the accumulation of significant amounts of CO_2 with maximum concentrations of <1.5% being reached. Similarly, O_2 depletion was never significant with a minimum concentration of 18.9% being observed. Under these circumstances the oxygen candle furnace and the carbon dioxide absorption unit was not used and therefore the effectiveness of the air purification system could not be evaluated.

The concentrations of hydrogen did not reach a significant level at any time during the trials. Similarly, in UK Oberon class submarines hydrogen levels were found to be less than 0.1% while peak CO concentrations of 35 vpm were recorded [7] compared with 18 vpm on HMAS Ovens which is consistent with a maximum of 15 vpm reported for a Canadian Oberon class submarine, HMCS Okanagan [8]. The suggested maxima for RAN submarines is 15 vpm for a 90 day period (MPC_{90}) and 200 vpm for a 1 to 24 hour exposure [6].

Although the peak CO concentrations were lower on RAN submarines compared with those of the Royal Navy, rapid rises of 2-3 vpm/h were observed, over a 3-4 hour dive period, on two occasions during the first trial (20, 21 March, Fig. 4a). This compares with 2.2 vpm/h for Royal Navy Oberons where there is a significant contribution from cigarette smoking [7]. As these were anomalous events they may have arisen from illicit smoking by crew members in the vicinity of the air sampling.

Of the air contaminants measured in HMAS Ovens, R-12, VOCs and aerosols appeared to be present at relatively high concentrations. Although the concentration of R-12 reached 178 vpm, had snorting not coincided with the R-12 leak potentially higher levels could have been reached. However, there remains a considerable margin between this reading and the suggested MPC_{90} for RAN submarines of 500 vpm or 2000 vpm for a 60 minute exposure period [6].

The PID was found to be relatively unreliable during the course of these trials, showing VOC levels < 1 vpm during the first trial compared with 1-15 vpm recorded during the second trial. Retrospective GC-MS analysis of whole air samples taken during the first trial indicated VOC levels of 15 vpm. The problem appears to be due to a low sensitivity of the detector at these levels and the apparent formation of organic deposits on the detector window causing signal attenuation.

The maximum VOC levels of approximately 15 vpm exceed the maximum permissible level of 10 vpm for RAN submarines [6] . By comparison, urban VOC levels are 1000 times lower [9,10]. The maximum concentration measured in a Royal Navy Oberon class submarine was 55 vpm in the engine room of HMS OTUS [7]. It is possible that higher levels of VOCs may have been found on HMAS Ovens if the PID was located in the engine room.

Levels above 7 vpm may contribute to personal discomfort and have been associated with "sick building" syndrome [11-13]. These have been measured in a non-industrial environment which is probably relevant to the submarine situation. However, a tolerance to toluene at a concentration of 40 vpm has been reported [14] without any apparent adverse effects.

The 0.15 mg m^{-3} aerosol concentrations regularly recorded is well below the RAN MPC_{90} of 0.5 mg m^{-3} [6]. Significantly higher levels of aerosols (0.2-2.3 mg m^{-3}) have been reported for Royal Navy Oberon class submarines [7]. A choice of different sampling areas and different occasions on RAN Oberon class submarines, may possibly reveal similar results to those reported for the Royal Navy boats since the sampling site on HMAS Ovens was well removed from the galley and engine room, the majors sources of aerosols. However, the highest aerosol concentration recorded on HMS Onslaught was in the accommodation space. This may not be surprising as cigarette smoking is unrestricted on Royal Navy submarines and consequently may be another reason for the high aerosols levels recorded compared with those found on HMAS Ovens.

The fact that the aerosols on HMAS Ovens essentially consisted of carbon particles compared with those reported on Royal Navy Oberon class submarines which contained both inorganic salts and organics suggests that on the Royal Navy boats there are sources in addition to the diesel engines, contributing to these aerosols. The presence of inorganic salts indicates the effect of sea air and the presence of a relatively high organic component (up to 44%) suggests a contribution from cooking oil or hot engine oil.

It is significant that the particle sizes are generally less than 2.5μm. These are "respirable" and can be deposited in the pulmonary tissue. Particles larger than 2.5μm which enter the upper respiratory system are not retained for very long and may be expelled within a day. However, the smaller particles deposited in the alveolar can be retained for weeks to months and consequently present a greater health hazard [15].

The particles appeared to principally consist of carbon particles indicating that the most likely source is the diesel engine. This allows comparisons to be made with situations where the automobile exhausts are the main contributors to the generation of aerosols.

The aerosol levels on HMAS Ovens are comparable with that of large cities such as Frankfurt, Germany [16] and 3 times the yearly maxima measured in an industrial suburb of Melbourne [17]. The average volume size distribution of these aerosols is similar to that in the submarine with most of the particles being less than 3μm [16]. Although the levels measured in the submarine may be relatively low compared with the MPC_{90} they may not be conducive to personal comfort and may be injurious to health.

5. Conclusions

These trials showed that commercial instruments can be successfully used for continuous air monitoring on submarines for hydrogen, carbon monoxide, carbon dioxide, oxygen, refrigerant R-12, VOCs and aerosols although care must be exercised to ensure that the instruments are functioning correctly by cross-checking data. Precautionary measures need to be taken in order to overcome the effects of power interruptions to the instruments in particular the internal air sampling pumps. Consideration should also be given to automated periodic introduction of a calibration gas mixture as an additional check on instrument readings. This particularly applies to the PID used in the measurement of VOCs

As the dive times were short, generally less than 4 hours, accumulation of air contaminants was limited. However, under these circumstances, the present study has found that of the contaminants measured, only the VOCs have exceeded the maximum permissible levels for RAN submarines. This is consistent with the odour complaints made by submariners. The main source of VOCs is most likely to be the diesel fuel although this may not be the only source of odour.

The aerosol levels measured in the submarine, although they do not exceed the maximum permissible levels, are high by comparison with outdoor environmental standards but considerably lower than those reported for Royal Navy submarines where smoking is permitted. However, the matter should not be ignored.

Although the concentrations of refrigerant R-12 did not exceed the maximum permissible levels during the trial period, the rapid rise in concentration, on one occasion, suggests that there is a potential for reaching excessive levels.

Personal comfort is an important consideration and impacts on morale and mental concentration. It is therefore in the interest of the Navy to ensure that the air quality does not adversely affect these factors and consequently comfort levels of air quality ought to be taken into consideration.

Thus, in the case of the Oberon class submarines, the major air contaminants contributing to the odour problems probably stem from diesel vapours although there may be other sources. These need to be identified and measures ought to be taken to reduce them to non-perceptible levels. Currently, an attempt is being made to identify the characteristic odour encountered on these submarines.

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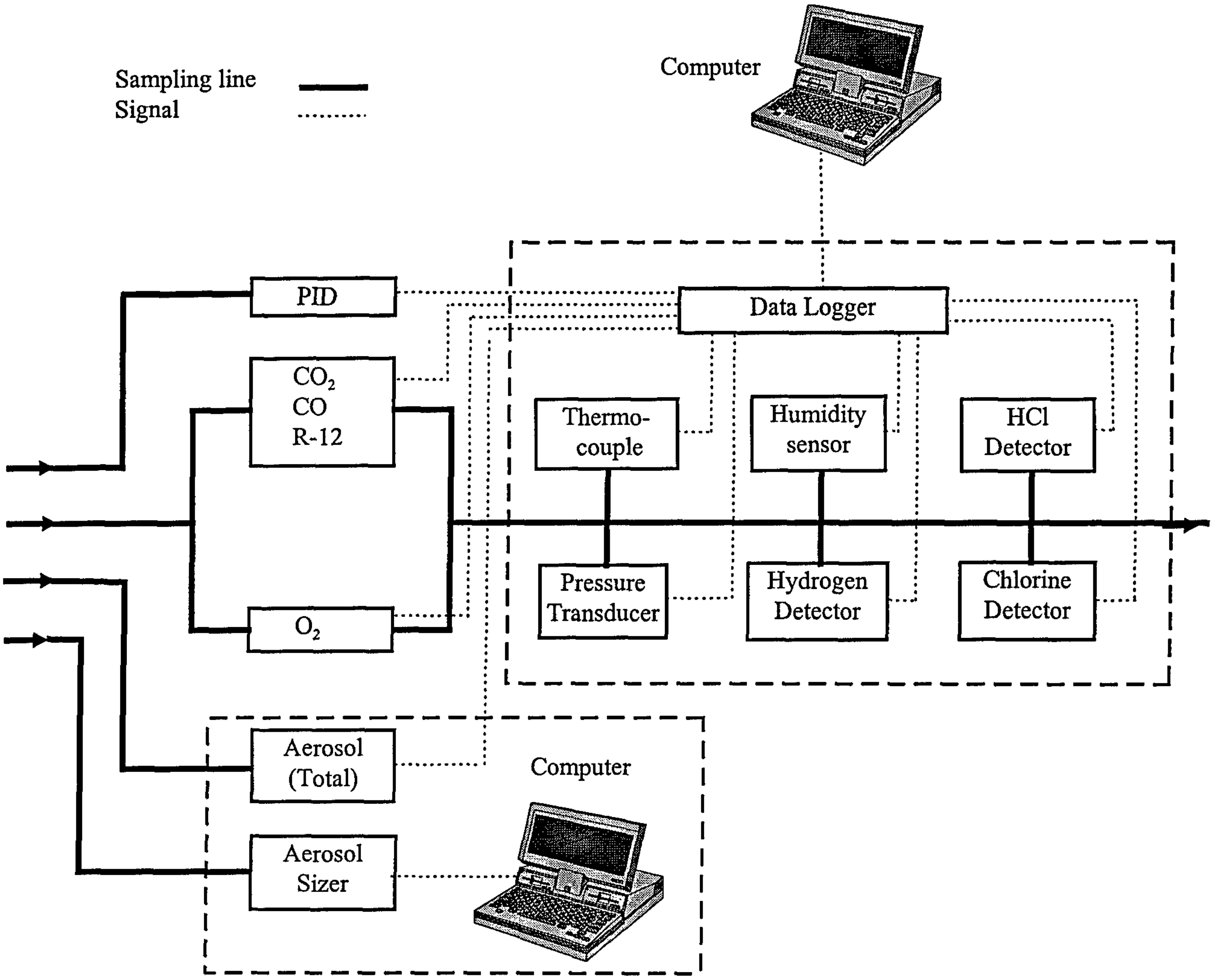

Figure 1a. Schematic diagram of the instrument assembly.

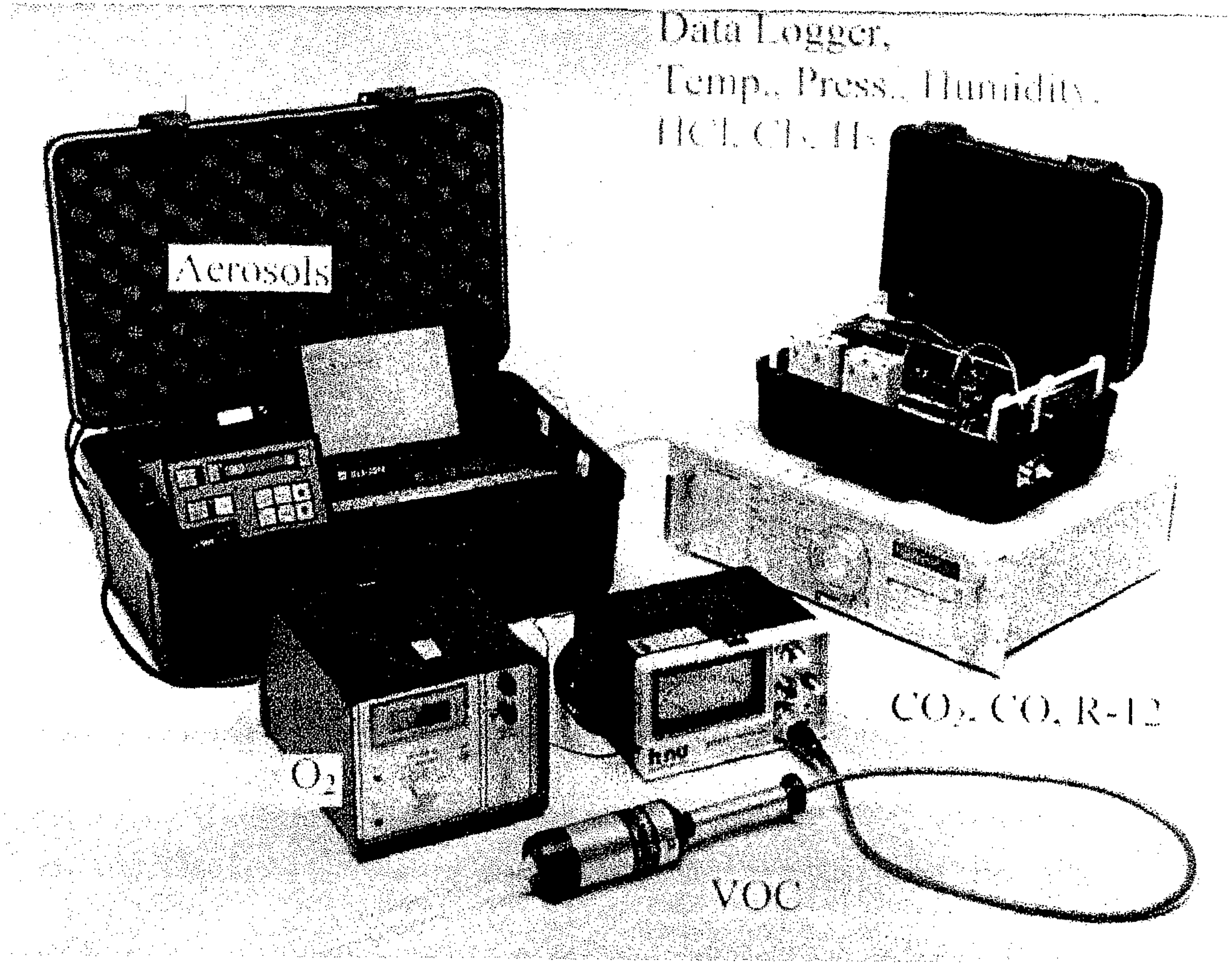

Figure 1b. Instrument assembly used in air monitoring trials.

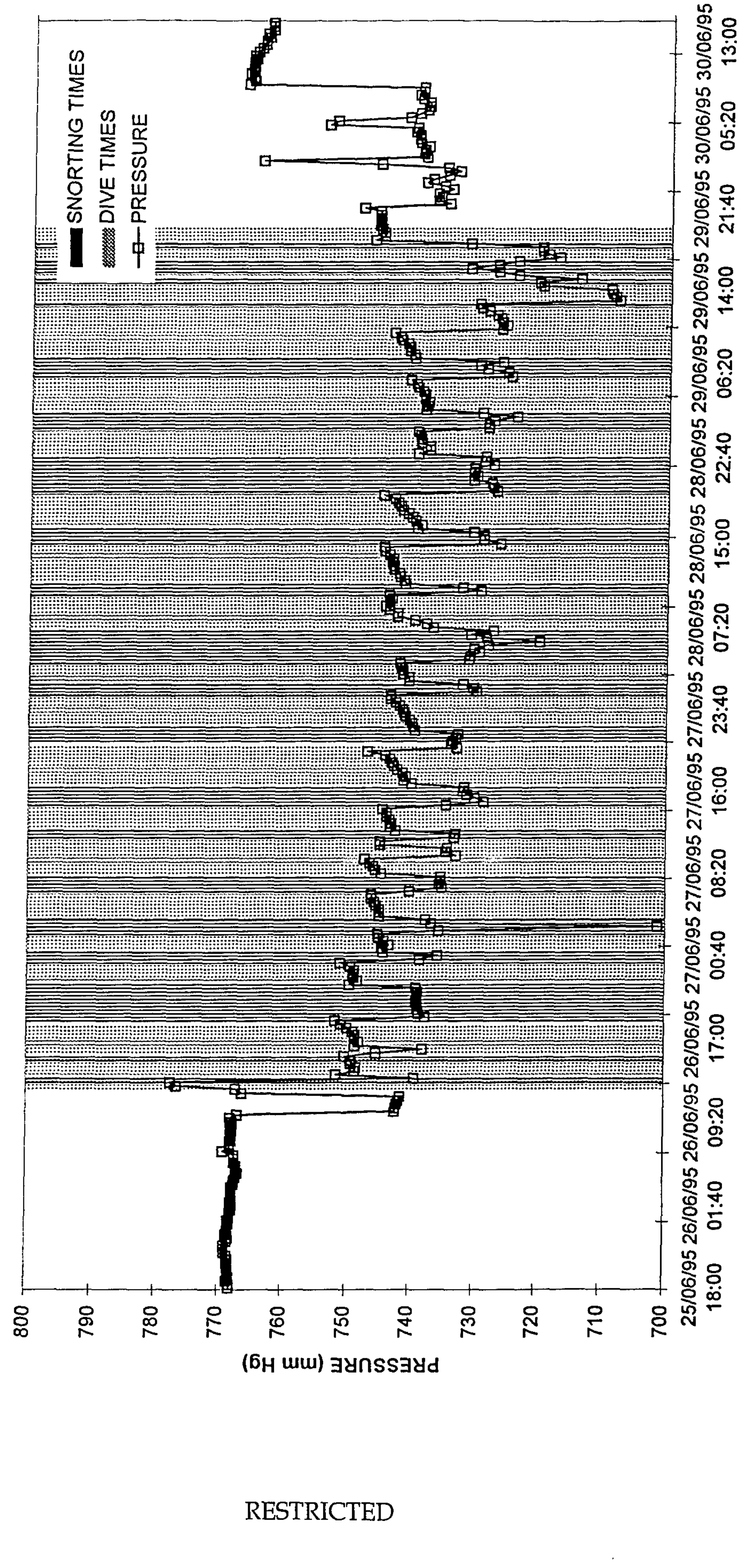

Figure 2. Correlation of snorting and dive times with pressure changes.

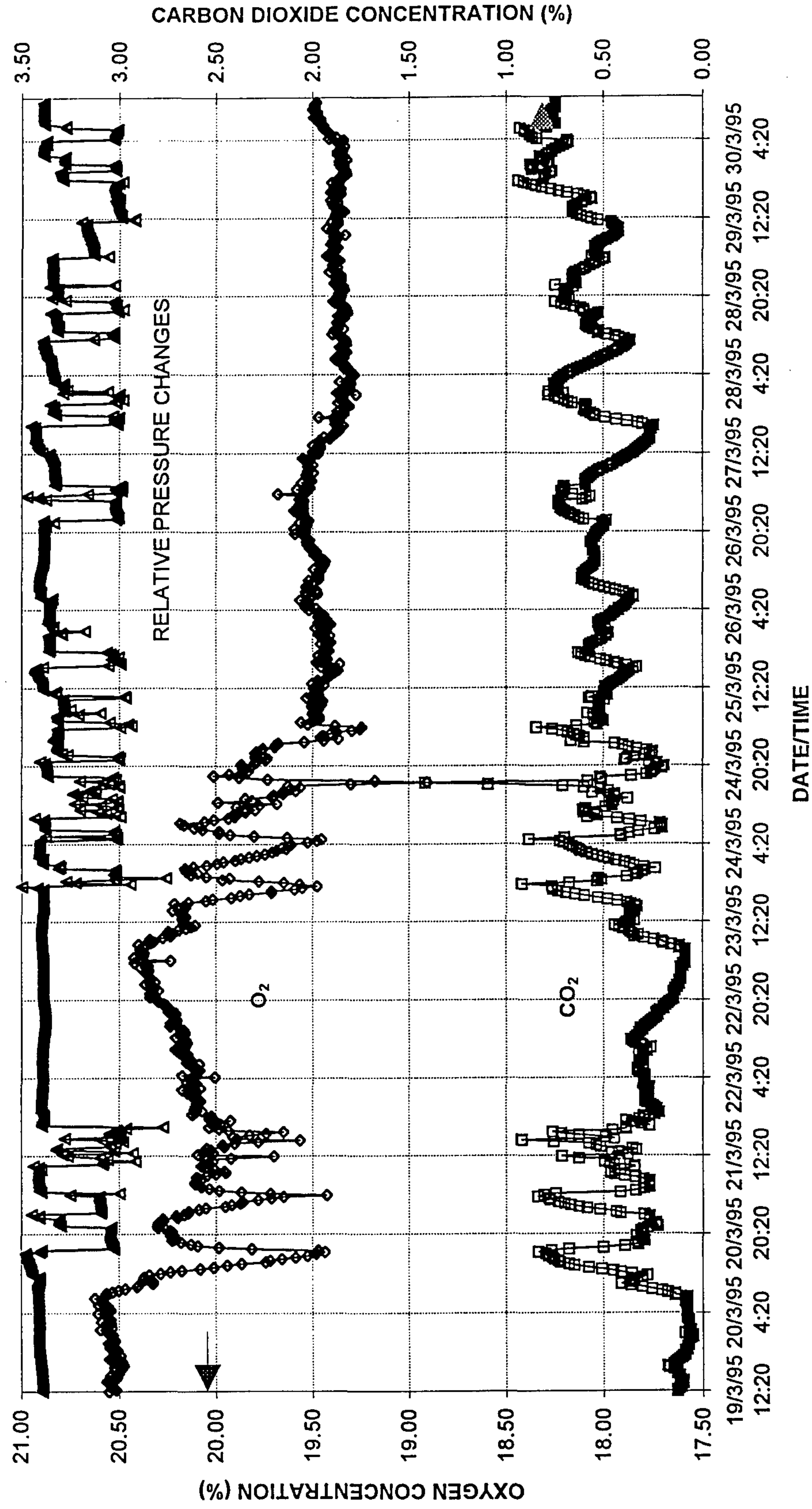

Figure 3a. Pressure and temperature corrected CO_2 and O_2 data with relative pressure changes.

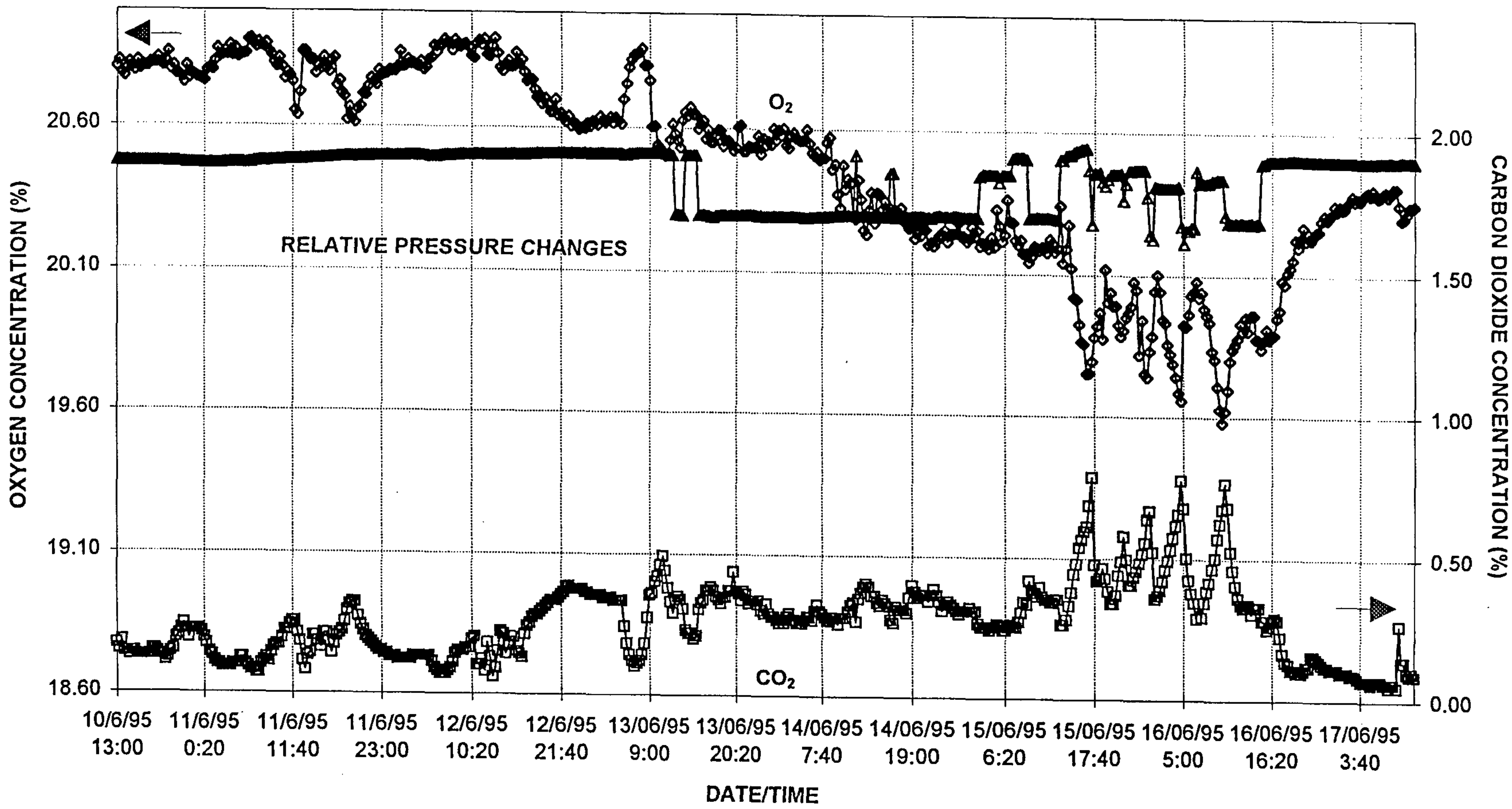

Figure 3b. Pressure and temperature corrected CO_2 and O_2 data with relative pressure changes.

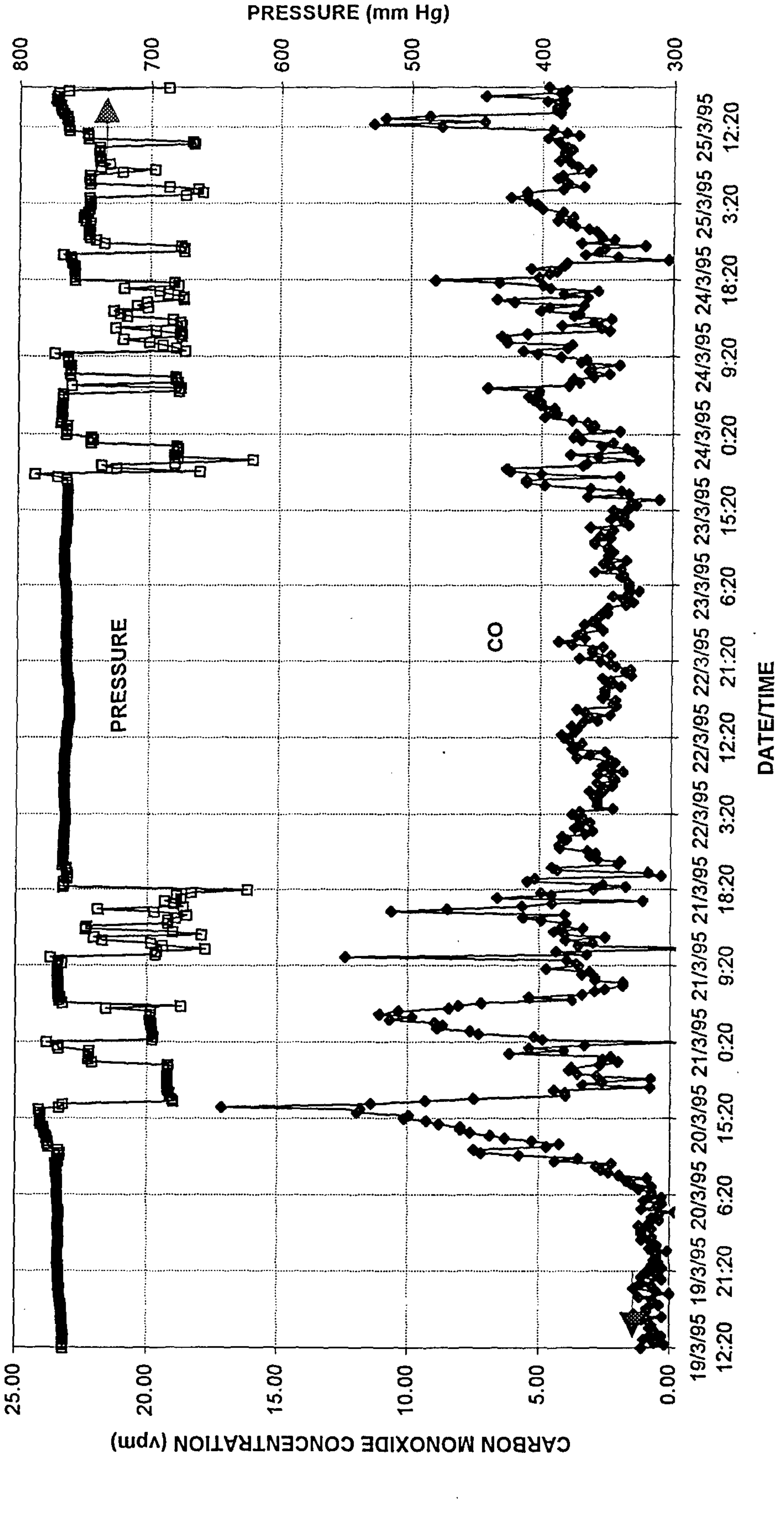

Figure 4a. Pressure and temperature corrected CO data together with pessure changes.

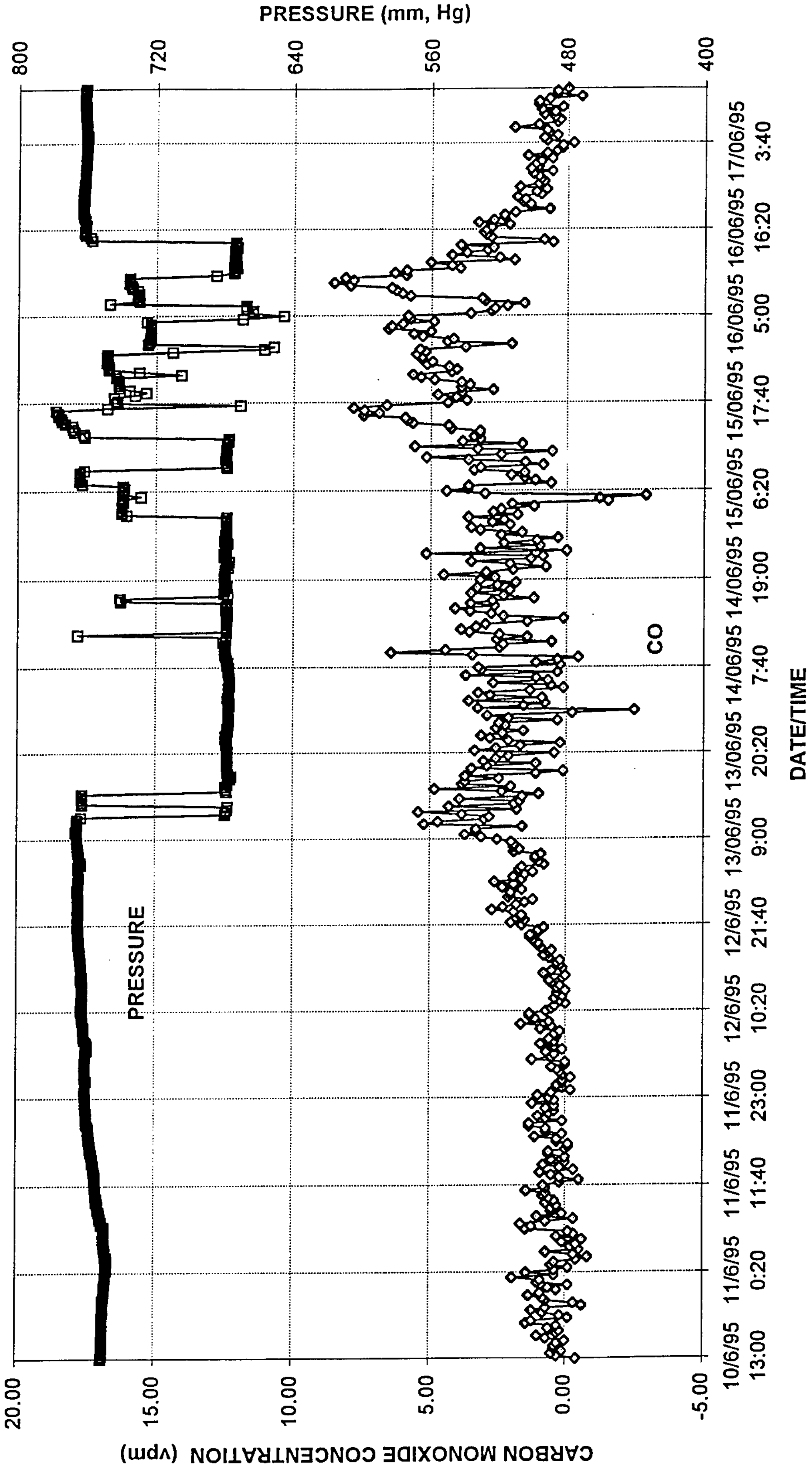

Figure 4b. Pressure and temperature corrected carbon monoxide concentrations.

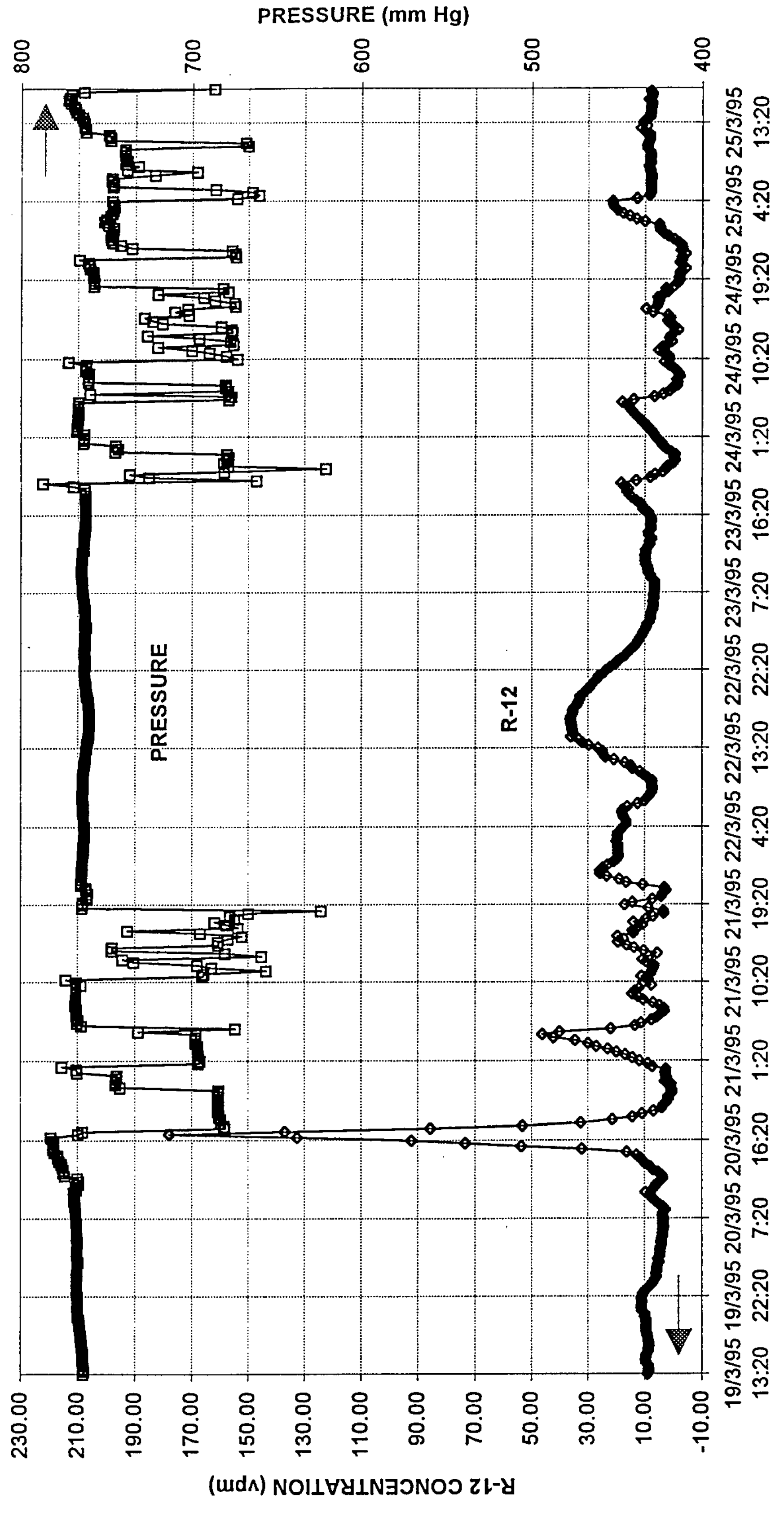

Figure 5a. Pressure and temperature corrected refrigerant R-12 concentrations.

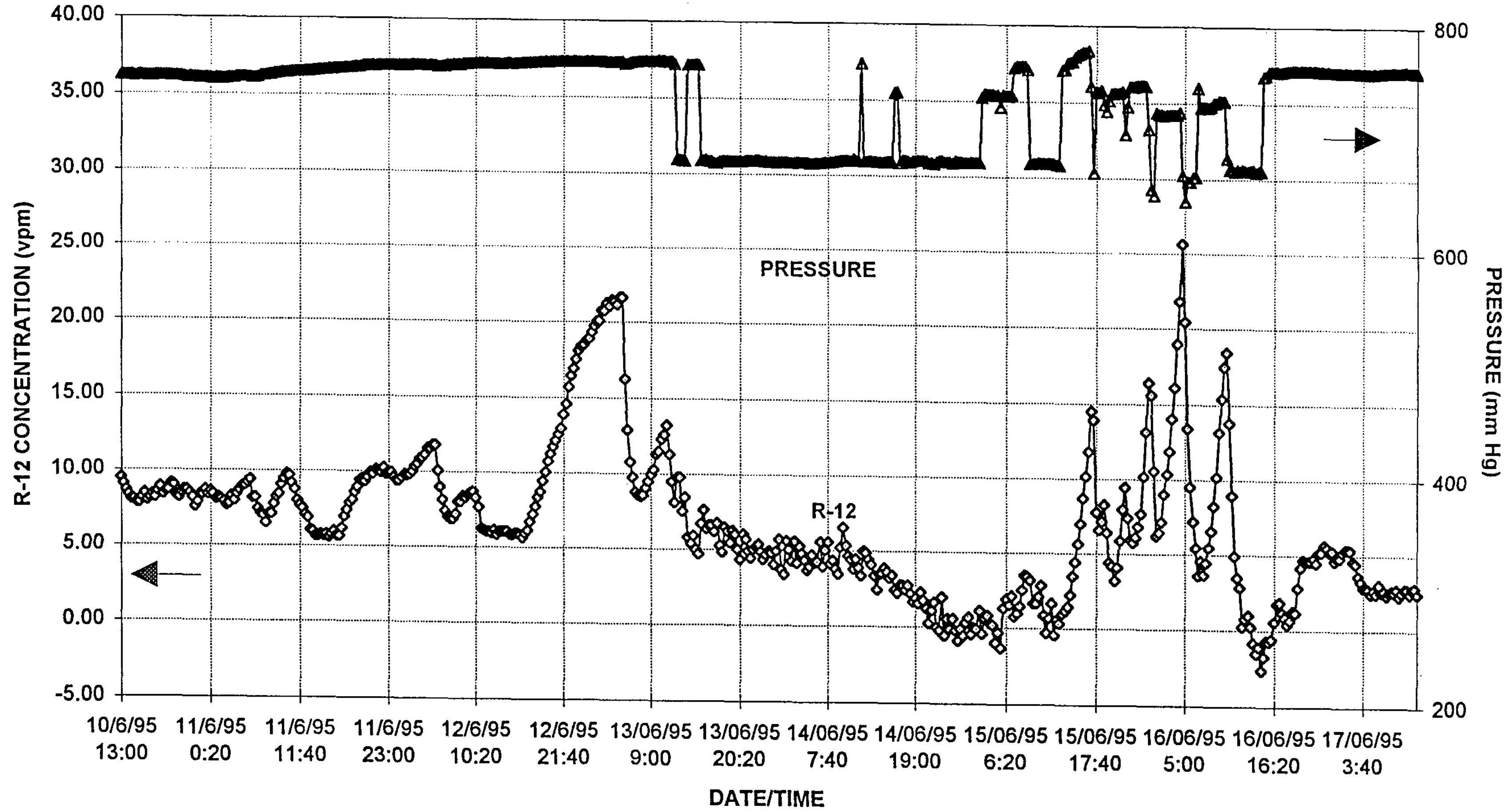

Figure 5b. Pressure and temperature corrected refrigerant R-12 concentrations.

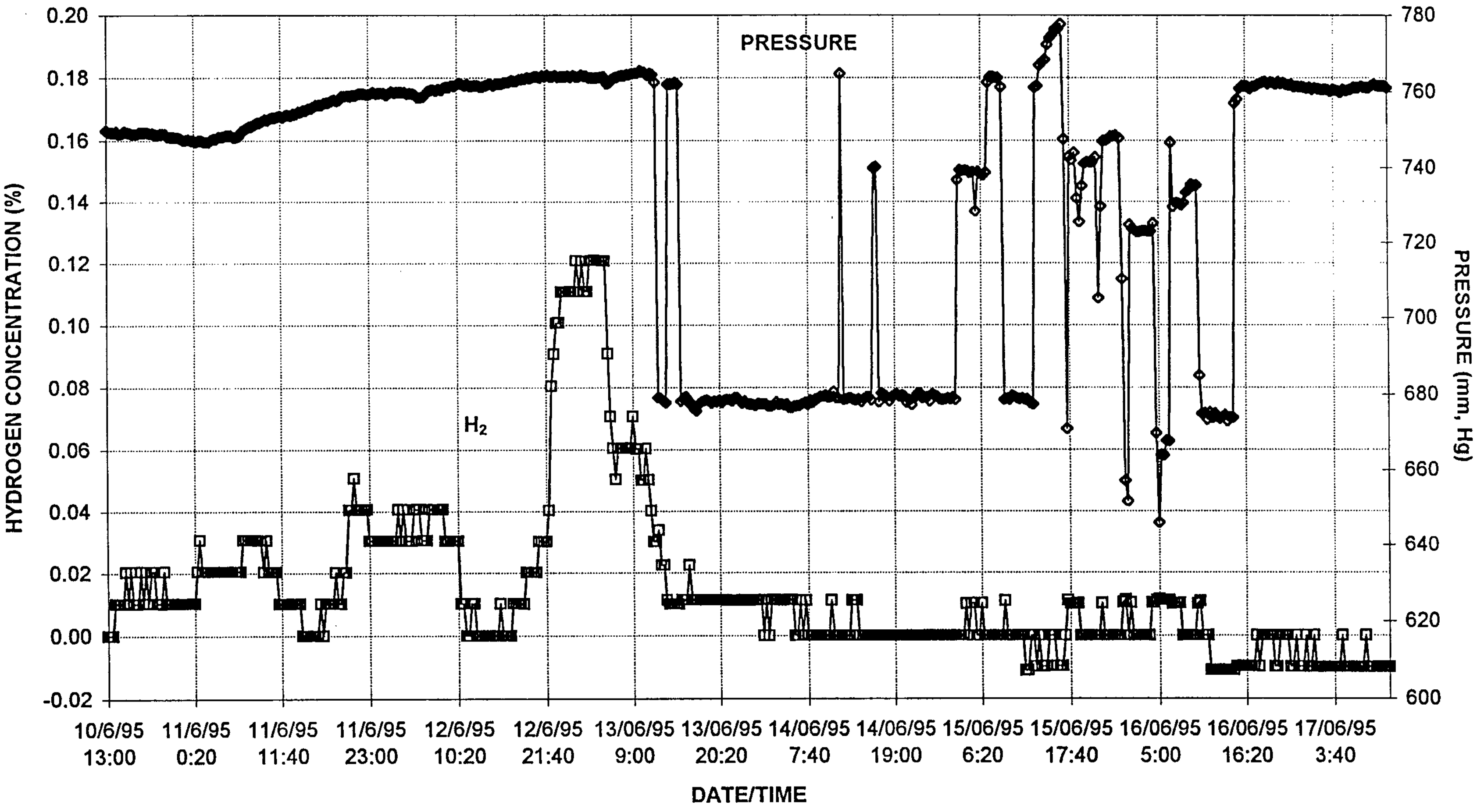

Figure 6. Pressure and temperature corrected hydrogen concentrations.

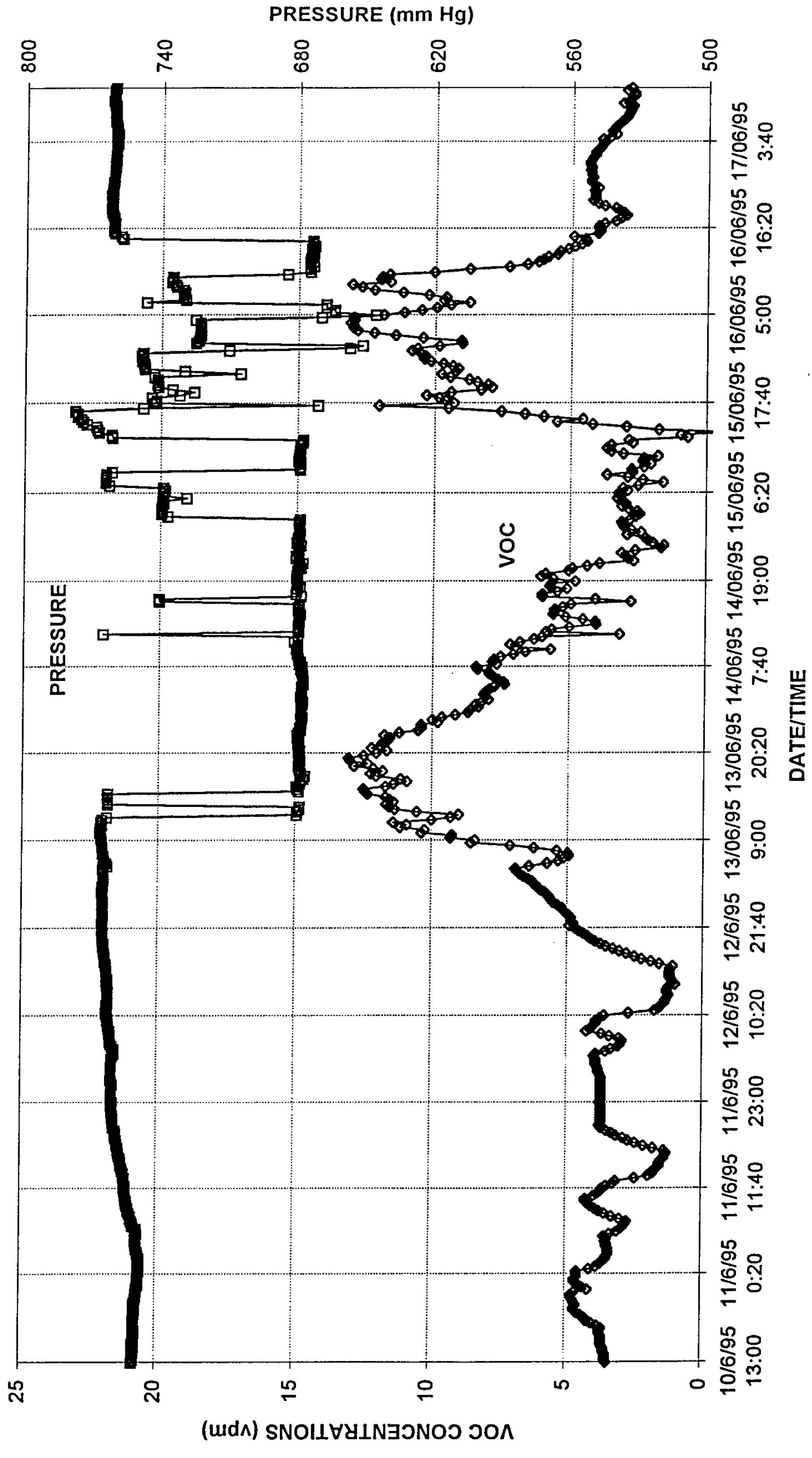

Figure 7a. Pressure and temperature corrected concentrations of volatile organic compounds (VOCs).

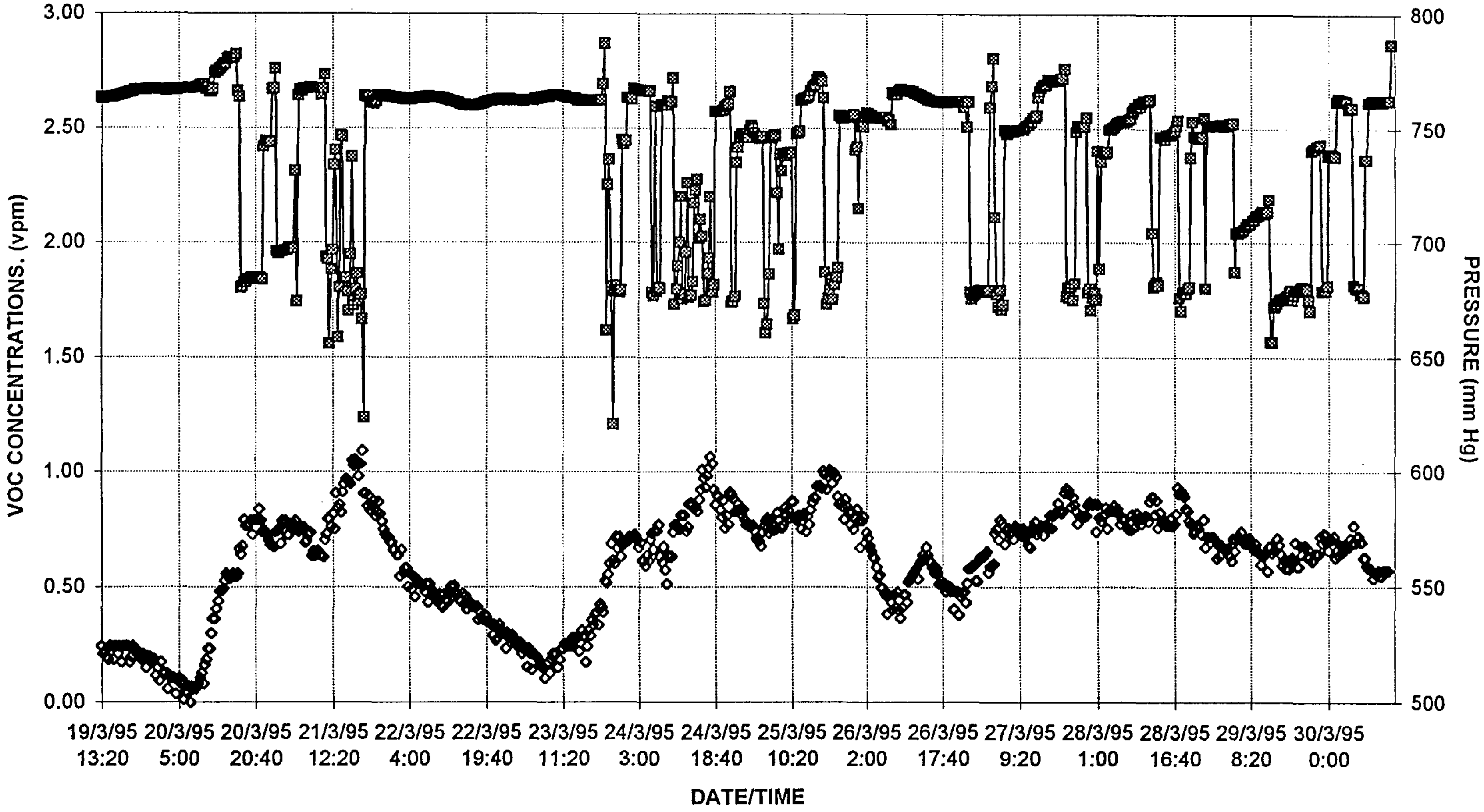

Figure 7b. Pressure and temperature corrected volatile organic compounds (VOCs) concentrations.

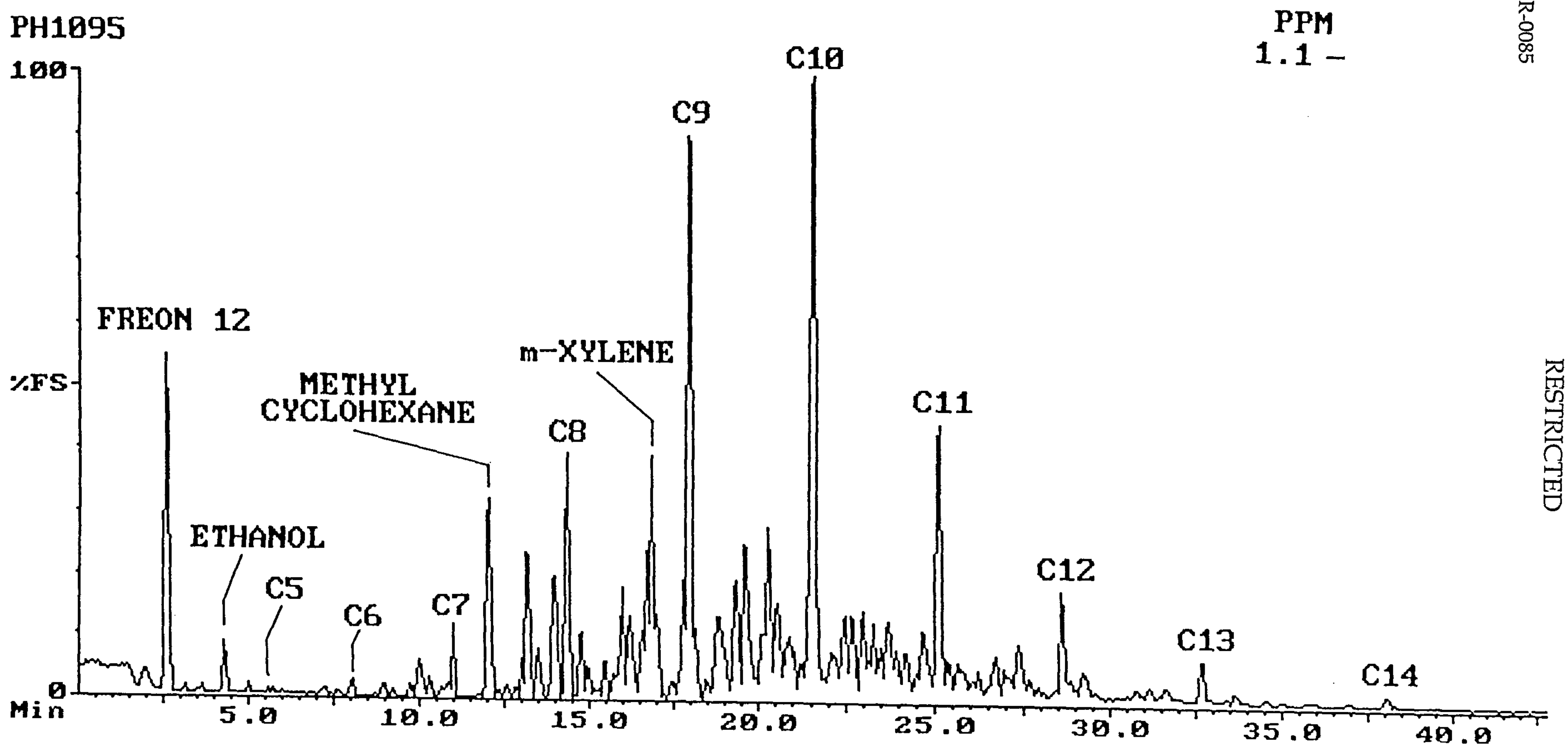

Figure 8. Gas chromatograph of a whole air canister sample from forward compartment with some peak assignments.

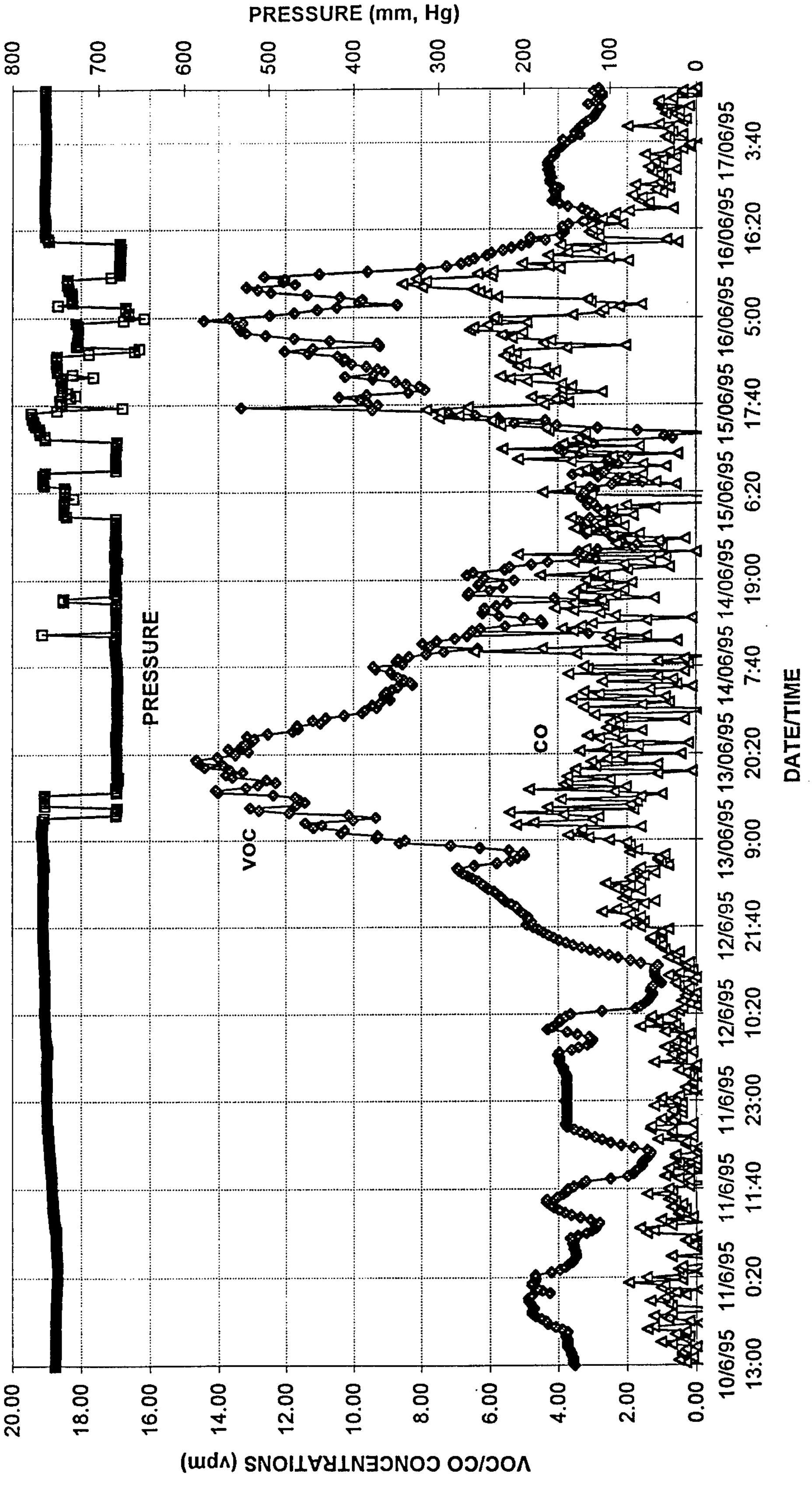

Figure 9a. Pressure and temperature corrected VOCs and CO concentrations.

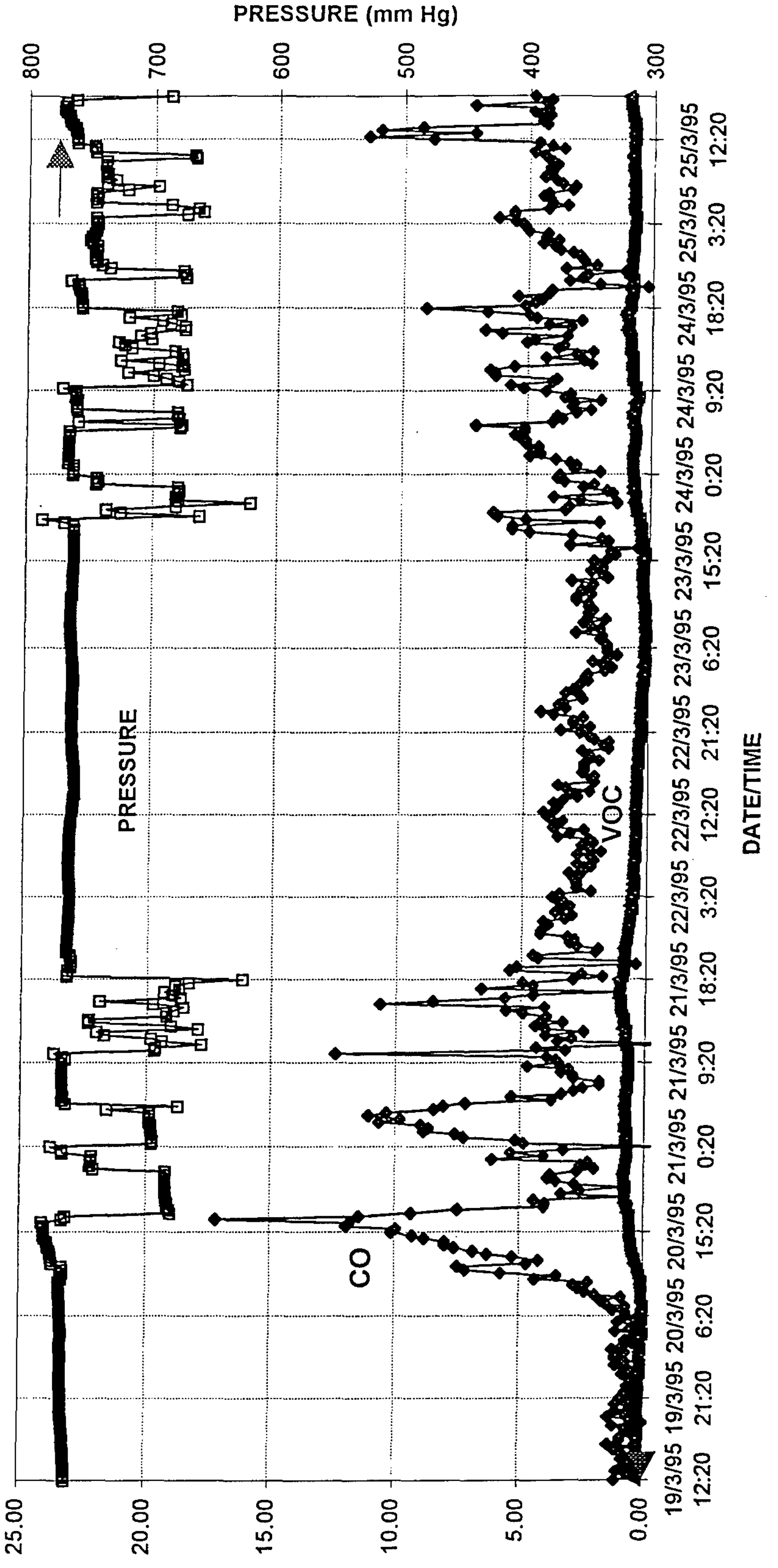

Figure 9b. Pressure and temperature corrected VOCs and CO concentrations.

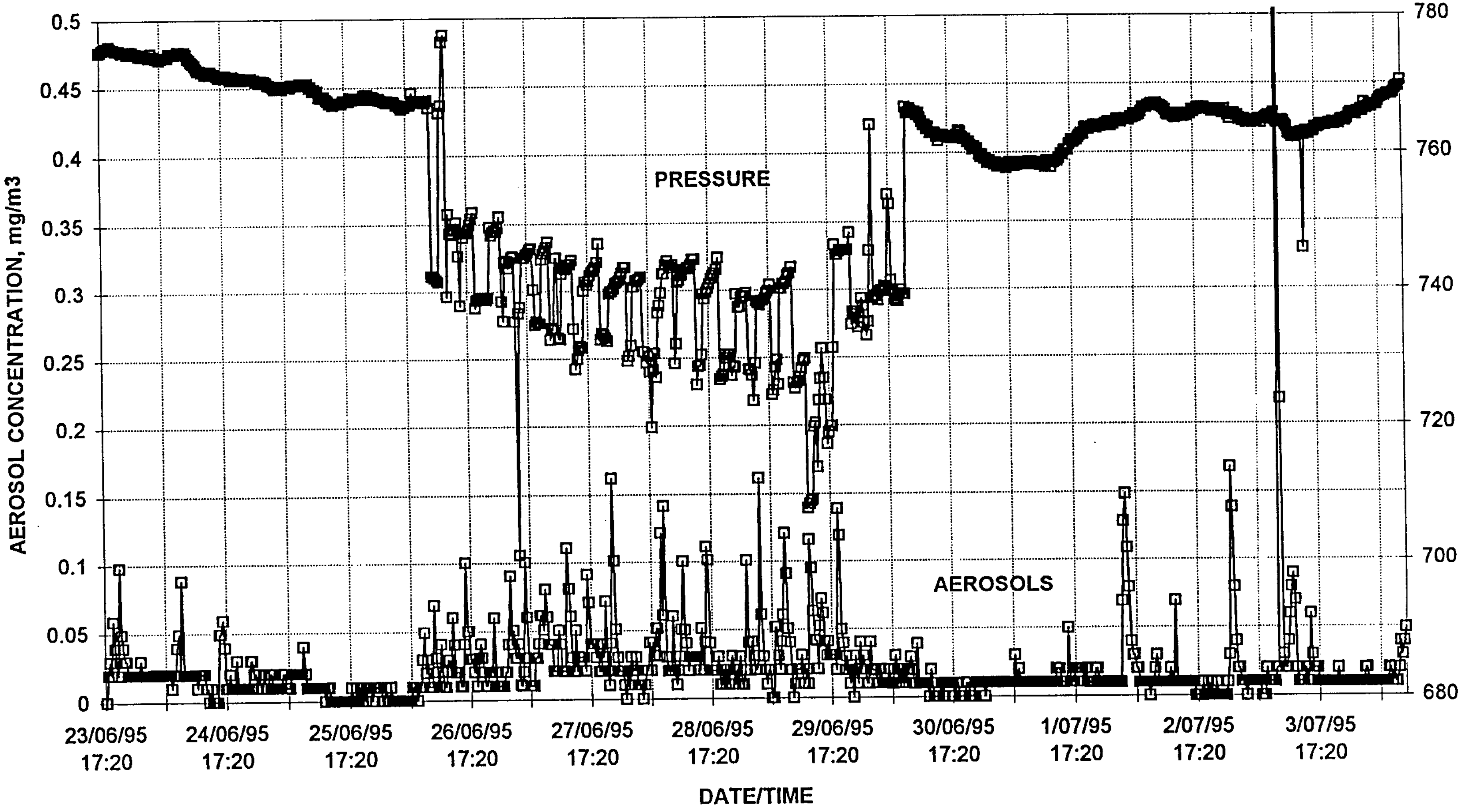

Figure 10a. Temperature and pressure corrected aerosol concentrations.

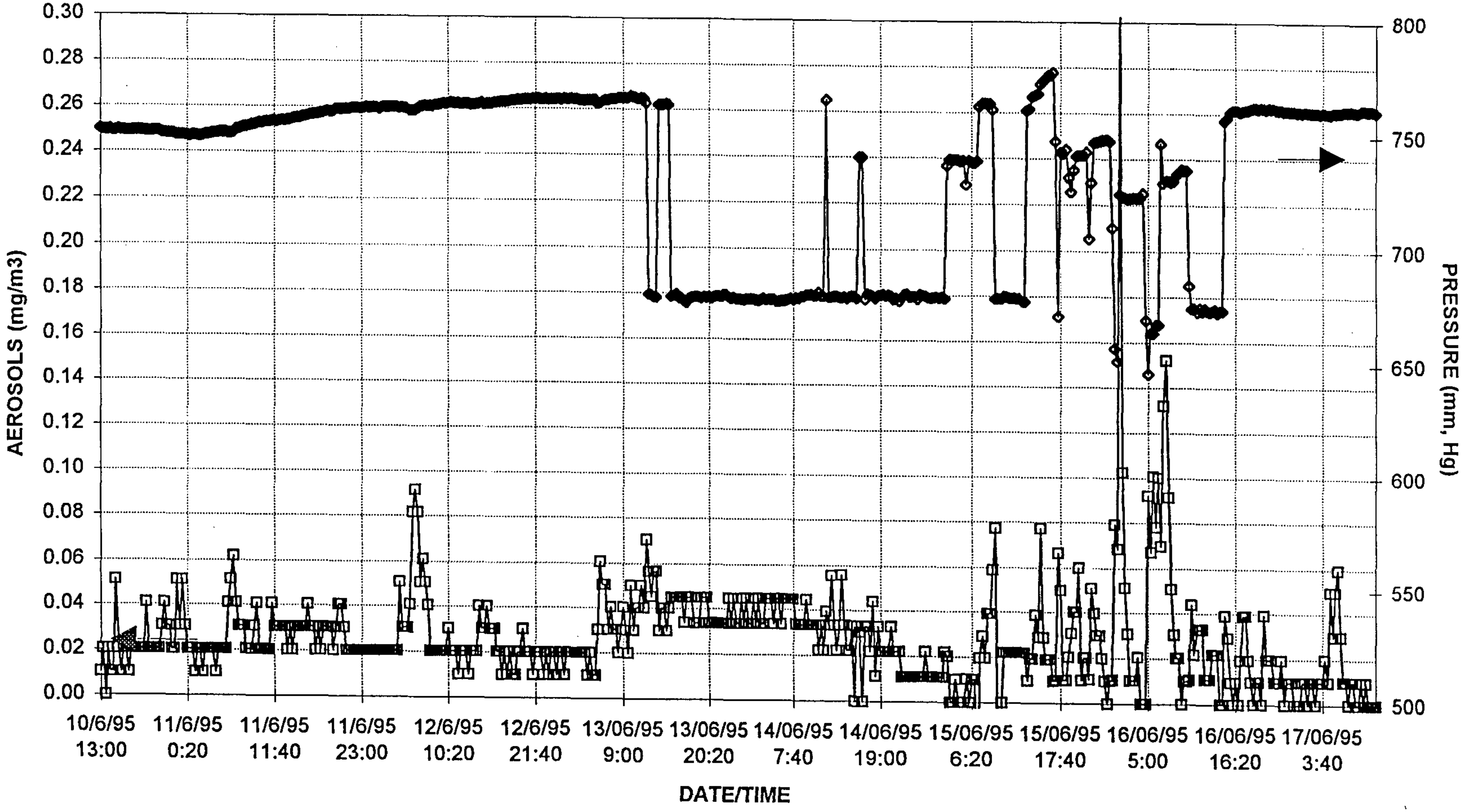

Figure 10b. Temperature and pesssure corrected aerosol concentrations.

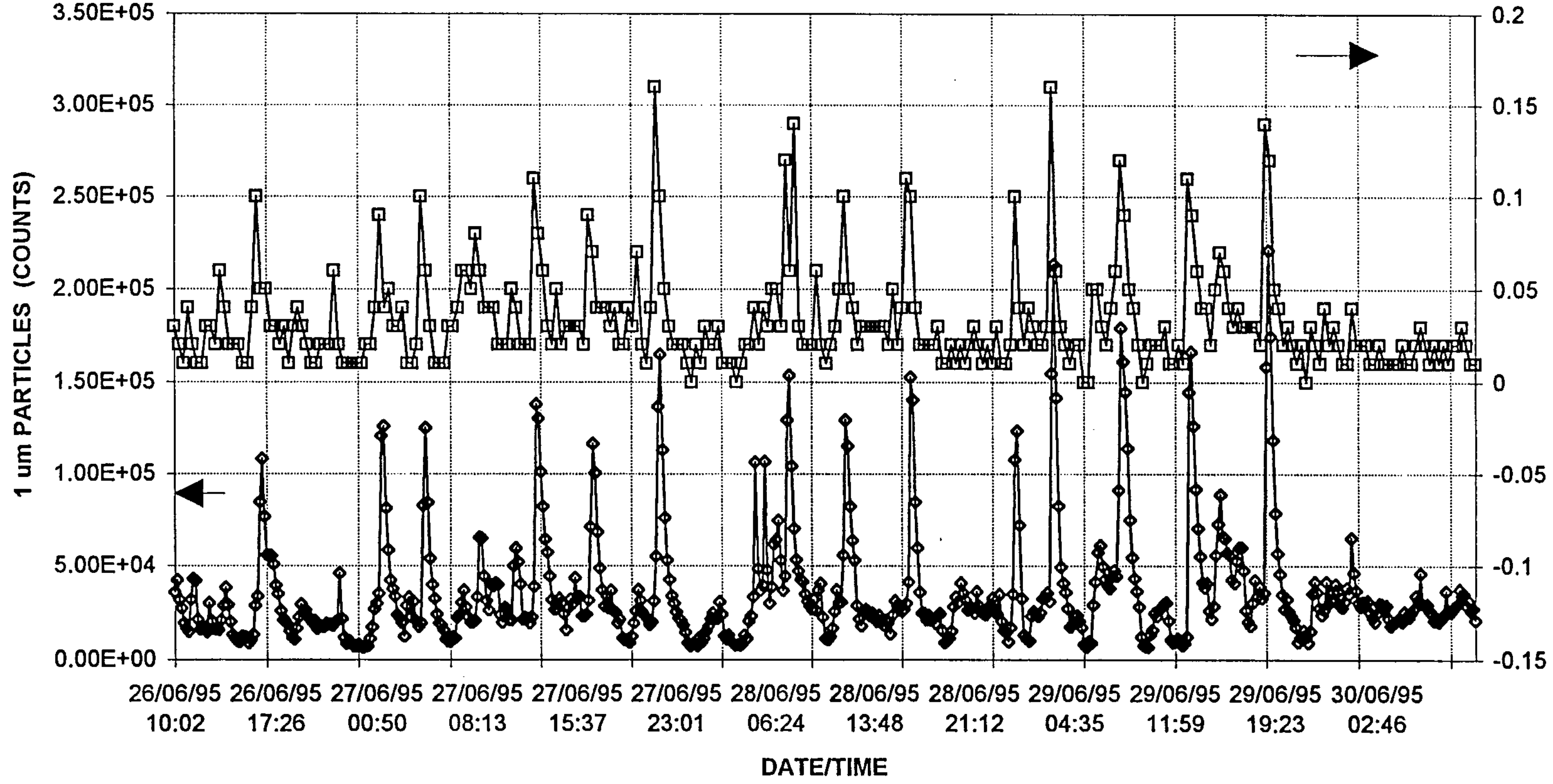

Figure 10c. Correlation between 1 um particle counts and total aerosol concentrations.

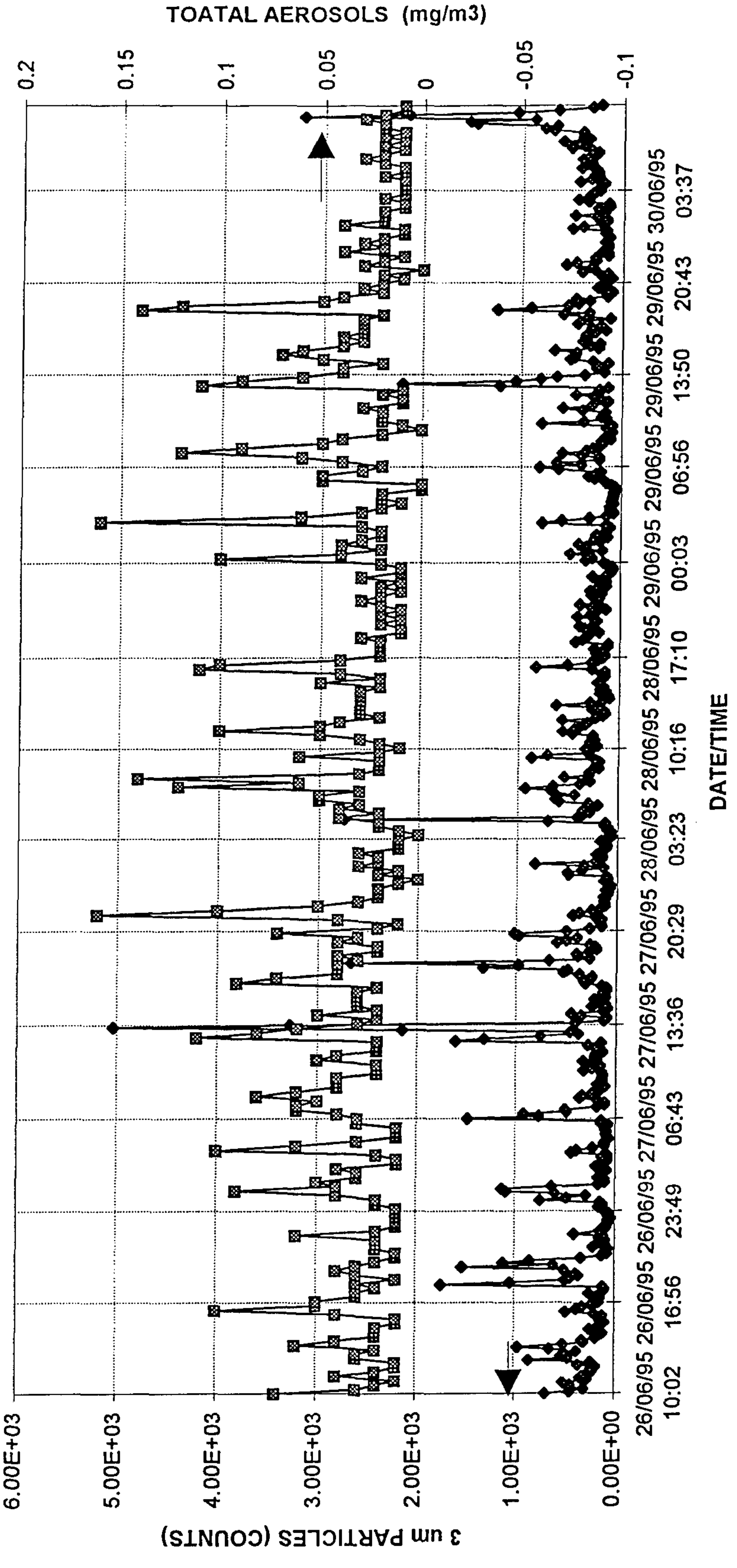

Figure 10d. Correlation between 3um particle counts and total aerosol concentrations.

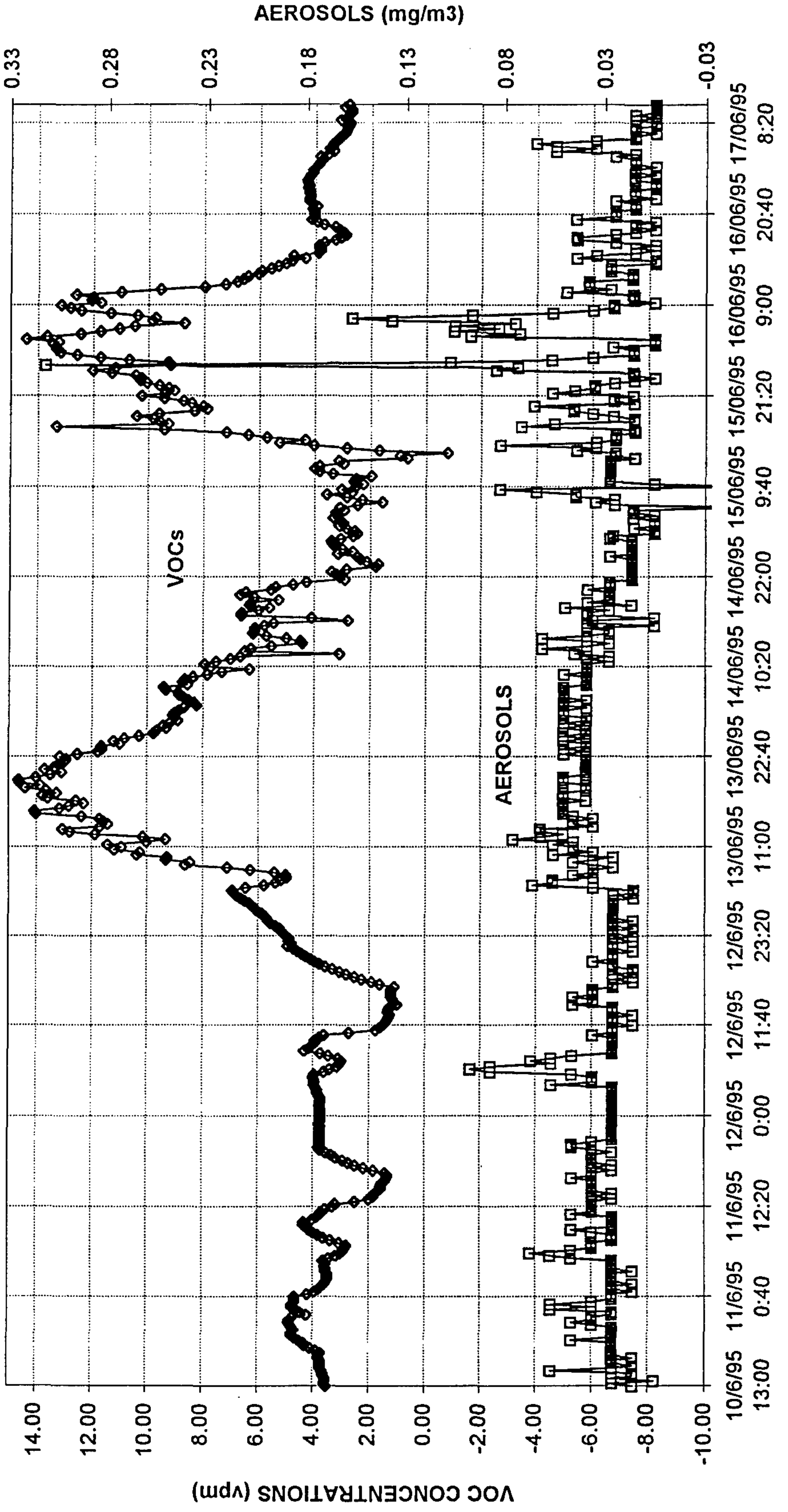

Figure 11. Correlation between aerosol and VOC concentrations.

APPENDIX A

```
    BEEP
  END SELECT
LOOP
CLS
END

SUB calibrate
DIM readparam$(9)
CLS
OPEN "cal10.cal" FOR INPUT AS #1
n = 0
FOR n = 1 TO 9
  LINE INPUT #1, readparam$(n)
NEXT
CLOSE #1
DO
 LOCATE 4
 PRINT "  Calibration factors ( Sn=low phys,high phys,low sign,high sign )"
 i = 5
 LOCATE i + 1, 10
 PRINT "2  Pressure              " + readparam$(1)
 LOCATE i + 2, 10
 PRINT "3  Humidity               " + readparam$(2)
 LOCATE i + 3, 10
 PRINT "4  Hydrogen               " + readparam$(3)
 LOCATE i + 4, 10
 PRINT "5  Oxygen                 " + readparam$(4)
 LOCATE i + 5, 10
 PRINT "6  Carbon monoxide        " + readparam$(5)
 LOCATE i + 6, 10
 PRINT "7  Carbon dioxide         " + readparam$(6)
 LOCATE i + 7, 10
 PRINT "8  Freon                  " + readparam$(7)
 LOCATE i + 8, 10
 PRINT "9  VOC                    " + readparam$(8)
 LOCATE i + 9, 10
 PRINT "X  Aerosol                " + readparam$(9); ""

 LOCATE 16, 10
 PRINT "Select channel to calibrate (type 0 to exit) "
 ch$ = INPUT$(1)
 ch$ = UCASE$(ch$)

  SELECT CASE ch$
   CASE "2"
    CLS
    LOCATE 10, 10
    PRINT readparam$(1)
    LOCATE 12, 10
    INPUT "Enter lower physical value :", lp$
    LOCATE 13, 10
    INPUT "Enter higher physical value :", hp$
    LOCATE 14, 10
    INPUT "Enter lower signal value :", ls$
    LOCATE 15, 10
    INPUT "Enter higher signal value :", hs$
    nv$ = "S2=" + lp$ + "," + hp$ + "," + ls$ + "," + hs$
    LOCATE 17, 10
```

```
   PRINT nv$
   LOCATE 19, 10
   INPUT "Do you want to replace the old parameters with these"; f$
   f$ = UCASE$(f$)
   CLOSE #1
   IF f$ = "Y" THEN
     MID$(readparam$(1), 1, 20) = nv$
     readparam$(1) = nv$
     OPEN "cal10.cal" FOR OUTPUT AS #1
     FOR i = 1 TO 9
     PRINT #1, readparam$(i)
     NEXT
     CLOSE #1
   END IF
   CLS
  CASE "3"
   CLS
   LOCATE 10, 10
   PRINT readparam$(2)
   LOCATE 12, 10
   INPUT "Enter lower physical value :", lp$
   LOCATE 13, 10
   INPUT "Enter higher physical value :", hp$
   LOCATE 14, 10
   INPUT "Enter lower signal value :", ls$
   LOCATE 15, 10
   INPUT "Enter higher signal value :", hs$
   nv$ = "S3=" + lp$ + "," + hp$ + "," + ls$ + "," + hs$
   LOCATE 17, 10
   PRINT nv$
   LOCATE 19, 10
   INPUT "Do you want to replace the old parameters with these"; f$
   f$ = UCASE$(f$)
   CLOSE #1
   IF f$ = "Y" THEN
     MID$(readparam$(2), 1, 20) = nv$
     readparam$(2) = nv$
     OPEN "cal10.cal" FOR OUTPUT AS #1
     FOR i = 1 TO 9
     PRINT #1, readparam$(i)
     NEXT
     CLOSE #1
   END IF
   CLS

  CASE "4"
   CLS
   LOCATE 10, 10
   PRINT readparam$(3)
   LOCATE 12, 10
   INPUT "Enter lower physical value :", lp$
   LOCATE 13, 10
   INPUT "Enter higher physical value :", hp$
   LOCATE 14, 10
   INPUT "Enter lower signal value :", ls$
   LOCATE 15, 10
   INPUT "Enter higher signal value :", hs$
   nv$ = "S4=" + lp$ + "," + hp$ + "," + ls$ + "," + hs$
```

```
  LOCATE 17, 10
  PRINT nv$
  LOCATE 19, 10
  INPUT "Do you want to replace the old parameters with these"; f$
  f$ = UCASE$(f$)
  CLOSE #1
  IF f$ = "Y" THEN
    MID$(readparam$(3), 1, 20) = nv$
    readparam$(3) = nv$
    OPEN "cal10.cal" FOR OUTPUT AS #1
    FOR i = 1 TO 9
    PRINT #1, readparam$(i)
    NEXT
    CLOSE #1
   END IF
  CLS

CASE "5"
  CLS
  LOCATE 10, 10
  PRINT readparam$(4)
  LOCATE 12, 10
  INPUT "Enter lower physical value :", lp$
  LOCATE 13, 10
  INPUT "Enter higher physical value :", hp$
  LOCATE 14, 10
  INPUT "Enter lower signal value :", ls$
  LOCATE 15, 10
  INPUT "Enter higher signal value :", hs$
  nv$ = "S5=" + lp$ + "," + hp$ + "," + ls$ + "," + hs$
  LOCATE 17, 10
  PRINT nv$
  LOCATE 19, 10
  INPUT "Do you want to replace the old parameters with these"; f$
  f$ = UCASE$(f$)
  CLOSE #1
  IF f$ = "Y" THEN
    MID$(readparam$(4), 1, 20) = nv$
    readparam$(4) = nv$
    OPEN "cal10.cal" FOR OUTPUT AS #1
    FOR i = 1 TO 9
    PRINT #1, readparam$(i)
    NEXT
    CLOSE #1
   END IF
  CLS

CASE "6"
  CLS
  LOCATE 10, 10
  PRINT readparam$(1)
  LOCATE 12, 10
  INPUT "Enter lower physical value :", lp$
  LOCATE 13, 10
  INPUT "Enter higher physical value :", hp$
  LOCATE 14, 10
  INPUT "Enter lower signal value :", ls$
  LOCATE 15, 10
```

```
  INPUT "Enter higher signal value :", hs$
  nv$ = "S6=" + lp$ + "," + hp$ + "," + ls$ + "," + hs$
  LOCATE 17, 10
  PRINT nv$
  LOCATE 19, 10
  INPUT "Do you want to replace the old parameters with these"; f$
  f$ = UCASE$(f$)
  CLOSE #1
  IF f$ = "Y" THEN
    MID$(readparam$(5), 1, 20) = nv$
    readparam$(5) = nv$
    OPEN "cal10.cal" FOR OUTPUT AS #1
    FOR i = 1 TO 9
    PRINT #1, readparam$(i)
    NEXT
    CLOSE #1
  END IF
 CLS

CASE "7"
 CLS
 LOCATE 10, 10
 PRINT readparam$(6)
 LOCATE 12, 10
 INPUT "Enter lower physical value :", lp$
 LOCATE 13, 10
 INPUT "Enter higher physical value :", hp$
 LOCATE 14, 10
 INPUT "Enter lower signal value :", ls$
 LOCATE 15, 10
 INPUT "Enter higher signal value :", hs$
 nv$ = "S7=" + lp$ + "," + hp$ + "," + ls$ + "," + hs$
 LOCATE 17, 10
 PRINT nv$
 LOCATE 19, 10
 INPUT "Do you want to replace the old parameters with these"; f$
 f$ = UCASE$(f$)
 CLOSE #1
 IF f$ = "Y" THEN
   MID$(readparam$(6), 1, 20) = nv$
   readparam$(6) = nv$
   OPEN "cal10.cal" FOR OUTPUT AS #1
   FOR i = 1 TO 9
   PRINT #1, readparam$(i)
   NEXT
   CLOSE #1
 END IF
 CLS

CASE "8"
 CLS
 LOCATE 10, 10
 PRINT readparam$(7)
 LOCATE 12, 10
 INPUT "Enter lower physical value :", lp$
 LOCATE 13, 10
 INPUT "Enter higher physical value :", hp$
 LOCATE 14, 10
```

```
  INPUT "Enter lower signal value :", ls$
  LOCATE 15, 10
  INPUT "Enter higher signal value :", hs$
  nv$ = "S8=" + lp$ + "," + hp$ + "," + ls$ + "," + hs$
  LOCATE 17, 10
  PRINT nv$
  LOCATE 19, 10
  INPUT "Do you want to replace the old parameters with these"; f$
  f$ = UCASE$(f$)
  CLOSE #1
  IF f$ = "Y" THEN
    MID$(readparam$(7), 1, 20) = nv$
    readparam$(7) = nv$
    OPEN "cal10.cal" FOR OUTPUT AS #1
    FOR i = 1 TO 9
    PRINT #1, readparam$(i)
    NEXT
    CLOSE #1
  END IF
  CLS

CASE "9"
  CLS
  LOCATE 10, 10
  PRINT readparam$(8)
  LOCATE 12, 10
  INPUT "Enter lower physical value :", lp$
  LOCATE 13, 10
  INPUT "Enter higher physical value :", hp$
  LOCATE 14, 10
  INPUT "Enter lower signal value :", ls$
  LOCATE 15, 10
  INPUT "Enter higher signal value :", hs$
  nv$ = "S9=" + lp$ + "," + hp$ + "," + ls$ + "," + hs$
  LOCATE 17, 10
  PRINT nv$
  LOCATE 19, 10
  INPUT "Do you want to replace the old parameters with these"; f$
  f$ = UCASE$(f$)
  CLOSE #1
  IF f$ = "Y" THEN
    MID$(readparam$(8), 1, 20) = nv$
    readparam$(8) = nv$
    OPEN "cal10.cal" FOR OUTPUT AS #1
    FOR i = 1 TO 9
    PRINT #1, readparam$(i)
    NEXT
    CLOSE #1
  END IF
  CLS

CASE "X"
  CLS
  LOCATE 10, 10
  PRINT readparam$(9)
  LOCATE 12, 10
  INPUT "Enter lower physical value :", lp$
  LOCATE 13, 10
```

```
      INPUT "Enter higher physical value :", hp$
      LOCATE 14, 10
      INPUT "Enter lower signal value :", ls$
      LOCATE 15, 10
      INPUT "Enter higher signal value :", hs$
      nv$ = "S10=" + lp$ + "," + hp$ + "," + ls$ + "," + hs$
      LOCATE 17, 10
      PRINT nv$
      LOCATE 19, 10
      INPUT "Do you want to replace the old parameters with these"; f$
      f$ = UCASE$(f$)
      CLOSE #1
      IF f$ = "Y" THEN
        MID$(readparam$(9), 1, 20) = nv$
        readparam$(9) = nv$
        OPEN "cal10.cal" FOR OUTPUT AS #1
        FOR i = 1 TO 9
        PRINT #1, readparam$(i)
        NEXT
        CLOSE #1
      END IF
      CLS


    CASE "S"
    PRINT
    CASE "0"
     EXIT DO
    CASE ELSE
     BEEP
  END SELECT
LOOP
CLS
CLOSE #1
LOCATE 10, 20

END SUB

SUB checkstat
CLS
LOCATE 10, 20
PRINT "Receiving parameters from Datataker"
OPEN "COM1:1200,N,8,1" FOR RANDOM AS #2 LEN = 4096
DIM stj$(9)
PRINT #2, "/U"
PRINT #2, "STATUS"
FOR i = 1 TO 2000: NEXT
FOR j = 1 TO 9
  LINE INPUT #2, stj$(j)
NEXT
PRINT #2, "/u"
FOR i = 1 TO 2000: NEXT
CLOSE #2
CLS
LOCATE 3
FOR j = 1 TO 9
  PRINT stj$(j)
NEXT
```

```
LOCATE 22, 15
PRINT "Press any key to exit"
DO
  keyinput$ = INKEY$
  IF keyinput$ <> "" THEN
    EXIT DO
  END IF
LOOP
END SUB

SUB meas
CLS
LOCATE 10, 25
PRINT "Communicating with Datataker...."
OPEN "COM1:1200,N,8,1" FOR RANDOM AS #2 LEN = 4096
PRINT #2, "GB"
PRINT #2, "/R"
DO
 keyinput$ = INKEY$
 IF keyinput$ <> "" THEN
   EXIT DO
 END IF
 readcal
LOOP
PRINT #2, "/r"
PRINT #2, "HB"
FOR i = 1 TO 2000: NEXT
CLOSE #2
END SUB

SUB measraw
CLS
LOCATE 10, 25
PRINT "Communicating with Datataker...."
PRINT
OPEN "COM1:1200,N,8,1" FOR RANDOM AS #2 LEN = 4096
PRINT #2, "/R"
PRINT #2, "GC"
DO
 keyinput$ = INKEY$
 IF keyinput$ <> "" THEN
   EXIT DO
 END IF
 readraw
LOOP
PRINT #2, "HC"
PRINT #2, "/r"
FOR i = 1 TO 2000: NEXT
CLOSE #2
END SUB

SUB readcal
IF NOT EOF(2) THEN
     FOR i = 1 TO 4000: NEXT
     CLS
     dinput$ = INPUT$(LOC(2), 2)
     LOCATE 5, 1
     PRINT "                    Realtime data from sensors"
```

```
    LOCATE 9, 1
    PRINT " Date    Time   Temp Press  Hum  H2  O2    CO  CO2  R12  VOC1 Part"
    LOCATE 10, 1
    PRINT "                Deg  mmHg  %RH   %   %    ppm   %   ppm  ppm  mg/m3"
    LOCATE 12, 1
    PRINT dinput$
    LOCATE 20, 1
    PRINT "                  Press any key to exit"
END IF
END SUB

SUB readraw
IF NOT EOF(2) THEN
    FOR i = 1 TO 4000: NEXT
    CLS
    dinput$ = INPUT$(LOC(2), 2)
    LOCATE 5, 1
    PRINT "                  Realtime data from sensors"
    LOCATE 9, 1
    PRINT " Date    Time   Temp Press  Hum  H2  O2    CO  CO2  R12  VOC1 Part"
    LOCATE 10, 1
    PRINT "                Deg  mA    mV   mV  mV    mA  mA   mA   mV   mV"
    LOCATE 12, 1
    PRINT dinput$
    LOCATE 20, 1
    PRINT "                  Press any key to exit"
END IF
END SUB

SUB sparam
DIM pline$(9)
CLS
LOCATE 10, 13
INPUT "Are you sure that you want to initialize Datataker ?", fl$
CLS
fl$ = UCASE$(fl$)
IF fl$ = "Y" THEN
  SOUND 400, 3
  SOUND 800, 3
  SOUND 400, 3
  SOUND 800, 3
  LOCATE 10, 13
  INPUT "      Are you really sure ?", fl$
END IF
fl$ = UCASE$(fl$)
IF fl$ = "Y" THEN
  OPEN "cal10.cal" FOR INPUT AS #1
  FOR l = 1 TO 9
    LINE INPUT #1, pline$(l)
  NEXT
  CLOSE #1
  CLS
  LOCATE 10, 25
  PRINT "Sending parameters to Datataker...."
  OPEN "COM1:1200,N,8,1" FOR RANDOM AS #2 LEN = 4092
  PRINT #2, "RESET"
  FOR i = 1 TO 10000: NEXT
  PRINT #2, "/e"
```

```
d$ = MID$(DATE$, 4, 2)
m$ = MID$(DATE$, 1, 2)
Y$ = MID$(DATE$, 7, 4)
PRINT #2, "D=" + d$ + "/" + m$ + "/" + Y$
FOR i = 1 TO 2000: NEXT
PRINT #2, "T=" + TIME$
FOR i = 1 TO 2000: NEXT
PRINT #2, "/S"
PRINT #2, "/o"
PRINT #2, "/D"
PRINT #2, "/T"
PRINT #2, "/u/n"
PRINT #2, "/r"
PRINT #2, "P22=32"
FOR i = 1 TO 3000: NEXT
PRINT #2, "P33=5"
FOR i = 1 TO 3000: NEXT
PRINT #2, "P25=42"
FOR i = 1 TO 3000: NEXT
FOR n = 1 TO 9
  PRINT #2, pline$(n)
  FOR i = 1 TO 1000: NEXT
NEXT

PRINT #2, "BEGIN"
PRINT #2, "RA15M"              'RA
PRINT #2, "1TK()"
PRINT #2, "2#I(S2,FF1,NR)"
PRINT #2, "3V(S3,FF1,NR)"
PRINT #2, "4V(S4,FF2,NR)"
PRINT #2, "5V(S5,FF2,NR)"
PRINT #2, "6#I(S6,FF1,NR)"
PRINT #2, "7#I(S7,FF2,NR)"
PRINT #2, "8#I(S8,FF1,NR)"
PRINT #2, "9V(S9,FF1,NR)"
PRINT #2, "10V(S10,FF2,NR)"


PRINT #2, "RB1S"              'RB
PRINT #2, "1TK(NL)"
PRINT #2, "2#I(S2,FF1,NL)"
PRINT #2, "3V(S3,FF1,NL)"
PRINT #2, "4V(S4,FF1,NL)"
PRINT #2, "5V(S5,FF1,NL)"
PRINT #2, "6#I(S6,FF1,NL)"
PRINT #2, "7#I(S7,FF2,NL)"
PRINT #2, "8#I(S8,FF1,NL)"
PRINT #2, "9V(S9,FF1,NL)"
PRINT #2, "10V(S10,FF2,NL)"

PRINT #2, "RC1S"              'RC
PRINT #2, "1TK(NL)"
PRINT #2, "2#I(NL)"
PRINT #2, "3V(NL)"
PRINT #2, "4V(NL)"
PRINT #2, "5V(NL)"
PRINT #2, "6#I(NL)"
PRINT #2, "7#I(NL)"
```

```
      PRINT #2, "8#I(NL)"
      PRINT #2, "9V(NL)"
      PRINT #2, "10V(NL)"
      PRINT #2, "END"
      FOR i = 1 TO 5000: NEXT
      PRINT #2, "H"
      FOR i = 1 TO 10000: NEXT
      CLOSE #2
   END IF
   END SUB

   SUB startlog
   OPEN "COM1:1200,N,8,1" FOR RANDOM AS #2 LEN = 4096
   CLS
   LOCATE 10, 13
   INPUT "Enter logging interval (1S =1 sek, 1M =1 min etc) ", int$
   int$ = UCASE$(int$)
   CLS
   LOCATE 10, 25
   PRINT "Sending parameters to Datataker..."
   PRINT #2, "RA" + int$
   PRINT #2, "/r"
   PRINT #2, "GA"
   PRINT #2, "LOGON"
   FOR i = 1 TO 4000: NEXT
   CLOSE #2
   END SUB

   SUB stoplog
   CLS
   LOCATE 10, 25
   PRINT "Sending parameters to Datataker..."
   OPEN "COM1:1200,N,8,1" FOR RANDOM AS #2 LEN = 4096
   LOCATE 10, 25
   PRINT "Sending parameters to Datataker..."
   PRINT #2, "HA"
   PRINT #2, "LOGOFF"
   FOR i = 1 TO 5000: NEXT
   CLOSE #2
   END SUB

   SUB uload
   OPEN "COM1:1200,N,8,1" FOR RANDOM AS #2 LEN = 8196
   CLS
   LOCATE 10, 30
   INPUT "Save data as "; file$
   IF file$ <> "" THEN
    file$ = file$ + ".dat"
    CLS
    PRINT #2, "/t /d"
    PRINT #2, "/r"
    FOR i = 1 TO 1000: NEXT
    LOCATE 8
    PRINT "Transfering data from Datataker to file: " + file$
    PRINT #2, "2SV"
    FOR i = 1 TO 1000: NEXT
    LINE INPUT #2, p$
    PRINT #2, "/T /D"
```

```
   FOR i = 1 TO 1000: NEXT
   c = VAL(p$)
   IF c = 0 OR c > 13500 THEN
     c = 22
   END IF
   lin = c / 11
   lin = FIX(lin)
   LOCATE 9
   PRINT "Total amount of samples to be transfered:"
   LOCATE 9, 43
   PRINT lin
   LOCATE 11
   PRINT "Sample nr: "
   LOCATE 14
   PRINT "Reading:"
   PRINT #2, "U"
   FOR i = 1 TO 5000: NEXT
   OPEN file$ FOR OUTPUT AS #1
   PRINT #1, "Date Time Temperature Pressure Humidity H2 O2 CO CO2 R12 VOC Unit"
   FOR i = 1 TO lin
      INPUT #2, dinput$
      LOCATE 11, 11
      PRINT i
      mileft = .01 * (lin - i)
      LOCATE 12
      PRINT USING "Time (min) until data is downloaded: ###.#"; mileft
      LOCATE 15
      PRINT dinput$
      PRINT #1, dinput$
   NEXT
   CLOSE #1
END IF
CLOSE #2

END SUB
```

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M. Loncar, P.J. Hanhela, T. H. Gan & W. Mazurek

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M. Loncar, P. J. Hanhela, T. H. Gan and W. Mazurek

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Aeronautical and Maritime Research Laboratory
PO Box 4331
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Atmosphere monitoring; Environmental monitoring; Air quality; Submarine atmospheres

19. ABSTRACT

(R) Three air monitoring trials were undertaken in an RAN Oberon class submarine, HMAS Ovens, using an instrument package consisting of commercially available monitors for hydrogen, hydrogen chloride, chlorine, oxygen, carbon monoxide, carbon dioxide, refrigerant R-12, volatile organic compounds (VOCs) and aerosols.

(R) During the trial periods, dive times were short so there was little opportunity for the build up of air contaminants. However, of the air contaminants measured, only the VOCs exceeded maximum permissible levels although aerosols concentrations were considered to be high by outdoor environmental standards.

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