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Environment Agency

A Review of the Industrial Uses of Continuous Monitoring Systems:

Incineration Processes

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A REVIEW OF THE INDUSTRIAL USES OF CONTINUOUS MONITORING SYSTEMS:

INCINERATION PROCESSES

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EXECUTIVE SUMMARY

This report examines the use of continuous monitors at incineration plant under four headings: Legal and Technical Framework; Process Parameter Monitoring; Monitoring of Emissions to Air; and, Monitoring of Releases to Water and Solid Residues . There are also detailed appendices which provide specific suppliers' details for continuous monitoring instrumentation.

- Legal and Technical Framework.

  This section examines the development of laws, regulations and technical guidelines concerning the use of continuous monitors at incinerators in the UK, Germany, Holland, the USA and the European Union (EU). Some of these frameworks, in particular the German and USA systems, are explained in some detail and many technical and statistical concepts that are an integral part of these frameworks are introduced. The legislation covering continuous monitors is examined, in particular the parameters that must be monitored continuously under the different legal systems. This will be of interest to plant operators in general. Some of the more complex concepts, in particular regarding calibration and verification, i.e. standard reference methods, detection limits, calibration curves, confidence and tolerance limits, relative accuracy etc., will be of more interest to legislators and specialists in this field.

  Probably the most developed legal and technical framework for the use of continuous monitors at incineration processes exists in Germany. The framework includes a clear legal requirement with regard to the use of continuous monitors;-the existence of a type approval system for continuous emission monitors (CEMs); a clear methodology for their on-site calibration and verification and the data they produce; and clear guidelines with regard to data handling and reporting formats.

  The framework in other European countries and the EU have been, and continue to be, heavily influenced by the experience to date in Germany.

  In the USA the laws and licensing practice for incinerators and the use of continuous monitors have evolved along different lines and in a much more diverse format than is the norm in Europe. The requirement for continuous monitoring is not as "standardised" as in Europe and much of the framework is currently based on state rather than federal laws. The system for calibration and verification is based on the methodologies widely used in the USA for CEMs at large combustion plant.

- Process Parameter Monitoring

  This section concentrates on the measurement of temperature, in particular the high temperatures associated with the primary and secondary combustion chambers in an incinerator. The problems associated with thermocouples and the use of a technical alternative, acoustic pyrometry, are examined.

  With a few exceptions, e.g. work by Her Majesty's Inspectorate of Pollution (HMIP) in the late 1980s, the accuracy and reliability of gas temperature measurements using

thermocouples in large scale incinerators has been largely ignored by both the incineration industry and legislators.

Work both in the UK, and more recently in Germany, has highlighted the difficulties encountered using thermocouples. The most attractive alternative, acoustic pyrometers, are very expensive. The use of these pyrometers might in certain circumstances be justified from the technical point of view by giving better control of the process and hence better economic performance.

The subject of verification of gas residence time in a secondary combustion chamber is also examined. Details are provided on current German developments in the technical guidance field on the positive demonstration, during compliance tests, of residence time.

The question of legal definitions of residence time in a secondary combustion chamber and the technically correct way of assessing this has been addressed in detail in the new proposed German regulations. The German proposal probably represents the ultimate in the literal approach to legal and technical measures in this area. The methodologies are associated with high costs.

The technology for the continuous measurement of residual oxygen (O_2), flue gas flow, flue gas water vapour and flue gas composition (prior to treatment) is also examined.

The continuous measurement of O_2 in incinerator flue gas is now state-of-the-art. A large number of both extractive and in-situ systems exist.

Systems are available for flue gas flow monitoring and several systems have been installed at operating incinerators. Flue gas water vapour monitoring is available via a number of instruments including as an option on some multi-component CEMs.

- Monitoring of Emissions to Air

The technology for compliance with TA LUFT 86 (1986 Technische Anleitung zur Reinhaltung der Luft - Technical Instructions on Air Quality Control) type standards and that required for the new standards being developed in Europe, in particular Germany and the EU, is examined. The review concentrates on those areas of CEM technology that are specific to incinerators, i.e. HCl, multi-component systems (developed specifically for incinerators), particulate matter and organic carbon monitoring. The principal technologies used for continuous monitoring of SO_2, NO_x, Particulate Matter, CO and CO_2 are well documented in a previous HMIP commissioned research report[Ref 4.1].

The performance of the available CEMs has been reviewed. This review has, in general, relied upon data from German approvals testing and tests carried out by the United States of America Environmental Protection Agency (USEPA). These are the only objective sources of information on the performance of CEMs systems. Strong conclusions with regard to, for example, cross duct versus extractive, Non Dispersive

Infra-Red (NDIR) versus Conductiometric (for HCl) cannot be drawn. Rather it can be objectively stated that a particular CEM met the minimum performance standard in properly organised and controlled tests.

A new generation of CEMs to monitor extremely low concentrations of pollutants has been developed in recent years in Germany to achieve compliance monitoring with the new regulations in the 17^{th} Regulation of the Federal Air Quality Law (Germany) 1990 (17BImSchV). Early operational experience has been good.

The current state of the German CEM market to meet 17BImSchV has led to very expensive systems, in excess of DM 500,000 per incinerator unit regardless of plant size. The development of these new systems has been accomplished in parallel with significant improvements in flue gas treatment technology, which results in emissions that are barely above the detection limits of the CEMs when the scrubbing system is working, and significant emissions when the technology malfunctions.

- Monitoring of Releases to Water and Solid Residues

Legislative requirements in the UK, Germany, Holland, the USA and the EU relating to continuous monitoring of releases to water and solid residues are examined. The review concentrates on monitoring techniques available for compliance with these requirements.

There are no legislative requirements for continuous monitoring of releases to land from incineration plants. There are, some requirements for continuous monitoring of releases to water, e.g. USA and UK.

1.0 INTRODUCTION

Entec was commissioned by the Energy Technology Support Unit (ETSU - as part of the Department of Trade and Industry's new and renewable energy programme) in association with Her Majesty's Inspectorate of Pollution (HMIP) to undertake a study entitled 'An Assessment of Continuous Monitors for Incineration Processes', including the following objectives:

- To detail the current and anticipated future requirements for continuous monitoring for incineration processes for both regulatory and process control purposes.
- To discuss and evaluate the currently available equipment in terms of its published performance and cost, and to assess its suitability for the tasks.
- To identify the numbers of instruments in operation and the general location of their installation.
- To report on the operational experience of continuous monitoring systems at selected sites, including performance, costs, problems and reliability.
- To report on systems in place for the calibration and verification of continuous monitoring equipment (including overseas).

Incineration processes studied included:

- Merchant & In-House Chemical Waste Incineration.
- Clinical Waste Incineration.
- Municipal Waste Incineration.
- Animal Carcass Incineration.
- The Burning out of Metal Containers.
- Sewage Sludge Incineration.

1.1 Project Methodology

The methodology developed for the project consisted of:

(1) **National and International Review of Legislation and Practice with regard to Continuous Monitoring (CM) at Incineration Plants.**

This task included review and assessment of the legal requirement for continuous monitoring (CM) resulting from national and international legislation, e.g. Environmental Protection Act 1990 (UK), 17BImSchV (Germany), Richlijn Verbranden (Holland), Draft EU Directive on Hazardous Waste Incineration, New

Source Performance Standards and State Regulations (USA). The review identified those parameters, in particular emissions to air, for which the installation of continuous monitoring technology is required. This covered Particulate Matter, SO_2, NO_x, HCl, HF, and TOC. Any requirement for the monitoring of ash quality, liquid effluent composition etc. was also identified.

The required performance standards, reference methods for instrument calibration, calibration procedures (linear regression analysis, Relative Accuracy etc.), and 'type approval' systems for CM instruments were also examined in detail.

(2) **Identification and Review of Continuous Monitoring (CM) for Process Parameters**

This included a review and assessment of among others:

- Temperature measurement - thermocouples, suction pyrometers, acoustic pyrometry (temperature mapping for secondary combustion chamber temperatures and for oxides of nitrogen reduction technology).
- Flue gas flow rate - averaging pitots, thermal dispersion, ultrasonic flowmeters.
- Residence time by monitoring of appropriate parameters.
- Flue gas O_2, moisture, CO, CO_2, pressure etc.
- Other process parameters, e.g. scrubbing liquor pH, NH_3 (for oxides of nitrogen reduction), etc.

(3) **Technology Review of Continuous Monitoring (CM) for Incineration Process Release Applications and Identification of Equipment Suppliers.**

This was completed by reference to a range of other published studies and literature and by direct contact with equipment suppliers.

During this technology review, UK, European and North American suppliers of suitable equipment were identified.

Individual companies were assessed with regard to strengths and weaknesses and individual CM systems were identified and assessed, i.e. techniques used, performance specifications, 'type approvals' obtained, detection limits and measurement ranges, compliance requirements of instruments, costs and ancillary equipment, etc.

(4) **Identification and Review of Research Needs and Current Activities.**

Areas of CM technology that are currently the subject of research were identified and the research itself subjected to a review with regard to aims and objectives, future influence of the developing technology, types of technology under research, benefits of developing technology compared to existing methods etc.

1.2 Report Structure

The report is presented in six sections including this introduction.

Section 2.0 examines the legal basis for the control of releases from incineration plant in the UK, Germany, Holland, USA and the European Union. The laws governing incinerators, including the licensing framework, are described and the release limits that apply to a range of controlled pollutants are given and compared. This section also includes a comparative review of international calibration and verification practices for continuous monitors.

Section 3.0 examines combustion control philosophies used to comply with legal requirements and the measurement technologies employed, and comments are made on the strength/weaknesses of each technology.

Section 4.0 examines continuous monitors for emissions to air, including multi-component monitors, HCl monitors, particulate monitors, organic carbon monitors and monitors for other parameters, such as sulphur dioxide and oxides of nitrogen. Research and future developments are also considered.

Section 5.0 reviews continuous monitors for releases to water and solid residues in a similar manner to that for Section 4.0.

Section 6.0 contains project conclusions and discusses the capabilities of CM compared to current and expected legislative requirements.

All tables and figures referenced in the report are to be found at the end of the corresponding section.

Glossary listing of abbreviations used in the report, follows Section 6.0.

References are given at the end of the report. For ease of reference they are given on a section by section basis. Where the same source is referenced in two or more sections, the reference is repeated.

Appendix I contains monitor details in tabular form for emissions to air.

Appendix II contains monitor details in tabular form for releases to water.

2.0 CONTINUOUS MONITORS - LEGAL AND TECHNICAL FRAMEWORK

Continuous monitors for incineration processes are used to:

- Monitor the process for plant control and supervision, providing the necessary information to the plant automatic control system and the operations staff to ensure safe and efficient operation.

- Demonstrate to the satisfaction of the plant licensing authorities that the plant complies with the operational requirements and release limits - to air, water and land - required under the relevant legislation and consequently specified in the plant operating licence or authorisation.

The legislative background is described in terms of the plant licensing requirements relevant to:

- The most important process conditions: incineration temperature in the secondary combustion chamber (SCC), the minimum flue gas residence time at the incineration temperature and the residual oxygen (O_2) content of the flue gas.

- The emission limits to air: i.e. concentration limits for carbon monoxide (CO), hydrogen chloride (HCl), hydrogen fluoride (HF), sulphur dioxide (SO_2), nitrogen oxides (NO_x), total organic carbon (TOC), heavy metals and polychlorinated dibenzo-p-dioxins and furans (PCDD and PCDF).

- Releases to water and land.

- The specified continuous monitoring requirement to demonstrate compliance with these conditions.

In addition to a clear legislative background, the successful use of continuous monitors, in particular continuous emission monitors (CEMs), for compliance monitoring purposes requires a national (or international) legal/technical framework within which the accuracy, comparability and reliability of monitoring results can be assessed. This framework should provide the scientific basis on which operators, licensing authorities and the enforcing judicial system can consider monitoring data from a common perspective with minimal disagreement on the actual representation of operational performance. The framework should be based on the existence of standardised measurement methods, performance criteria and quality control / quality assurance (QA/QC) procedures for continuous monitors, and data-logging and processing criteria.

The existence of a comprehensive set of Standard Reference Methods (SRMs) is the logical starting point for the framework. For flue gas concentration measurements, SRMs are fairly well defined and researched. These methods are prepared and published by the national and international standards organisations, e.g. International Standards Organisation (ISO), the European Standards Organisation (CEN), British Standards Institute (BSI), Verein Deutsche Ingineure (VDI), US Environmental Protection Agency (USEPA) etc. The performance characteristics of the SRM must be known, preferably for the application in question, i.e.

measurement in incineration plant flue gas, and at the expected concentration range. Important characteristics are the precision or relative standard deviation and the detection limit.

The availability of the standard deviation and detection limit for the SRM for the particular application and concentration range is extremely important for the framework within which continuous monitors operate. Measurement results obtained using an SRM may be deemed to be legally acceptable within the limitations described in the method performance characteristics. Therefore, the legal acceptability of CM data will depend, to a certain degree, on the performance of the CM system relative to the performance of the SRM. A central point of published performance criteria for continuous monitors under the various national and international systems is the relationship between the data obtained by the use of CM and that which would have been obtained if the SRM had been used.

Performance criteria for continuous monitors have been developed in a number of countries and by ISO. CEN is also working on performance criteria.

The legislation, the national/international SRMs used, the performance criteria for CEMs, data-logging and processing requirements and any performance criteria for process monitoring are described below.

2.1 The United Kingdom

2.1.1 Legislation

The principal legislation governing incineration plant in the UK is the Environmental Protection Act (EPA 1990)[Ref 2.1]. Incineration processes with capacities greater than one tonne per hour are prescribed for Integrated Pollution Control (IPC) regulated and authorised by the Environment Agency in England and Wales, the Scottish Environmental Protection Agency (SEPA) in Scotland, and the DoE (NI) in Northern Ireland.

Over 100 IPC authorised incineration processes were reported in England and Wales in 1994. The approximate breakdown was as follows:-

Municipal Waste Incinerators	46%
Clinical Waste Incinerators	7%
Drum Cleaning Incinerators	4%
Merchant Hazardous Waste Incinerators	4%
Sewage Sludge Incinerators	8%
In-house Incinerators	30%
Others (e.g. Animal Carcass Incinerators)	1%

IPC requires that the concepts of using Best Available Techniques Not Entailing Excessive Cost (BATNEEC) and Best Practical Environmental Option (BPEO) are applied to the authorisation process. Original guidance notes IPR 5/1, 5/2, 5/3, 5/4, 5/5 and 5/11 [Refs 2.2 - 2.7] published by HMIP in May 1992 described and interpreted what constituted BATNEEC and BPEO for the various types of incineration plant relevant to IPC. Environment Agency IPC Guidance Note S2, 5.01 [Ref 2.8] has now superseded these notes in the form of one document. In the preparation of the authorisation the Environment Agency will refer to the guidance provided in the current note in setting limits on releases and other operational conditions. There is an onus on the process operator to take account of the latest techniques for pollution prevention. IPC Guidance Notes represent the state of understanding and techniques at the time of writing and are revised at not more than four-yearly intervals from the date of publication to reflect improvements in pollution prevention. An overview of the emission limits that would be achievable for new incineration plant is given in Table 2.1 and the requirements for continuous monitoring are given in Table 2.2.

The new plant standards expressed in the original IPR 5 Guidance Notes reflected the limit values specified by the EU Directive 89/369/EEC (Council Directive of June 1989 on the prevention of air pollution from new municipal waste incineration plants). The 'benchmark' levels expressed in IPC Guidance Note S2, 5.01 reflect the more stringent limits of the Hazardous Waste Incineration Directive. The authorisation process and the inclusion of appropriate limits is used to execute the legal responsibilities of the UK Government in complying with the requirements of any relevant European or international agreements. The authorisation issued to a particular plant is usually subject to review every four years, but can be within this period where significant technological or legal implications have occurred. The review may result in tighter limits, if it is considered that BATNEEC for the plants has improved, or if new legal obligations are forthcoming from international agreements.

2.1.2 Standard Reference Methods

With the exception of the specification of BS 3405[Ref 2.9] for particulate monitoring, the Process Guidance Notes for incineration have not contained any specific information on the manual monitoring methods to be used for compliance monitoring purposes or for CEM calibration or verification. However, HMIP (now part of the Environment Agency) has issued general Technical Guidance Notes on the monitoring of emissions of pollutants at source[Ref 2.10, 2.11]. The notes describe, in outline, the available national and international standard methods for the types of pollutants to be found in flue gases, including those from incineration processes.

The standards described include:

- BS 3405 and BS 6069: Section 4.3 [Ref 2.12] in addition to German (VDI), Italian (Unichem), French (AFNOR) and American (USEPA) methods for particulate matter.
- German, French Italian and American methods for SO_2, NO_x, HCl, HF, metals and organics.
- BS 1756[Ref 2.13] for both SO_2 and NO_x in flue gas; and BS 6069: Sections 4.1[Ref 2.14] and 4.4[Ref 2.38] for manual and continuous measurement of SO_2 respectively..

2.1.3 Performance Criteria and QA/QC Procedures for CEMs

Process Guidance Notes include the following recommendations:

All continuous monitoring instruments should be maintained and calibrated according to the manufacturers' recommendations and to recognised standards. Regular zero and span checks should also be carried out. Particulate monitors should be calibrated at least annually against manual tests to the relevant standard. The instruments should also be recalibrated following replacement of any part which could affect the calibration not restorable by a span and zero resetting. Where continuous monitoring equipment is fitted the measurements should be either recorded continuously on paper charts or similar, or be held in computer storage.

2.1.4 Data-Logging and Processing

In Germany a well defined administrative structure exists for the reporting of data from CEM systems. Present UK guidelines require the results of all monitoring and inspections are to be recorded in a log book, or on computer storage, as appropriate, within one day of the measurement or inspection being made, unless otherwise agreed by the licensing body on grounds of impracticability. This record should be retained at the works for a minimum of four years after the date of the last entry and be made available for examination as and when required by the licensing body. Adverse results should be recorded in the log book and investigated immediately. The cause should be identified and corrective action taken with comprehensive records retained in the log book.

2.1.5 Performance Criteria for Controlled Process Measurements

UK legislation contains no specific guidance on process measurements.

2.2 Germany

2.2.1 Legislation

The construction and operation of all types of incineration plant in Germany, i.e municipal waste incinerators (MWIs), hazardous waste incinerators (HWIs), medical waste and sewage sludge incinerators, are controlled by two primary pieces of federal legislation - the Abfallgesetz (AbfG or Waste Law)[Ref 2.15], and the Bundes-Immissionschutzgesetz (BImSchG or Federal Air Quality Law)[Ref. 2.16]. The legislation implements a requirement for plant licensing and nominates the licensing authority, in most cases the state *Regierungspraesident.* (Note : Germany is divided into *Laender* or states under the federal constitution. Each state has its own government and can enact its own legislation. Each state is further divided into *Regierungen* or regions which have an appointed administration. This administration has primary responsibility for regional waste management.) The minimum requirements for operating conditions and emission limits, which are to be used in the preparation of the plant licence, are given in a regulation under BImSchG, i.e. the 17th Regulation (17BImSchV,[Ref 2.17]). This regulation came into force on the 1 December 1990 for new plant. Existing plant has to reapply for new operating licenses with compliance with 17BImSchV according to a timescale commencing in 1994 and finishing in 1996. The conditions in the regulation replaced guidance given in TA LUFT 86 (1986 Technische Anleitung zur Reinhaltung der Luft - Technical Instructions on Air Quality Control).

Part I of 17BImSchV describes the scope of the regulation and defines the terminology. Part II of 17BImSchV describes the required operating conditions, i.e. temperature, residence time and operating flue gas oxygen level, and the emission limits to be applied. Part III of the regulation deals specifically with the requirements for compliance monitoring. It states that each incineration plant operator should, as a minimum, continuously measure and record:

- The mass concentration of CO, total particulate matter, TOC (as total carbon), gaseous inorganic chlorine compounds (as HCl), gaseous inorganic fluorine compounds (as HF), sulphur oxides (as SO_2) and nitrogen oxides (as NO_2) in the flue gas.

- The volume content of oxygen in the flue gas.

- The temperature of the flue gas at the exit from the secondary combustion zone.

- The process parameters, in particular temperature, volume flow, water vapour content and pressure of the flue gas.

(Note : The regulation allows operators to claim an exemption from the requirement to measure HF continuously in cases where a flue gas treatment system to reduce HCl emissions is in place and where HCl is measured continuously. If HCl emissions are low then due to the higher reactivity of HF, its emission concentration will be negligible)

It is also stated in the regulation that additional parameters should be measured continuously as soon as appropriate monitoring technology is developed, e.g. mercury and other heavy metals and polychlorinated dioxins and furans.

The 17BImSchV emission limits and the monitoring requirements are summarised in Tables 2.1 and 2.2.

The relatively simple statement of monitoring requirements in the 17BImSchV regulation was expanded upon in a technical guideline issued by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) in 1992 - 'Guidelines for the Evaluation of Continuous Emission Measurements according to the Regulation on Incineration Plant'[Ref 2.18]. This guideline, together with two earlier guidelines on continuous emission monitoring issued in 1988 and 1990[Refs 2.19 and 2.20], defines the performance requirements of continuous monitoring equipment to be used at incinerators and also the requirements for recording and data processing to demonstrate compliance with both emission limits and process conditions. The VDI has also published two guidelines on the technology of both Municipal Waste Incinerators (MWI) and Hazardous Waste Incinerators (HWI)[Refs 2.21, 2.22] which contain sections on monitoring methods and technology to be employed.

There are no specific regulations on incineration for continuous monitoring of releases to water or land. Most German plants are moving to wastewater free operation. Any solid or liquid releases would be covered by general industrial regulations in these areas. Site visits were carried out at six German incinerators. None of the plants had requirements for continuous monitoring of releases to water or land.

2.2.2 Standard Reference Methods

The BMU and the VDI guidelines have specified a range of Standard Reference Methods (SRMs) to be used for emission monitoring purposes for incinerators. These are summarised in Table 2.3. The performance characteristics are described in the methods and would appear, in general, to be adequate for the task involved. However, due to the low emission limits specified, the methods specified for HCl, particulate matter and TOC warrant further comment.

The SRM recommended in Germany for HCl measurement is VDI 3480 Part 1 (Ref 2.23). This involves drawing a sample of flue gas through a heated probe and filter and absorbing the HCl in de-ionised water in two gas washing bottles. No allowance is made for isokinetic sampling. Three separate analytical methods are described for chloride determination in the solution, depending on the expected concentration and the likely interferences.

For the standard sample volume recommended by the method, 30 litres, the detection limit for analytical methods is given as 2 mg/m^3. Increasing the sample volume will lower the method detection limit to less than 1 mg/m^3.

The method standard deviation derived from double determinations is also given for various applications and measurement ranges. The standard dates from 1984 and hence all the validation work for the method refers to the late 1970s/early 1980s. Consequently no validation data are provided for low levels of HCl from incineration with wet scrubbers. However, in the concentration range 2.5 - 10 mg/m^3 (average 5 mg/m^3) a standard deviation of +/- 0.73 mg/m^3 is given for tunnel pickling, i.e. steel descaling by HCl acid which results in emissions of HCl. Therefore it is reasonable to assume that any HCl measurement result using this method for this application is within approximately +/- 30% of the average value that would be obtained if many individual measurements were carried out on the same flue gas at the same time i.e.:

$$\textit{Uncertainty } U = S_D t_{0.95}, \text{ with } t_{0.95} \approx 2.$$

Therefore, U = 1.46 mg/m3 or approximately 30% of average value (5 mg/m^3).

Recent experience in Germany using this method for low levels of HCl from incinerators has indicated that VDI 3480 Part 1 is adequate for measurement at low concentration levels, e.g. less than 10 mg/m^3 (Ref 2.24). Modern incinerators currently in operation and under construction in Germany usually employ some form of flue gas reheat for downstream NO_X and PCDD/PCDF removal equipment and given that the scrubbing systems employed are designed to a high specification, the flue gases are dry and have very low levels of possible interfering compounds. The detection limits and standard deviation of the method are deemed to be acceptable.

Any further development of the German standard for HCl has been suspended due to the activities of CEN (see Section 2.5.2).

The SRM recommended in Germany for particulate matter is either VDI 2066 Part 3 (Ref 2.25) or VDI 2066 Part 7 (Ref 2.26). Both of these methods involve sampling isokinetically at a high rate and separating the particulate matter from the flue gas using either a titanium thimble filled with quartz glass wool or a flat fibreglass filter. Two arrangements are permitted i.e.

with heated in-stack filter or with heated external filter. Where the flue gases are water saturated the external filter arrangement is recommended. The collected particulate matter is determined gravimetrically.

For VDI 2066 Part 3, a high sampling rate is specified, i.e. 40 m^3 /hr. The absolute detection limit for particulate matter in the titanium filter thimble is given as 9 mg. Therefore for a 40 m^3 sample volume, the method detection limit is 0.225 mg/m^3. The method standard deviation derived from double determinations is also given in the standard for various applications and measurement ranges. For a dry particulate matter scrubbing system, i.e. a bag filter, the standard deviation of an average particulate matter concentration of 6.9 mg/m^3 is given as 0.6 mg/m^3 (U= +/- 18.7%). For a wet particulate matter scrubbing system at an MWI, the standard deviation is 1.95 mg/m^3 (U= +/- 33%) for an average particulate matter concentration of 14.6 mg/m^3.

For the flat filter method, the absolute detection limit for the filter material is approximately 0.1mg. Therefore for a sample volume of 2 m^3 the relative detection limit is approximately 0.05 mg/m^3. The measurement Uncertainty, *U*, for measurements at MWI plants in the concentration range 0 - 10 mg/m^3 is quoted at 0.23 mg/m^3.

Recent experience in Germany indicates that the use of the flat filter is the preferred method for low level particulate matter measurements at incineration plants.

The German SRM for TOC is VDI 3481 Part 2 [Ref 2.27] and is based on the use of silica gel absorbtion tubes followed by analysis for CO in the laboratory. However, for the emission limit specified in 17BImSchV, i.e. 10 mg/m^3 as a daily average, the method cannot be used due to interference caused by other flue gas components, in particular water vapour [Ref 2.28]. It is recommended therefore that the SRM in Germany be based on Flame Ionisation Detectors (FID) and that the performance tests for installed FID CEMs be based on assessing the performance of the new system against that of an approved FID. Further details on the use of FID for TOC measurement are given in Section 4.

2.2.3 Performance Criteria and QA/QC Procedures for CEMs

German legislation (TA Luft 86 and 17BImSchV) states that the types of CEMs which can be used at incinerators must have successfully completed "suitability tests" for type approval for the particular application and measurement range. The type approval of a particular CEM system requires that the CEM is submitted to an independent body for both laboratory and site assessment. The criteria against which the performance of the CEM is tested are given in [Refs 2.19 and 2.20]. If the CEM meets or exceeds the minimum performance requirement, a "type approval" notice is published in the Joint Ministerial Gazette of the Federal Ministry of Environment [Ref 2.20]. The approval notice will list the name of the CEM system, the measurement range over which the tests were successfully carried out, any limitations with regard to application and any qualifications to the general approval. This testing only needs to be carried out once for the particular type of CEM and the particular application and measurement range. The performance criteria used are given in Table 2.4. Of particular relevance to the measurement of low concentrations of pollutants is the requirement for German CEMs to have a maximum measurement range of 1.5 times the 30 minute limit value while the limitation on zero and span drift and the definition of detection limit are given in terms of a percentage of the 24 hour average value. The detection limit is the concentration that can be distinguished from zero with 95% certainty and is limited to a maximum of 2% of the 24 hour average limit value. For example a CEM to supervise the German HCl emission limits must have the following characteristics:

- max. range : 0 - 90 mg/m³ (i.e. 1.5 times 60 mg/m³, the 30 minute average limit value)
- zero drift : 0.2 mg/m³ (2% of 10 mg/m³, the 24 hour average limit value) over the maintenance interval.
- span drift : 0.4 mg/m³ (4% of 10 mg/m³, the 24 hour average limit value) over the maintenance interval.
- detection limit: : 0.2 mg/m³ (2% of 10 mg/m³, the 24 hour average limit value)

The maintenance interval is the maximum time of unattended operation, i.e. the maximum operating period over which no operational or maintenance adjustments are necessary for the CEM. This interval is determined during the type approval testing. One of the most frequent maintenance operations is the adjustment of the zero and span gain settings by means of certified calibration gases. Therefore the zero and span drift, as defined above, are determining factors for the maintenance interval.

In addition to the installation of a "type approved" CEM, the operator of an incinerator must also employ an independent body to carry out an on-site calibration and verification of the system. The calibration procedure, which is described in the VDI 3950 Part 1 [Ref 2.29], involves concurrent measurement using an SRM and the CEM, during which the milliamp output signal from the CEM is averaged over the sampling time of the SRM. At least 20 sets of paired measurements are required. The data are subjected to linear (if the response of the CEM is linear) regression analysis to obtain a "best fit" curve relating the CEM output to the concentration values measured with the SRM. The curve relationship therefore takes all flue gas specific influences into consideration and should be considered as separate from the CEM response curve to certified calibration gas. The data set is subjected to further statistical analysis to determine a 95% confidence interval for the position of the curve and a 95% tolerance interval for the total data set. An example of the calibration curve with the confidence and tolerance interval is given in Figure 2.1. The calibration procedure described above is important for an understanding of the difficulties of measuring low pollutant concentrations in incineration flue gas.

The definition of the calibration curve, as derived by regression analysis, is an estimate based on a limited number of measurement pairs. The confidence and tolerance intervals define the uncertainty that is inherent in the measurement system and hence the uncertainty associated with deriving a pollutant concentration based on the CEM response. The statistical analysis [Ref 2.28] for the derivation of these intervals is rather complicated. However the 95% confidence interval can be considered to be a measure of the accuracy of the estimation of the position of the calibration curve, i.e. at any particular CEM response there is at most a 5% probability that the true position of the curve, corresponding to that response is outside the concentration range defined by the confidence interval. The tolerance interval defines a concentration range within which there is a 95% probability that 75% (or 95% depending on the precise definition of tolerance interval used) of all individual SRM measurement values giving rise to a particular CEM response are to be found. The concept of confidence and tolerance intervals is described in detail in an earlier HMIP report concerning Large Combustion Plant [Ref 2.30].

In the guidelines issued by the German authorities on the interpretation of measurement results obtained by CEMs [Ref 2.18], this measurement uncertainty is evaluated to the benefit of the operator. The compliance criteria for the specified emission limits in Germany states that no average emission concentration may be above the corresponding limit value. *If a CEM is used as the primary source of compliance data*, the emission limits can be redefined as follows:

- No 24 hour average concentration to exceed the emission limit *plus* the CEM confidence interval.

- No 30 minute average concentration to exceed the corresponding emission limit *plus* the CEM tolerance interval.

Clearly the size of the confidence and tolerance intervals achievable with available CEM technology is an important consideration with regard to the feasibility of using CEMs as compliance monitoring methods. A CEM to supervise an emission limit of 10 mg/m^3 with a confidence interval of +/- 20 mg/m^3 is of little use.

No limit is put on the maximum permitted size of the confidence or tolerance interval in the German guidance notes. However, the EU has suggested a maximum confidence limit as a CEM performance criteria (see Section 2.5.3).

2.2.4 Data-Logging and Processing

The data-logging system for the installed CEM, which must also be "type approved", should build 30 minute average values for a pollutant from the monitor output. The average value should be normalised to the standard conditions - dry gas at 273 K, 101.3 kPa and 11% O_2 - and should then be classified into one of 22 concentration classes (The class system is a means of simplifying the storage and reporting of emission data, i.e. the number of average values within a concentration range is stored rather than every actual average concentration). Classes 1 to 20 should be chosen to ensure that the limit value is in Class 20, i.e. for HCl Class 1 is 0 - 3 mg/m^3, Class 2 is 3 - 6 mg/m^3...... Class 20 is 57 - 60 mg/m^3. Class 21 should start at the limit value and end with the limit value plus the *tolerance interval* derived during the calibration tests. The *tolerance interval* should be at least 5% of the limit value, i.e. +/- 3 mg/m^3 for HCl.

The daily average values should be formed from the 30 minute averages and should be stored in one of three classes. Class 1 should contain all the values less than the emission limit. Class 2 should contain all the values greater than the limit value but less than the limit value plus the *confidence interval* . Class 3 should contain all the values greater than the limit value plus the *confidence interval*.

2.2.5 Performance Criteria for Controlled Process Measurements

The measurement of the flue gas temperature in the secondary combustion zone is dealt with in two short clauses in the 17BImSchV Regulations [Ref 2.17]. Ten minute average values are to be formed from the temperature data and these are to be stored in one of 20 temperature range classes. The minimum temperature, either 850 or 1200°C, should be on the border between Class 10 and 11. The total classification should cover a temperature range of at least 400 K. In recognition of the importance of temperature measurement for the incineration process and the lack of a standardised methodology for temperature and operational parameter measurement, a working group of the State Committee for Air Quality (*Laenderausschusses fuer Immissionschutz)* has commenced work on a new technical guidance note. The new guidance [Ref 2.31], deals with:

- Continuous measurement of the minimum required temperature and O_2 concentration in the SCC as well as the approval and verification of the measurement equipment and measurement position
- Acceptance tests of the incineration plant with the aim of positive demonstration of meeting the minimum requirements
- Verification and calibration of the measurement systems
- Parameterisation of the emission data computer
- Interlocking and control of waste feed and the firing of the combustion support burner(s).

The technical requirements in the guideline are examined in more detail in Section 3.

2.3 <u>The Netherlands</u>

2.3.1 Legislation

The controlling legislation for incineration plant in the Netherlands is the Waste Disposal Act [Ref 2.32]. The licensing authorities for new and existing plants are the regional municipalities. These organisations are responsible for the issuing of waste disposal licences and the licences that govern emissions to air and incinerator operations. Releases to controlled waters are generally controlled by the Rijkswaterstaat who are a national body fulfilling the same role as that of the former National Rivers Authority in England and Wales.

In 1989, the Dutch Government issued guidelines for the operation of incinerators which included new emission limits to air for a range of pollutants. The Richlijn Verbranden -RV89 [Ref 2.33] was to be used by the municipalities as the basis for authorisations for new plants. Existing plants had to achieve the new limits by the end of 1993. The guideline was raised to the status of a binding regulation in 1993 (Besluit luchtemissies afvalverbranding [Ref 2.34]). The emission limits to be applied to Dutch incinerators are summarised in Table 2.1.

A working group was established shortly after the publication of RV89 - Meetmethoden RV89

- to establish guidelines for the measurement methods to be used for compliance monitoring. The work of this group resulted in the issue by the environmental ministry, VROM, in 1993 of regulations which specified the level of compliance monitoring and the standard methods to be used for both continuous and manual monitoring - Regeling meetmethoden luchtemissies afvalverbranding [Ref 2.35].

The requirements of the regulation can be summarised as follows [Refs 2.35 and 2.36]:

- Continuous monitoring is required for CO, total particulate matter, TOC (as total carbon), gaseous inorganic chlorine compounds, sulphur oxides (as SO_2) and nitrogen oxides (as NO) in the flue gas.

- The results from the continuous monitoring of particulate matter and HCl are to be used for indicative purposes only - compliance monitoring is to be based on manual determinations of these parameters at least four times per year.

- A range of standard methods, e.g. ISO, VDI, CAN/CSA, etc. are specified for both manual and continuous measurements.

- If the inorganic chlorides monitor measures HCl only, the measurement result must be multiplied by a factor to take other inorganic chlorides into consideration. This factor should be determined by manual measurements at least four times per year.

- The method specified for TOC measurement is FID. The response factors for the organic compounds - butane, heptane, cyclohexane, isopropanol, toluene, acetone, butyl acetate and ethyl acetate - should be within the limits 0.85 to 1.15 (response factor for methane = 1).

- The continuous monitoring of flue gas temperature and O_2 in the SCC is required.

- The continuous measurement of water vapour content in the flue gas is not required. The regulation allows the use of determined factors for the normalisation of any measurement result obtained for a 'wet' gas to a dry basis.

- The continuous measurement of flue gas volume flow is not a general requirement, but is decided upon on a case by case basis. However, TUV approved systems are considered acceptable i.e averaging pitot (annubar).

The monitoring requirements are summarised in Table 2.2

There are no specific regulations on incineration for continuous monitoring of releases to water or land. Most Dutch plants are moving to wastewater free operation. Any solid or liquid releases would be covered by general industrial regulations in these areas. Site visits were carried out at four Dutch incinerators. None of the plants had requirements for continuous monitoring of releases to water or land.

2.3.2 Standard Reference Methods

The Dutch have defined the SRMs to be used for incineration applications [Refs 2.36, 2.37] and these are summarised in Table 2.3. The performance characteristics of the SRMs given are not discussed in any of the Dutch literature obtained for this study. However, the low emission limits given in the Dutch legislation for HCl, particulate matter and TOC, in a similar manner to the German situation, warrant further comment

The method specified for HCl is the German VDI 3480 Part 1, therefore the comments made earlier with regard to this standard apply.

The method specified for particulate matter is ISO 9096 [Ref 2.12]. Within the text of the standard, it is stated that the method is suitable for particulate matter concentrations in the range 5 mg/m^3 to 10 g/m^3 with a stated 'inaccuracy' of +/- 10% ('inaccuracy' is not defined). It is also stated that at particulate matter levels below 50 mg/m^3 the inaccuracy may be greater than 10%. Due to these limitations, the method is of little use for the calibration of CEMs to supervise an emission limit of 5 mg/m^3. Therefore VDI 2066 Part 7 is widely used and the new CEN standard for particulate matter, when published, will supersede ISO 9096 for incinerator applications (see Section 2.5.2).

No manual SRM is defined for TOC. The use of VDI 3481 Part 3 (FID method) is specified for continuous measurement.

2.3.3 Performance Criteria and QA/QC Procedures for CEMs

The Dutch have not published their own performance criteria / standards for CEMs or any standard methodology for CEM verification and QA/QC. However, where available, international standards have been specified for the CEM measurement task. Of particular importance is the adoption of the appropriate ISO (draft or full) standards for particulate matter - ISO 10155 [Ref 2.37], SO_2 - ISO 7935 [Ref 2.38] and NO_x - ISO/DIS 10849 [Ref 2.39].

The main elements of the ISO performance criteria are described in [Ref 2.36]. Many of the individual criteria are defined and used in a similar manner to those tested during the German suitability tests, in particular zero and span drift; detection limit; response time and cross sensitivities. For the gas concentration CEMs - for SO_2 and NO_x - ISO does not require the derivation of the analysis function (or calibration curve) against SRM data. However a quantity called the Integral Performance is defined which limits the size of the standard deviation of the difference between the CEM and SRM data (measured simultaneously during an evaluation check). There is also a limit put on any negative bias discovered during tests. ISO does not specify whether the size of the Integral Performance or the negative bias should be checked on a case by case basis, or whether the supplier of the equipment can claim compliance with the ISO standard on the basis of one set of independent tests. The Dutch are also silent on this point.

The ISO standard for particulate matter CEMs does describe the derivation of a calibration curve against SRM data in a similar manner to the German methodology together with the derivation of confidence and tolerance intervals.

2.3.4 Data-Logging and Processing

The Dutch regulations state that data from the CEMs should be continuously recorded. There is no type approval system for data-logging and processing equipment. The system installed must meet the approval of the licensing authority and demonstrate that the compliance criteria have been met. For emission limits which are supervised by means of CEMs, compliance is specified as that 97% of all one hour averages within a calender 12 month period must be below the limit. No specific mention is made in the Dutch regulations with regard to the measurement uncertainty, i.e. confidence or tolerance intervals. However, general air pollution control guidelines issued in 1992, Netherlands Emission Regulations - Air [Ref 2.40], contains a chapter on the interpretation of CEM data. The guideline introduces the concept of a confidence interval which is defined by the characteristics of the CEM. The 90% confidence interval for any particular method is assigned to the benefit of the operator, i.e. any average concentration which is less than the limit value plus the 90% confidence limit is acceptable.

2.3.5 Performance Criteria for Controlled Process Measurements

Article 13 of the Dutch regulation deals with temperature measurement and the demonstration of the flue gas residence time. Temperature is to be measured using 'general measurement practice'. The measurement position should correspond with the exit from the zone in which the two second residence time is allocated. The determination of compliance with the two second requirement is to be determined by the licensing authority by the use of plant design data, e.g. SCC dimensions, and design flue gas flow rate.

2.4 <u>The USA</u>

2.4.1 Legislation

The laws which impact upon the design and operation of incineration plant in the USA operate at both a federal and state level.

Congress enacts federal laws or statutes to ensure national consistency in issues that cut across state boundaries, such as air and water pollution. These federal laws authorise an administrative agency, such as the US Environmental Protection Agency (USEPA), to implement the law and to provide regulations specifying in greater detail the exact procedures and requirement under the law in question. It is usual that the enforcement of the main parts of these regulations are delegated to the individual states who must produce state programmes that comply with and are approved by the USEPA. The individual states may, in their own enforcement programme, specify environmental or monitoring conditions which go further than the federal requirements. Therefore the federal requirements specify an environmental baseline or minimum standard. In certain cases enforcement responsibility may be retained by the USEPA. In the absence of a federal standard it is the responsibility of the individual states to pass legislation controlling the design and operation of individual plant.

Emissions to Atmosphere

The two most important pieces of federal legislation for incineration plant, in particular monitoring requirements, are the Clean Air Act (CAA) and the Clean Air Act Amendments (CAAA) from 1990 for MWIs and the Resource Conservation and Recovery Act (RCRA) from 1976 for HWIs.

Under the CAA, the USEPA publishes National Source Performance Standards (NSPS) to cover emission limits and compliance monitoring for a wide range of industrial sources. The first set of standards covering MWIs was published in the 1970s. In the late 1980s the USEPA prepared an updated NSPS for MWIs which were promulgated in 1991 as subparts of Title 40 Code of Federal Regulations Part 60 (40CFR60), i.e. Subpart C_a - Emission Guidelines and Compliance Times for Municipal Waste Combustors (existing plant) and Subpart E_a - Standard of Performance for Municipal Waste Combustors (new plant) [Ref 2.41]. Both of these subparts apply to MWIs with an aggregate incineration capacity of greater than 250 tonne per day. In addition to specifying emission limits to air and the compliance schedule, the subparts contain guidance on compliance monitoring, including the use of CEMs. Normally, individual states would have 12 months to submit a state programme to implement the USEPA regulation. However, both subparts are incomplete - no limit values are given for heavy metals and consequently the 12 month period has not yet started and all MWIs in the USA still operate under state legislation. In 1994, the USEPA published drafts of new subparts C_b and E_b to cover both small and large MWIs and to promulgate emission limits for heavy metals. It is possible that Subparts C_a and E_a will be withdrawn and federal limits will then be based on the new draft subparts when these are finally agreed. The state and local permits that are currently issued to operating MWIs do not therefore have to conform to the standards given in subparts and draft subparts C_a, E_a, C_b or E_b. However, the state permitting authority will be heavily influenced by these subparts and they have become a *de facto* standard. Table 2.1 which describes in summary form the emission limits to be found in the relevant subparts provides the model for state permits.

For HWIs, the RCRA contains details of the licensing procedures, the emission limits and general performance standards that are applied. The RCRA places a heavy emphasis on the destruction of target organic substances in the hazardous waste stream and the demonstration of the destruction efficiency in controlled 'trials burns'.

There is no current federal legislation covering medical waste and sewage sludge. Therefore state legislation will apply in both cases. The emission limits are to be influenced by the federal limits for the other incineration processes.

Due to the non-uniformity of legal requirements for incineration in the USA, the precise nature of the monitoring requirements for any particular incineration plant will depend on its type and location. However, based on the federal requirement where it exists, and information from state and regional monitoring programmes, general monitoring requirements can be summarised as follows:-

CO - The continuous monitoring of CO in the flue gas is a requirement specified in RCRA and the NSPS sub-parts and is a standard requirement in state permits for all types of incineration plant.

Particulate matter - The emission limits for particulate matter in federal rules is given as both a mg/m^3 and a percentage opacity. The mg/m^3 limit is supervised by regular manual testing while a CEM for opacity is required (calibrated and reading percentage obscuration/opacity).

HCl - The use of CEMs for HCl compliance monitoring is not a requirement in any of the federal rules. Compliance monitoring is based on manual determinations. The USEPA would not specify the use of CEM HCl until it had published a performance standard for the CEM (see Section 2.4.3). During the late 1980s and early 1990s, the USEPA sponsored studies on the performance of available HCl CEMs at both MWIs and HWIs with a view to publishing a performance standard. The testing programme highlighted a range of difficulties with regard to the operation of HCl CEMs (see Section 4) and the research programme was terminated without reaching a formal performance standard. The USEPA did, however, propose that SO_2 CEM data could be used for surrogate HCl monitoring. The efficient reduction of SO_2 over the acid gas control system would be a good indication of high HCl removal as well.

Despite the absence of a federal rule requirement for HCl CEMs many states specify their installation in state permits. A performance standard has also been prepared and published by a workshop organised by the Northeast States for Coordinated Air Use Management (NESCAUM) [Ref 2.41].

HF - The use of CEMs for HF compliance monitoring is not a federal requirement in any of the relevant legislation.

SO_2 - CEMs for SO_2 monitoring is a requirement in RCRA and NSPS rules. The USEPA and most states propose using CEMs for monitoring both before and after the acid gas control system. The emission limits for SO_2 are usually expressed as emissions being below a concentration limit, e.g. 30 ppmv, or an 80 % reduction in potential SO_2 emissions - whichever is less stringent (NSPS, Subpart E_a). Therefore it is in the interests of operators to monitor continuously, both before and after the scrubbing equipment. As mentioned above, the percentage reduction of SO_2 is also a good indication of scrubber efficiency for HCl.

NO_x - NO_x CEMs is a requirement under the federal rules for MWIs and is required for most state permits. It is not a general specified requirement for HWIs under RCRA, however it may be specified by USEPA for individual plants.

TOC - CEMs based on FID technology is a requirement of the Boiler and Industrial Fuels Rules (BIF) [Ref 2.42] but not a general requirement in federal or state legislation for incinerators. BIF regulates the use of waste materials as fuel substitutes for industrial boilers, cement kilns etc.

Others - Manual discontinuous monitoring is specified for other emission parameters, i.e. dioxins/furans, metals etc. Continuous monitoring of the process parameters, O_2, combustion temperature, waste feed rate and possibly flue gas velocity are normal components of operating permits.

In addition to the requirement for monitoring and CEMs, the federal rules for incinerators specify requirements for data-logging and processing, in particular with regard to averaging times and percentage valid data capture requirements.

Releases to Water

The Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977 regulates the discharge of pollutants into the "navigable waters" of the United States. The primary means by which this Act is enforced is through the issue of National Pollution Discharge Elimination System permits ("NPDES permits"). All discharges of wastewater into waters of the United States from "point sources" (discernable or discrete sources of pollutants) must be conducted pursuant to an NPDES permit.

The NPDES permit programme is primarily based on an "end-of-the-pipe" control approach which focuses on specifying effluent limitations guidelines or concentration limits for individual pollutants in permits. These effluent limitations for individual pollutants are based on technologies meeting performance standards identified in Section 301 of the Act, including:-

- "Best Practicable Control Technology Currently Available (BPT) or Best Conventional Pollution Control Technology (BCT) for "conventional pollutants" such as Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), pH.

- "Best Available Technology Economically Achievable" (BAT) for toxic pollutants and non-conventional pollutants (e.g. pollutants other than conventional pollutants or toxics).

The NPDES permit application process and requirements are defined in regulations under 40 CFR Part 122. The USEPA may delegate the NPDES permit programme to states meeting the criteria specified in 40 CFR Part 123. There are four basic categories of NPDES permits, each of which has its own programme which may be delegated separately to a state:

1. Municipal and Industrial Permit Programme.
2. Federal Facilities Programme.
3. Pretreatment Programme.
4. General Permit Programme (permits for classes of dischargers).

Wastewater streams are produced at incineration plants from a variety of sources, including process wastewater, "blowdown" from the cooling water system, and sanitary wastewater. If this wastewater were to be discharged directly into navigable water of the United States, NPDES permit requirements would apply.

2.4.2 Standard Reference Methods

US federal legislation on incinerator emissions is very specific on the SRMs to be used both for compliance monitoring and the evaluation of CEM performance. The methods to be used are published in 40 CFR 60 Appendix A. These are given in Table 2.3..

Performance characteristics are given for some of the methods in terms of detection limit and method standard deviation. Of particular interest is the standard for HCl, EPA Method 26. This standard, which is relatively recent, has a claimed standard deviation of 6.2% at a concentration of 3.9 ppm and 3.2% at 15.3 ppm.

The SRM for TOC is also based on FID technology, i.e. there is no manual method for this measurement.

2.4.3 Performance Criteria and QA/QC Procedures

There is no type approval system for CEMs in the USA. Both federal and state legislation calls for the site certification of installed systems to ensure that they comply with defined minimum performance criteria. The certification testing can be carried out by consulting companies or the operator themselves, with a full report, including system description and test results, submitted to the appropriate permitting authority.

The USEPA has published performance criteria for SO_2, NO_x, CO, O_2 and continuous opacity monitors. These are reproduced in 40 CFR 60 Appendix B. No performance criteria are given for HCl CEMs as described above, however, NESCAUM and several states have prepared and adopted criteria for HCl based on those published by the USEPA for the other parameters.

Following installation, commissioning and debugging of a CEM, the operator of an incinerator must notify the permitting authority that certification is being sought. He must then carry out a series of tests on the installed system to demonstrate compliance with the given performance criteria. The characteristics tested are:-

- A Seven Day Calibration Error Test.
- A Linearity Check.
- A Relative Accuracy Test Audit (RATA).
- A Bias Test.
- A Cycle Time/Response Time Test.

Details of the definitions and testing methodology are given in [Refs 2.43] and explained in detail in [Ref. 2.30] However, the criteria given for Relative Accuracy and Bias are of particular importance.

The Relative Accuracy (*RA*) of a CEM for a particular pollutant can be defined as:-

'The degree of correctness with which the measurement system yields the value of gas concentration of a sample relative to the value given by a defined reference method' [Ref 2.43].

This accuracy is expressed in terms of error, that is the difference between the paired concentration measurements.

The reference method referred to in the definition is one of the US SRMs as described.

The RATA should be carried out over a seven day test period and involves the completion of a minimum of nine sets of paired CEM and SRM test data. Each set of measurements should be conducted over a 30 to 60 minutes time frame. More than nine sets may be carried out, if desired, and the tester then has the option of discarding a maximum of three sets as long as there remains at least nine sets for the RA determination.

The paired values from the tests are used to calculate the mean difference between the CEM and SRM as follows:

$$\bar{d} = \frac{1}{n}\sum_{i=1}^{n} d_i$$

where:

$\bar{d}$ is the arithmetic mean of the differences

n is the number of data points (data sets; min 9)

d_i is the difference between a reference method value and the value from the CEM (SRM_i - CEM_i)

A one sided 97.5% confidence interval can be calculated using the standard deviation S_d of the mean difference which is given by:

$$S_d = \sqrt{\frac{\sum_{i=1}^{n} d_i^2 - [\frac{1}{n}(\sum_{i=1}^{n} d_i)^2]}{n-1}}$$

and the calculation of the confidence coefficient *CC*:

$$CC = t_f\,(0.975)\,\frac{S_d}{\sqrt{n}}$$

where:

$t_f\,(0.975)$	is the Student t-factor which is obtained from standard tables based on the value of n-1.

The *RA* is then calculated from:

$$RA = \frac{|\bar{d}| + |CC|}{\bar{RM}} \times 100\ \%$$

where:

$\bar{RM}$	is the mean of the SRM
$\lvert\bar{d}\rvert$	is the absolute value of the mean difference
$\lvert CC \rvert$	is the absolute value of the confidence coefficient.

RA, defined in this way, can be interpreted as a working accuracy of the CEMs in providing concentration data relative to that which would have been provided by the use of the Reference Method.

If a very large number of paired determinations are made during the RATA test and in the absence of bias, *d* should tend to zero. Because only nine pairs of measurement data are generally available the value of the mean difference, *d*, derived is an **estimate** of the true value of *d*. Therefore, the confidence coefficient *CC* defines a confidence interval for the estimate of *d* which implies that the true value of *d*, with a probability of 95%, lies within the interval *d* + *CC* to *d* - *CC*. Or there is a 97.5% probability that the true value of d lies below *d* + *CC* (one-sided confidence interval). If the two-sided interval does not include the numerical value 0, then bias must be assumed to exist between the two measurement methods.

Specifying a numerical maximum for *RA*, e.g. 10%, as a performance criterion for a CEM therefore implies that the CEM, over any series of comparative tests, will yield results which, on average, must be within +/- 5% of the average value obtained by the SRM. This is implied because of the requirement for *CC* to be less than *d* to avoid bias. Therefore *d* can at most contribute 50% of the RA figure.

The *RA* does not consider the absolute accuracy of the CEM determination, i.e. how close the measured value is to the actual concentration. As stated, it defines accuracy relative to the results obtained with the SRM.

The bias test is carried out to determine whether the CEM is measuring consistently low compared to the SRM. The calculated values from the RATA test are used to assess the CEM bias. If the mean difference *d* is greater than the absolute value of the confidence coefficient *CC*, then the CEM has failed to meet the bias criteria. Any value of *d* not equal to zero could be considered to be a bias. However, due to the random variations of the CEM response when compared to the SRM value, any value of $d > 0$ can only be significant if it exceeds the value of *CC*, which is itself a measure of the random (i.e. non systematic) variation of *d*. If $d < CC$, it can be stated that there is at most a 2.5% probability that low bias was mistakenly identified during the RATA test.

2.4.4 Data-Logging and Processing

Both NSPS subparts and RCRA contain sections on reporting requirements and data averaging values for CEM data. The complete system, including the data processing system is subject to certification.

2.4.5 Performance Criteria for Controlled Process Measurements

The federal legislation contains no specific guidance on temperature measurement with the exception of the nomination of US standards for thermocouples. Performance standards are given for CO and O_2 CEMs in Appendix B to 40 CFR 60.

2.5 The European Union

2.5.1 Legislation

The European Union (EU) has been very active in recent years with regard to directives covering the incineration of wastes.

Two directives were issued in 1989 - 89/429/EEC and 89/369/EEC - to cover the prevention of air pollution from existing and new municipal waste incinerators respectively [Refs 2.44 and 2.45]. The directives concentrated on specifying operating conditions and limiting emissions to air.

The EU also commenced work on a directive to cover hazardous waste incineration in 1990 which was finalised and adopted in December 1994 (94/67/EC [Ref 2.46]). This contains very stringent emission limits to air in addition to operation condition requirements.

During 1994, the EU also commenced work on a directive to cover all types of incineration processes not covered by the Hazardous Waste Incineration Directive, i.e. municipal waste, clinical waste etc. The emission limits to air under discussion in the Commission for this directive are similar to those for hazardous waste. However, in addition to limits to air, limits are also being proposed for releases to water, i.e. concentration limits for polluting substances in liquid effluent from the plant scrubbing system and also concentration limits in liquid leachate from incinerator ash.

The emission limits to air specified in the latest EU Directives are summarised in Table 2.1.

The standards contain Articles and Annexes which refer specifically to monitoring requirements.

Article 6 of 89/369/EEC - new municipal waste plants - calls for:

- The continuous monitoring of particulate matter, CO, O_2, HCl and H_2O (if pollutant measurements are on a 'wet basis') in the emission flue gas.
- The periodic measurement of SO_2, heavy metals, TOC and HF.
- At least one verification of the flue gas residence time in the SCC during commissioning under the most unfavourable conditions.
- The continuous monitoring of the SCC temperature.

Article 11 of the 94/67/EC Hazardous Waste Incineration Directive calls for:

- Continuous monitoring of CO, particulate matter, TOC, HCl, HF (not necessary for HF if acid gas scrubber installed), SO_2, O_2, pressure, temperature and H_2O (if pollutant measurements on a 'wet basis') in the flue gas.
- Periodic measurement of heavy metals and dioxins/furans.
- Continuous monitoring of SCC temperature.
- At least one verification of residence time during commissioning and under the most unfavourable conditions.

Article 11 also states that continuous monitoring of other flue gas parameters, i.e. metals and dioxins/furans may be required as soon as appropriate technology is available and that continuous monitoring of some of the parameters mentioned above may not be necessary if it can be demonstrated that, due to the licensed waste input, the maximum possible emission of a substance is less than 10 % of the emission limit.

Annex III in the 94/67/EC provides information on measurement standards and performance characteristics for continuous monitors (see Sections 2.5.2 and 2.5.4).

The draft directive for other incineration processes contains some even more stringent emission limits than given for hazardous waste incinerators. Also, continuous monitoring of NO_x and NH_3 in the flue gas and flow of liquid effluent will be required.

There are no specific EU Directives on releases to water/land.

2.5.2 Standard Reference Methods

Paragraph 2 of Annex III to the 94/67/EC Hazardous Waste Incineration Directive states that;

"*Sampling and analysis of all pollutants including dioxins and furans as well as reference methods to calibrate automated measurement systems shall be carried out as given by CEN-standards elaborated on the basis of orders placed by the Commission. While awaiting the elaboration of CEN-standards, national standards will apply.*"

The Commission has therefore mandated CEN - the European standards organisation - to examine the whole issue of standard methods to be applied for compliance monitoring for incineration plant. CEN established a technical committee, TC 264, to examine the issues raised and to prepare the required standards. The work is being carried out by working groups (WGs) allocated specific tasks by TC 264. TC 264 has an appointed chairman and a secretary and each WG has an appointed secretariat, secretary and a convenor. CEN has also agreed to coordinate the work of TC 264 with TC 146 of ISO - the International Standards Organisation - who are also examining the question of standards and performance criteria for emission monitoring. Publication of new national standards by the national standards agencies is not permitted on measurement problems that have been mandated to CEN. Therefore the German VDI, for example, who have their own standards for dioxins/furans and HCl have ceased work on the generation of validation data at the new lower emission limits until the work of CEN has been completed. New CEN standards when finalised will become mandatory in European countries.

The most relevant WGs within TC 264 are working on standards for HCl, dioxins/furans, particulate matter at low concentration, TOC, mercury, heavy metals in general and performance criteria for continuous monitors.

WG1 has produced a standard for dioxin/furan measurement for use at the proposed emission limit of 0.1ngTEQ/m^3. Work has concentrated on the examination of sampling and analysis methods and the preparation of validation data based on field and laboratory work. Standards on sampling, extraction and clean-up, and analysis have been issued under the European Norm numbers EN 1948-1, EN 1948-2 and EN 1948-3 respectively (now available as British Standards from BSI as BS EN 1948-1:1997, BS EN 1948-2:1997 and BS EN 1948-3:1997).

WG3 is working on an SRM for HCl. A draft standard was produced in 1994 which contained details of validation tests carried out at low concentrations in flue gases from operating incinerators. The work carried out at a MWI with wet scrubbing resulted in a method standard deviation of 0.7 mg/m^3 in the concentration range 3 to 8 mg/m^3. For higher concentration, i.e. up to 40 mg/m^3, the standard deviation was 0.8 mg/m^3. This corresponds to a measurement uncertainty of 35% and 5% respectively.

WG4 is working on standards for TOC at concentrations less than 20 mg/m^3. A draft has been published based on the use of FID technology. It was not considered reasonable to develop a manual reference standard (see Section 2.2.2 on experience in Germany).

WG5 is working on both a manual SRM for particulate matter and performance criteria for an automated measurement method. The manual method must be suitable for particulate matter levels below 20 mg/m^3.

WG8 is working on an SRM for mercury emissions.

WG9 is working on Quality Assurance of Automated Measurement Systems.

WG10 is a working group on metals.

2.5.3 Performance Criteria and QA/QC Procedures

CEN TC 264 WG9 is working on CEM performance criteria related to operational quality control. This is being supported at CEN's request by an ISO TC 146 working group (SC4, WG7) who have been asked to identify general performance characteristics for instrument testing.

Annex III of the Hazardous Waste Incineration Directive defines maximum 95 % confidence limits as percentages of the parameter emission limit, i.e:

Pollutant	max 95% confidence limit
CO	10%
SO_2	20%
particulate matter	30%
TOC	30%
HCl	40%

For example, a CEM for HCl must demonstrate that the size of the 95% confidence limit around the emission limit value, i.e. 10 mg/m^3, is no greater than approximately +/- 4 mg/m^3 (see definition of confidence limit in Section 2.2.3). It is not stated in the Annex whether compliance with this criterion should be demonstrated once, i.e. during a type approval test, or should be checked on a case by case basis at individual incineration plant.

CEN TC 264 WG9 will need to consider this question and also whether the formulation of performance criteria for CEMs used in the published ISO standards for SO_2, e.g. defining an acceptable 'integral performance' (see Section 2.3.3), are more appropriate.

2.5.4 Data-Logging and Processing

With the exception of defined averaging periods for CEM data and the related compliance criteria, none of the EU Directives provide detailed requirements for data-logging and processing.

The averaging times and compliance criteria in the Hazardous Waste Incineration Directive are based on 30 minute and 24 hour averages for most flue gas parameters and 10 minute averages for CO. All 24 hour averages must be below the 24 hour limit while 97% of the 30 minute averages must be below the 30 minute value.

2.5.5 Performance Criteria for Controlled Process Measurements

No detailed guidance is provided in any of the EU Directives or draft Directives.

TABLE 2.1
SUMMARY OF NATIONAL AND INTERNATIONAL EMISSION LIMITS

Pollutants	IPR 5/1	IPR 5/3	17BImSchV	RV89	EU Haz. Waste Directive	USEPA NSPS Subpart Cb (draft)	EU Draft Directive on Incineration of Waste	IPC Note S2 5.01
Particulate Matter	20	30	10 (30)	5	10 (30)	20	10 (30)	25 (37)
Hydrogen Chloride	10	30	10 (60)	10	10 (60)	40	10 (60)	30 (60)
Hydrogen Fluoride	2	2	1 (4)	1	2 (4)	-	1 (4)	2 (spot)
Carbon Monoxide	100	100	50 (100)	50	50 (100)		50 (100)	50 (100)
Organic Carbon	20	20	10 (20)	10	10 (20)	-	10 (20)	10 (20)
Sulphur Dioxide	50	300	50 (200)	40	50 (200)	70	50 (200)	50 (200)
Nitrogen Oxides	350	350	200 (400)	70	-	260	200 (400)	200 (400)
Total Metals	1.0	1.0	0.5	1	0.5	-	0.5	1.0
Cadmium	0.1	0.1	0.05	0.05	0.05	0.03	0.05	0.1
Mercury	0.1	0.1	0.05	0.05	0.05	0.07	0.05	0.1
PCDD/PCDF	1.0	1.0	0.1	0.1	0.1	0.35	0.1	1.0

1. All concentrations, with the exception of PCDD and PCDF, are quoted as mg/Nm^3, dry flue gas corrected to 11% oxygen.
2. PCDD and PCDF stand for polychlorinated-dibenzo-dioxin and polychlorinated-dibenzo-furan respectively.
3. Concentration for PCDD and PCDF are quoted in ng/Nm^3 of the toxic equivalent of 2, 3, 7, 8 Tetrachloro-dibenzo-dioxin, dry flue gas at 11% oxygen.
4. The figures quoted for 17BImSchV, the EU Hazardous Waste Incineration Directive and the EU draft Directive on Incineration of Waste are 24 hour averages with 30 minute averages in brackets.
5 The figures quoted for the draft Subpart Cb are approximations. The actual limit values are quoted in ppmv at a standard 7% O2.
6. The figures quoted for IPC Guidance Note S2 5.01 are 95th percentiles of hourly averages with peak values in brackets.
7. The PCDD/PCDF benchmark is 1.0 ngI-TEQ/m^3 with a target of 0.1 (subject to overriding Directive requirements).

TABLE 2.2
LEVEL OF COMPLIANCE MONITORING FOR EMISSIONS TO AIR.

Pollutant	UK HMIP IPR5 Series	The Netherlands RV 89	Germany 17 BImSchV	EU Directives	USEPA Draft Subpart Cb	UK IPC Note S2 5.01
Particulate	continuous	continuous / manual (Note 1)	continuous	continuous	continuous opacity annual particulate	continuous
HCl	continuous	continuous / manual (Note 1)	continuous	continuous	annual	continuous
HF	manual, quarterly	manual, quarterly	none (Note 2)	none (Note 2)	annual	manual
CO	continuous	continuous	continuous	continuous	continuous	continuous
TOC	manual, quarterly	continuous	continuous	continuous	annual	continuous
SO_2	manual, quarterly	continuous	continuous	continuous	continuous	continuous
NO_x	manual, quarterly	continuous	continuous	continuous	continuous	continuous
Metals (incl., Hg and Cd)	manual, quarterly	manual, quarterly	manual, annual	manual, biannual	annual	manual
PCDD + PCDF	manual, annual	manual every six months	manual, annual	See Note 3	annual	See Note 3

Notes

1. Both Particulate and HCl monitoring is for indicative purposes only due to the low emission levels to be supervised. Legal compliance is determined on the basis of manual measurements four times per year.

2. If a flue gas scrubbing system is installed to remove HCl, it is assumed that HF will also be removed. Monitoring of HCl will give an indication of scrubber performance and hence separate monitoring of HF is not required.

3. Testing for PCDD/PCDF will be determined when a European standard exists for measurement.

TABLE 2.3
STANDARD REFERENCE METHODS

Parameter	Germany		Netherlands		USA	
	Standard Reference Method	Continuous Monitoring Performance Standard	Recommended Manual Method	Recommended Continuous Method	Recommend Manual Method	Recommended Continuous Method
Particulate	VDI 2066 Parts 3 and 7	VDI 2066 Bl6 and VDI 2463 Bl5	NPR 2788, ISO 9096	ISO 10155	USEPA Method 5	-
HCl	VDI 3480 Part 1	NDIR, Potentiometric, conductometric	German SRM	General Practice	USEPA Method 26	-
HF	VDI 2470 Bl 1	-	NYN 2819, VDI 2470 Bl 1	-	USEPA Methods 13A & 13B	-
CO	VDI 2459 Bl 6	NDIR	German SRM	VDI 2459 Bl 6		-
SO_2	VDI 2462 Bl 8	NDIR/NDUV conductometric	ISO 7934, EPA Method 8	ISO 7935	USEPA Method 6	-
NO_x	VDI 2456 Bl 1	NDIR/NDUV chemiluminescence	ISO/CD 11564, NEN 2044, 2046, 2039	ISO/CD 10849.2		-
TOC	VDI 3481 Bl 2	VDI 3481 Bl 1, flame ionisation detection	German SRM	VDI 3481 Bl 3 FID		-
Heavy Metals	VDI 2066 Bl 3 and VDI 2268 Bl 1	-	NPR 2817	-	USEPA Method 5	-
PCDD + PCDF	VDI 3499 Bl 1, 2 and 3	-	Instructions from RIVM/TNO	-	USEPA Method 23	-

TABLE 2.4

GERMAN PERFORMANCE CRITERIA FOR TYPE APPROVAL OF CEMs

Performance Criteria	Numerical Value (or comment)
Measurement Range	Dual Range I 1.5 times the 24 hour limit value. II 1.5 times the 30 minute limit value.
Characteristic calibration curve	To be checked against manufacturer supplied curve
Cross sensitivity (interfering substances)	+/- 4% of the measurement range
Sample throughput, sample temperature	Influence to be determined
Temperature dependent zero and span drift	zero : +/- 2% of range span : +/- 3% of range
Response time	200 seconds
Analysis function	To be determined during test
Precision (Reproduzierbarkeit)	30
Lower detection limit	2% of range
Availability and maintenance interval	95% availability over test period. Period of unattended operation to be determined
Time dependent zero and span drift	zero : +/- 2% of range span : +/- 4% of range

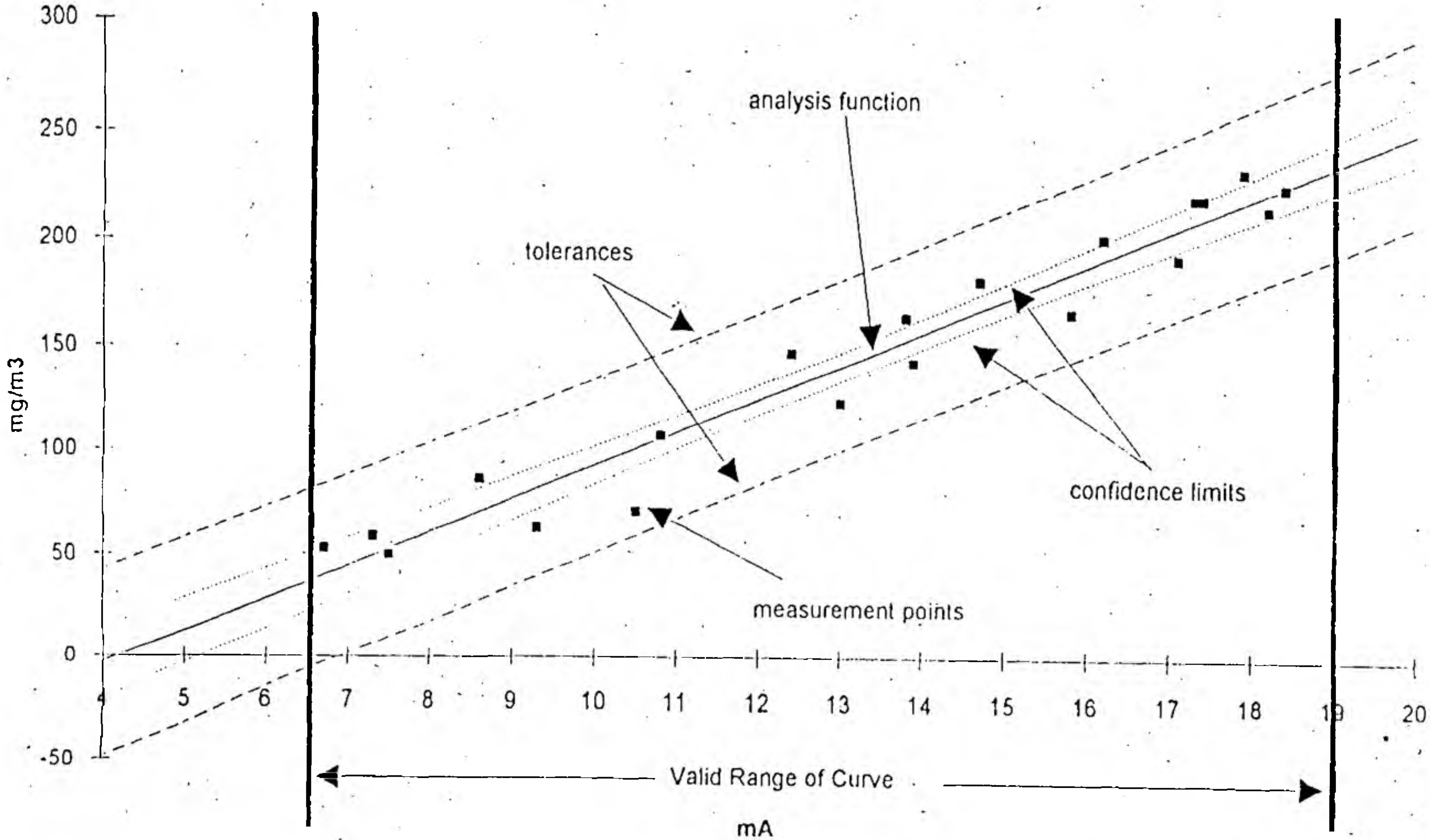


FIGURE 2.1

ANALYSIS FUNCTION AND CONFIDENCE/TOLERANCE LIMITS

3.0 PROCESS PARAMETER MONITORING

3.1 Secondary Combustion Chamber Temperature, O_2 and Gas Residence Time

The minimum requirements with regard to temperature, O_2 and gas residence time in the SCC are clearly stated in EU Directives. They are not, however, specified in any detail in US federal legislation which concentrates on emission limits and states that the permitting authority will specify appropriate process conditions.

The requirements of Environment Agency IPC Guidance S2 5.01, 17BImSchV, RV89 and current EU Directives approximate to:

- A minimum temperature of 850°C (or 1200°C if waste contains chlorinated organic compounds) in the SCC under the most unfavourable conditions must be maintained and monitored.
- A minimum O_2 content of the flue gas of 6% (or 3% if only liquid waste is incinerated) must be maintained and monitored.
- The flue gas must be subjected to these minimum requirements for a period of at least two seconds in an SCC and this residence time must be positively demonstrated during plant commissioning or licensing trials.

There is very little supporting information or guidance in Europe or elsewhere on precise methodologies for complying with these monitoring and demonstration requirements. Practice to date has been based on the use of thermocouples for temperature measurement, O_2 analysers from the power plant industry for O_2 monitoring, and use of design information - flue gas flow and plant geometry - to calculate the theoretical gas residence time.

Work carried out by Warren Spring Laboratory in the late 1980s [Ref 3.1] and work in Germany over the last few years [Refs 3.2, 3.3] has cast doubt on the validity of this approach.

The Warren Spring report indicated that, for a then conventional MWI, there was a very high variability of gas temperature and gas flow patterns depending on load, air distribution, firing of burners, etc.. There was, at times, a very poor relationship between the temperature indicated by the plant thermocouple and actual gas temperature. It was also concluded that the calculated gas residence time - from temperature and gas flow data - could fluctuate by a factor in excess of two, depending on actual operational conditions. The report dates from the late 1980s and many modern plant might have resolved some of this variability due to improved and optimised combustion control. However, it is clear that gas residence time is not a given constant for any particular incineration plant and that any positive demonstration of residence time must concentrate on measurements during 'worst case' conditions. Positive demonstration - in addition to theoretical demonstration - will involve considerable measurement effort in terms of man power and costs.

In Germany, these issues are currently being addressed for incinerators. A guidance note has been prepared by the *Laenderausschusses fuer Immissionschutz* (State Committee for Air Quality) which attempts to provide a common technical framework for new and existing plants [Ref 3.4].

The guideline proposes to address the following issues:

- Continuous measurement of the minimum temperature and minimum O_2 in the SCC and the suitability and measurement position of the instruments.
- Acceptance tests or trials, i.e. the positive demonstration of residence time by means of a test programme of compliance with the minimum criteria.
- Verification and calibration of the instruments.
- Parameterisation of the data-logging system.
- Interlocking of waste feed and support burner operation to the process conditions.

The approach being considered in Germany may be considered to be excessively time consuming and expensive. However, it represents the first attempt of any legislative system to develop a clear and unambiguous methodology for the accurate and precise demonstration of compliance with the legal requirements. The proposed methodology/practice can be summarised as follows.

Continuous Temperature Measurement : Two measurement instruments are to be installed at a suitable position at the end of the claimed SCC e.g. boiler roof or wall for a MWI.

Continuous O_2 Measurement: The installation of an O_2 analyser in the flue gas duct after the boiler is recommended, rather than in the SCC, due to the high temperature and particulate matter conditions to be found in the latter. A measurement position between the boiler and the first flue gas scrubbing stage is normal practice. The O_2 signal, which might be available from the stack CEM (used for normalisation of the emission data to standard conditions) cannot generally be used due to the change in CO_2, O_2 and H_2O concentrations caused by the scrubber. Both in-situ and extractive systems can be employed. However if an in-situ system is used, the measurement result must be compensated for the H_2O of the flue gas (either measured or by the use of an agreed factor).

Demonstration of Minimum Temperature (on commissioning) : Two measurement planes (horizontal or vertical depending on SCC design) are to be chosen in the SCC by discussion between the plant operator, designer and the licensing authority. The planes should correspond with the start and end of the claimed SCC, e.g. for an MWI, in the first pass of the heat recovery boiler above the grate (see Figure 3.1). The planes are divided into grid points corresponding to one grid point per 2 m^2. Measurement of temperature and O_2 are to be made at each individual point.

The start of the SCC is defined as the plane, after the last injection of combustion air, where 'complete mixing' of flue gas and secondary air is achieved. The end of the SCC is defined as the plane over which the gas achieves the two second criterion while still maintaining the required temperature. A definition of 'complete mixing' is given. It is the plane over which, at each individual grid point, the 10 minute average O_2 concentration is at least 3% or where there is at most a negative 50% deviation in O_2 content at any individual measurement point compared to the average over the plane. The measurement plane at the start of the SCC should be chosen by the plant designer in consultation with the licensing authorities. If it is found during subsequent testing that these conditions are not met, the measurement plane must be moved and new measurement ports installed.

When the planes and the grid points have been chosen, measurements are made at each point under stable operating conditions. The measurements are made using a suction pyrometer (see Section 3.2.1.2). The temperature measurements are made according to the following schedule:

- stable, full load — three grid measurement campaigns (measuring at individual points) over a three hour period, recording 10 minute average temperatures.
- part load — three grid measurement campaigns (measuring at individual points) over a three hour period, recording 10 minute average temperatures.
- start up without waste — one grid measurement campaign over one hour.

Compliance with the minimum temperature limit is based on each individual 10 minute average for each individual grid point being above the minimum.

Demonstration of Minimum O_2 (during commissioning) : The O_2 at each point on the grid is measured simultaneously with the temperature. An extractive system (possibly built into the suction pyrometer) should be used. Compliance is demonstrated if, at each grid point, there is an excess O_2 of at least 3% or, for all points on the plane, the maximum negative variation from the plane average is 50%.

Demonstration of Residence Time (during commissioning) : From the temperature data, the average temperature difference between planes 1 and 2 is determined as well as the average temperature in the SCC. At the same time as the grid measurements, the flow of flue gas should be measured in the flue gas duct down-stream of the boiler. Using recorded CO_2, H_2O, temperature and pressure data, the flow measured in the duct is used to calculate the actual gas flow under SCC conditions. Plug flow should be assumed and the residence time calculated based on the geometry of the SCC and the calculated flow. The assumption of plug flow is discussed in Ref 3.4 and is accepted due to the unpublished results of research work carried out in the 1980s by a German research institute using tracer gases in the SCC and measuring the time delay between injection and detection at the SCC entrance and exit respectively.

Calibration of the Thermocouples: The operational thermocouples placed at the exit to the SCC should be calibrated against the average SCC temperature as determined by six grid measurements on both planes. The output from the thermocouples should be recorded and integrated over the grid measurement time so that at least six measurement pairs are available - output of the thermocouples against average SCC temperature determined by suction pyrometers. The data set is then subjected to linear regression analysis in the same manner as described in Section 2.2.3 to derive the relationship between the temperature measured by the permanent thermocouples and the actual average SCC temperature. A 95% confidence interval is also derived. The calibration curve is used by the plant data-logger to derive the actual (within the confidence interval) average SCC temperature based on the thermocouple output. This calibration is carried out for each licensed load condition. This test should be carried out on commissioning and at intervals of three years thereafter. The position and type of thermocouple cannot be changed without the prior agreement of the licensing authority. Any significant changes to the temperature measurement system may result in a requirement for a full re-calibration.

Calibration of the O_2 Analyser: This should be carried out according to the calibration methodology as described in Section 2.2.3.

3.2 Continuous Monitoring Technology

3.2.1 Temperature Measurement

The primary types of technology employed for temperature measurement, in particular high temperatures at incinerators, are thermocouples, suction pyrometers, acoustic pyrometers and optical pyrometers.

3.2.1.1 Thermocouples

If two wires of different materials are in good electrical contact at a pair of ends and the junction is heated, an electromotive force (emf) is developed. If the other two ends are joined through a current detecting instrument a current flows, provided there is a temperature difference between the junctions. If the reference junction is kept at a constant temperature the generated emf is a measure of the hot junction temperature.

Industrial thermocouples consist of the hot junction and thermocouple connecting wires contained in a protective sheath to protect them from mechanical and chemical attack. There are many types of standard thermocouple available. The most common types used for high temperature flue gas measurement are Type K (NiCrNi), Type R/S (Pt12Rh-Pt/Pt10Rh-Pt). The properties of these standard thermocouples are given in national and international standards, e.g. BS 1041 - Temperature Measurement [Ref 3.5]. The stated temperature ranges in air for these thermocouples are given as:

Type K	-270°C to 1372°C
Type R/S	up to 1500°C

For high temperature applications a thermocouple construction with a Sicromal (X 10 CrAl 24) outer sheath and an inner ceramic sheath has been widely used. The outer sheath provides gas tightness and protection from chemical attack. The inner sheath provides stability to the construction due to its better thermal resistance. Deformation of thermocouples due to the high temperatures is a common problem at incinerator applications and it has proved sometimes difficult to remove thermocouples from their flanges due to bending and bowing of the sheath. For this reason Ref 3.4 recommends that, where possible, the thermocouples should be installed vertically, e.g. through the roof of the SCC.

Ref 3.4 also gives details of the performance of the thermocouple types under incinerator conditions and states that Type K thermocouples should not be used to supervise a minimum temperature of 850°C with temperature fluctuations in the range +/- 300 °C due to calibration failure and drift. The temperature range given in the standards for Type K, i.e. up to 1372 °C, is not applicable for accurate measurement under incinerator conditions. At 1000 °C, the calibration error and the drift can amount to 7.5 °C and 10 °C/annum respectively. These errors can occur within a very short space of time if the thermocouple is regularly subjected to these high temperatures and temperature cycling. Also, above 1000 °C, the drift properties are no longer linear. The recommended thermocouple is Type S for incinerator applications and this has become the standard in Germany.

The Cleanaway HWI in Ellesmere Port, which operates with an SCC in the range 1000 to 1200 °C specifies Type S thermocouples. The operational life can vary enormously however, the thermocouples subjected to the greatest mechanical and thermal stresses can last up to two months.

The use of thermocouples for high temperature measurement has many advantages including relatively low cost, simplicity, ruggedness etc.. However, there are several problems associated with their use, both for the minimum temperature compliance monitoring and for plant control.

- Each individual thermocouple provides information on the gas temperature at one point only. Due to the sometimes complex gas flow patterns in a relatively large SCC, the temperature at the measurement point may bear little relation to the average gas temperature. In addition, the temperature profile across the SCC will depend on load patterns and the distribution of combustion air flows. Choosing the most representative position or positions for the point measurement has generally been a haphazard process based to a large extent on guesswork and experience. The only way to ensure that the measured signal is relevant to actual SCC conditions is to carry out an extensive series of tests to understand the flow and temperature patterns in the SCC. The testing methodology currently proposed in Germany, as described in the preceding section, i.e. calibration against grid suction pyrometer measurements followed by linear regression analysis, represents perhaps an extreme, but logical methodology for ensuring a good representation of actual temperature.

- Thermocouples also suffer from radiation effects. At the incinerator SCC temperature ranges, heat transfer to the thermocouple by radiation from SCC surfaces may be significant. Therefore the temperature measured by the thermocouple can be significantly different from the actual gas temperature with the thermocouple being in thermal equilibrium with the cooler SCC walls rather than with the gas. Errors in the range 100 - 200 °C have been reported [Refs 3.1, 3.2, 3.3] between thermocouple temperature and actual gas temperature for incinerator SCC, with the thermocouples measuring low. Calibration of the thermocouple, as described, would take this radiation effect into account and would provide a means of compensation. As a general rule, however, the thermocouple measuring point should be as far away from the SCC walls as is practically possible.

- The temperature measured by the hot junction of the thermocouple, in the absence of radiation effects, depends on the temperature of the medium surrounding the protective sheath, the rate of heat transfer from the gas to the sheath and through the sheath to the junction. There is an inevitable time delay associated with this process which is exacerbated by any slag or particulate matter deposits that build up on the sheath. The time delay can be quantified by the t_{50} and t_{90} response of the thermocouple to a step change in gas temperature, i.e. the time taken for the thermocouple output to correspond to 50% and 90% of the step change respectively. These times can be of the order of several minutes for low gas velocities and heavy slag/particulate matter deposits. For a steady state process this might not be a significant factor. However, for an incineration process where the quality of the waste feed displays high variability, this slow speed of response can cause operational difficulties if temperature measurement is an integral part of the combustion control system. Precise control of incinerator load and temperature will be extremely difficult if the combustion air flow, the operation of support burners and waste feed rate are influenced by the indicated thermocouple temperature which represents past rather than actual conditions.

The operational and legal compliance issues associated with these recognised characteristics of conventional thermocouples will depend on the design/operational mode of the incinerator and the combustion control philosophy. Large, well designed, HWIs or MWIs which can operate in an approximately steady state mode, will not suffer unduly by the inherent time delays associated with thermocouples. Also good mixing conditions and careful selection of the measurement position might compensate for both radiation effects and the representativeness of the measurement. However, for plants which are poorly designed and operated, or have chosen the incorrect measurement position or display very high variability of waste quality - for example clinical waste, the information supplied by thermocouples cannot be considered to be a good representation of actual conditions.

3.2.1.2 Suction Pyrometers

Suction pyrometers consist of a thermocouple housed within a long sampling tube. The tube may be water cooled for high temperature applications. The thermocouple hot junction resides a short distance from one end of the tube (inside the tube). A ceramic protective particulate matter filter may be used (see Figure 3.2). The pyrometer is placed through a sampling port and hot gas is extracted through the tube and over the thermocouple at high velocity, usually by means of an air vacuum pump. The outer tube provides radiation shielding for the thermocouple and the high gas velocity ensures that the thermocouple measures gas temperature only with a minimal response time .

They are not designed for continuous use but are used on a campaign basis during tests. They have become the standard reference method for gas temperature measurement in Germany for official minimum temperature measurement.

3.2.1.3 Acoustic Pyrometers

The speed of sound waves through a gas will depend on the gas temperature according to the following equation:

$$C = \left(\frac{\chi \times R}{M} \times T\right)^{\frac{1}{2}}$$

where:

χ is the adiabatic gas constant;
C is the speed of the sound wave;
R is the universal gas constant;
M is the molecular weight of the gas;
T is the gas temperature.

Acoustic pyrometry systems use this relationship to provide a non-invasive measurement of gas temperature. In a practical system, the measurement of the time of flight for a sound impulse, over a precisely defined distance in the gas between a sender and a receiver, is used to generate a temperature signal according to:

$$T = \frac{D^2}{B \times t^2} \times 10^6 - 273.16$$

where:

T is the average path temperature °C;
D is the path distance between sender and receiver;
t is the measured flight time of the sound impulse;
B is the acoustic constant = χ . R/M in m^2/s^2K.

Two acoustic pyrometry systems are commercially available.

Codel in the U.K., jointly with the Central Electricity Generating Board (CEGB) Marchwood Engineering Laboratory, developed a system for temperature measurement in large utility boilers during the 1980s. The system is based on a transmitter unit using a storage capacitor and a 10kV generator to produce a sound pulse generated by the rapid discharge of the capacitor between two electrodes. A microphone receiver is mounted on the other side of the boiler to detect the sound impulse. Computer based signal processing is used to measure the sound pulse flight time across the boiler and to calculate the average gas temperature over the flight path. Both single path and multiple path arrangements can be used. The multi-path arrangement uses a series of paired transmitters and receivers arranged around a boiler on one measurement plane (see Figure 3.3). The flight time is measured sequentially for each path. This data is used to generate a two or three dimensional temperature distribution profile across the measurement plane (see Figure 3.4).

The second commercially available system was developed in the USA by Scientific Engineering Instruments Inc. in Nevada. The system is marketed in Germany and central Europe by Bonnenberg & Drescher GmbH under the trade name AGAM. AGAM uses the same concept as the Codel system, i.e. time of flight measurement over single or multi-path, however the method of sound pulse generation is different. The system is based on combined sender/receiver units in which a sound pulse is generated by compressed air. The unit also includes a microphone which will receive sound pulses from other units placed in the measurement plane. The use of compressed air ensures that the sender/receiver unit is self cleaning. A typical arrangement is shown in Figure 3.5.

Acoustic pyrometry systems are claimed to be accurate to within 2% of the actual average gas temperature. The possible sources of error include the variation of the molecular weight of the gas (composition); errors associated with the measurement of the flight path distance; and any deviation from a 90% angle between flight path and gas flow direction.

Both Bonnenberg & Drescher and Codel claim that, following an initial calibration of the system using an average gas molecular weight, the variation in gas molecular weight during normal operation at both boilers and waste incinerators is negligible. This has been confirmed by a series of demonstration tests carried out at the MWI Essen Karnap in Germany [Ref 3.3].

A 1% error in the measurement of the flight path length can lead to a 2 % error in the temperature measurement. Therefore this path length must be measured during installation to an accuracy better than 0.5%

If the angle between the flight path and the direction of gas flow deviates from 90°, errors can be introduced due to the increased speed of sound in the direction of gas flow.

Measurement along one path length requires between one and five seconds. Therefore a single path measurement system has an extremely fast response time compared to a conventional thermocouple. For a 24 path system up to two minutes is required to produce a thermal map. During this time the temperature conditions must remain constant. The minimum distance between sender and receiver is approximately 1.5 metres for the AGAM system.

Both systems were originally developed for the investigation of temperature profiles in large utility boilers, to provide data for research on firing patterns, pulverised coal size distribution, slagging effects (tube damage and thermal performance) and the identification of thermal windows for NH_3 or urea injection as part of a selective non-catalytic NO_x control system (SNCR DENOX). Both systems have, however, been used at operating incineration plants, in particular the AGAM system in Germany.

The Codel system was used by Warren Spring Laboratory (WSL) in a series of tests carried out at the MWI in Coventry in 1989 [Ref 3.1]. The tests were designed to investigate the influence of operational conditions on the thermal conditions within the incinerator and to test the temperature measurement systems. Warren Spring used six sender/receivers arranged on three walls of the incinerator, and also measured at grid points across the measurement plane using suction pyrometers. The temperature data recorded by the acoustic pyrometer were within an average of 3% of the temperatures measured by the suction pyrometer. At the same time, disagreement of the order of 100° C were recorded between the suction pyrometer and the plant thermocouple. Since the date of the tests at Coventry, Codel have not supplied any further systems to the incinerator industry - mainly due to the costs involved.

The main application has remained the utility boiler market. Some trials have also been carried out at cement works.

The AGAM system in Germany has met with more, but still limited, success in the market place for incinerator applications. References include:

- Demonstration tests carried out in 1989 - 1990 at the MWI at Essen Karnap. The scope of the tests was similar to the tests at Coventry, with broadly similar results with regard to agreement between acoustic pyrometry and suction pyrometry data.

- Two MWI units at Munchen Nord have each been equipped with four sender/receiver AGAM systems - single path at two levels within the first pass of the boiler. The measurement signals are used for control of the NH_3 injection as part of a SNCR DENOX system for the incinerators and are used by the plant control system for combustion control.

  Measurement results obtained by AGAM during the commissioning phase of the DENOX system indicated strong temperature swings within the furnace of approximately +/- 250°. Therefore, the reaction window for the DENOX process was moving up and down the incinerator. The measurement signal from AGAM, which has a response time of less than 10 seconds, is used to control the injection level within the incinerator (injection ports at various levels up the first pass of the incinerator) and the amount of NH_3 injected.

  Further investigations on the cause of the large and rapid temperature fluctuations revealed that the response time of the O_2 measurement system to changes in concentration was greater than 30 seconds. The O_2 value was used in the combustion control system together with measurement signals from the thermocouples (which have response times in minutes). Therefore, the plant control system was not receiving the required information fast enough to compensate for waste calorific value variations. The integration of AGAM into the control system resulted in a damping of the temperature fluctuations to +/- 50°C, a stabilisation of the steam generation rate, damping of O_2 variations and an elimination of CO peaks.

- Two MWI units at MVB Hamburg have been equipped with eight sender/receiver unit AGAMs. These have been used for research purposes and for testing the system's suitability as the 'legal' temperature measurement system for 17BImSchV. The measurement plane chosen is at the end of the designated SCC zone. The test results have been very positive [Ref 3.6]. Further testing to assess the suitability of AGAM for legal temperature compliance purposes, i.e. as described in Section 3.1 above, has been concluded and it is expected that AGAM will be accepted by the licensing authorities. This will be the first official sanction of AGAM for compliance with the 17BImSchV Regulations.

- One system has been installed at the HWI Widdig near Cologne. The system has been tested for SCC temperature measurement. Again the results have indicated large differences - up to 200°C between AGAM and thermocouples, with the thermocouples measuring low (see Figure 3.6) .

- One system has been installed at a HWI at a Ciba Geigy site in Switzerland. The licensed minimum SCC temperature for this plant is 1500°C. The operators considered that there is no other reliable temperature measurement system available for this temperature.

- A multi-path system has recently been installed at MVA Oberhausen (MWI). This will again be used for combustion research purposes - temperature profiles etc. and may be considered as the legal temperature measurement system.

Market penetration in the incineration sector in Germany has been slow, mainly due to the high costs involved. The budget price quoted for AGAM starts at DM 110,000 (approx £44,000) for a single path system and rises to DM 240,000 (£96,000) for a 24 path system. The high base cost is due to the standard data processing unit which is independent of the number of paths. There has also been some resistance from operators due to the very high quality of the information obtained. AGAM will reveal areas of low as well as high temperature.

Bonnenberg & Drescher are optimistic that AGAM will prove itself in the coming years and they argue that there is already an economic case for the installation of AGAM due to the improved combustion control achievable, resulting in improved plant economic performance. Also, the costs of a full calibration test as described in Section 3.1 is of the order of DM 50,000 (£20,000). It is possible that repeat tests every three years might not be necessary if AGAM can produce such superior temperature data compared to the thermocouples used at present.

3.2.1.4 Optical Pyrometers

Optical pyrometers measure the radiation given off by a hot body or flame as an indication of temperature. They have found limited applications in the incineration industry.

In the hazardous waste incineration industry, they have been used to measure the slag temperature at the exit from a slagging rotary kiln. A system is installed at the Cleanaway plant in Ellesmere Port.

They have also been used at Essen Karnap (MWI) in Germany. Each unit is equipped with six 'flame eyes' (optical pyrometers supplied by Siemens) looking at the flame conditions on the refuse grate.

A new plant control concept was developed based on the information available [Ref 3.8]. The measurements are used as feedback control for grate speed, feeding rate and amount and distribution of air.

The results of long term trials indicated much better control of steam generation rate - better than +/- 5% - and the ability to operate with a much lower excess air level without undue influence on flue gas CO. The lower air ratio resulted in lower flue gas volume flow and hence resulted in higher flue gas temperature, longer residence time and better liquid flowrate to gas flowrate (L/G) ratios in the flue gas scrubbing system.

3.2.2 O_2 Measurement

The two main types of O_2 analyser commonly used for incineration processes are the extractive paramagnetic analyser and the in-situ zirconia, ZrO_2, probe system. Both have found wide application for measurements in the flue gas before the scrubbing system to assist with combustion control. Both types have proved reliable and robust. Many different suppliers are available and over 20 different analysers have undergone 'type approval' testing in Germany.

No major difficulties have been reported by operators with the operation of either of these types of analyser. The choice between the two types will depend on the experience of the operator, the importance of speed of response (the in-situ ZrO_2 is faster) and the possibly higher maintenance requirement for the extractive system.

Details of O_2 equipment suppliers to the U.K. are given in Appendix I.

3.2.3 Flue Gas Flow

The continuous measurement of flue gas flow is a common requirement in plant operating licences in Europe. The information can be used as a continuous indication of plant performance and is useful for diagnostic purposes and the calculation of pollutant mass flows.

There is a wide range of gas flow measurement systems available on the market, many of which have been tested for flue gas applications on both utility boilers and incinerators. The most commonly used technology includes:

Averaging Pitot: The averaging pitot or annubar type flow sensor measures the gas flow by averaging the difference between static and dynamic (static pressure plus pressure component caused by the gas velocity) pressure over the flue gas duct diameter. Many different makes are available, some of which have been successfully submitted to 'type approval' testing in Germany.

Ultrasonic: The measurement principle is based on the measurement of the time of flight for a sound pulse between a sender and receiver mounted on opposite sides of the flue gas duct, one further downstream than the other. There are at least two such systems currently on the market, one of which, the Model VMA2 from Erwin Sick, has been approved for use at incinerator applications in Germany.

Thermal Dispersion: The measurement principle is based on the cooling of a heated thermistor placed in the gas stream. The temperature difference between the measurement and a reference thermistor is proportional to gas mass flow. These systems have been used at utility boiler applications in the USA and at least one system has been "type approved" for incinerator applications in Germany.

The normal measurement range for a flow system is 2 - 30 metres/second.

Each of these measurement systems, with the claimed exception of ultrasonics, must assume constant flue gas conditions due to the impact of gas density on the measurement. Gas temperature variations can be compensated for, assuming the temperature is measured continuously. However, an average gas composition must be assumed during factory calibration. The systems can be calibrated against an SRM on site following installation to increase accuracy.

The accuracy and reliability of flow systems depends on the specific flue gas conditions at the measurement site - wet, dusty and corrosive conditions will place high demands with regard to maintenance and cleaning of the systems. The choice of measurement site is also critical - i.e. a position in the flue gas duct where the flow is as uniform as possible. Site selection criteria are identical to the criteria for isokinetic particulate matter sampling and guidance provided in several standards, i.e. BS 3405, ISO 9096 etc.

The costs of a flow measurement system are site specific. However the expected range is £7,000 up to £25,000, the higher costs being associated with large duct diameters and the use of special corrosion resistant materials.

U.K. based suppliers of flow measurement systems are given in Appendix I.

3.2.4 Flue Gas Water Vapour

The continuous measurement of water vapour in the flue gas might be required if, for example, pollutant concentration is measured on a wet basis, but the emission limit and compliance criteria are given on a dry basis. This is a common problem for example for HCl emission monitoring where most available systems measure the HCl on a wet basis.

This has not been a standard measurement at incinerators in the past and experience is limited. Although specific water vapour analysers are available, the multi-component emission measurement systems from Perkin Elmer - Bodenseewerk and OPSIS offer continuous water vapour monitoring as one of the measured components. The FTIR systems now arriving on the market also offer water vapour monitoring . These systems are described in Section 4.

Performance standards have been published in Germany for continuous water vapour measurement [Ref 3.8] which are similar to the standards described for other German CEMs in Section 2. Both the Perkin Elmer and OPSIS systems have been "type approved" for use at German incineration plant. Both systems measure the flue gas components' wet and water vapour data is a requirement for correction to a dry basis.

An alternative approach which is sometimes seen is inferential water vapour analysis from wet and dry oxygen measurements.

3.2.5 Flue Gas Composition Measurement for Control of Flue Gas Treatment

As flue gas treatment systems become more complex and the required scrubbing efficiency increases, it can be meaningful in certain cases to measure continuously the concentration of flue gas pollutants, either before the scrubbing system or at intermediate stages in the scrubbing process. The measurement signals can be used, for example, to control reagent dosing for a dry scrubbing system or for safety/process supervision.

The continuous measurement of inlet SO_2 and/or HCl concentration to a dry scrubbing system is relatively common at incinerators in both Europe and North America. In the USA the continuous measurement of the percentage reduction of SO_2 is a standard requirement for incinerators. The types of measurement technologies used are identical to those used for emission monitoring as described in Section 4. Due to the much higher concentrations encountered, the requirements with regard to measurement range, detection limits and precision/accuracy are not so critical. Therefore, with the exception of increased demands on the sampling system - high particulate matter, etc. - the measurements may be considered to be technically less difficult than the measurements of very low concentrations in the stack. A number of novel applications of continuous monitoring technology have been encountered.

Woesthoff GmBH in Germany produce a combined SO_2/HCl continuous analyser based on the change of conductivity of an absorbing solution following contact with sampled flue gas. Alkaline substances are removed by a probe filter upstream of the analyser. The change in conductivity is caused by the concentration of hydrogen ions in the solution following contact with the gas and hence the monitor measures acidic components in the flue gas. Careful selection of the solution ensures that interferences by other potentially acidic components, i.e. CO_2 and NO_x is negligible [Ref 3.9]. The smallest approved measurement range is 0 - 15 mg/m^3 with a maximum range of up to 10,000 mg/m^3. As described in Section 4, Woesthoff offer specific HCl monitoring by installing a second measurement circuit which measures SO_2 only - the signal difference corresponding to HCl. Woesthoff have been trying to convince licensing authorities in Germany for some time that given the extremely high efficiency of modern scrubbing systems, in particular those which utilise activated carbon as a final scrubbing stage, the combined SO_2/HCl concentration in the cleaned gas is consistently below the HCl limit value - therefore the combined monitoring offers acceptable compliance monitoring.

They have also marketed the monitor with the higher measurement range as a process analyser for flue gas scrubbing system control. To control accurately lime injection into a dry scrubbing system data on both SO_2 and HCl are normally required. The Woesthoff combined system provides the required information without the need for two separate instruments. In addition, Woesthoff have carried out tests with a German supplier of fixed bed activated carbon filters. The combined analyser has been used for carbon depletion supervision, i.e. a sampling probe is placed in the bed shortly before the flue gas exit and gas is sampled. It normally measures a constant very low level of SO_2/HCl. As soon as any increase is detected, this is an indication of the imminent saturation of the carbon. The bed then requires replenishment.

The combined analyser has a budget price of approximately DM 55,000 (£22,000) with a further DM 15,000 (£6,000) for a heated sampling system. This is cheaper than installing

. individual SO_2 and HCl monitors.

The MWIs at MVA Dusseldorf are equipped with activated charcoal filters and were used as the demonstration plant for the technology. During initial commissioning and testing problems were experienced with hot spots developing within the carbon resulting in fires -a major safety problem. A monitoring system was installed to detect hot spots at an early stage and to take the appropriate action. CO is measured at the inlet and outlet from the filters. A rise of 10 mg/m^3 is considered normal, however, if the increase in CO goes above this figure it can be assumed that problems are occurring. The sampling systems have been designed to ensure that response times of the individual CO analysers are synchronised, i.e. the outlet measurement is time delayed to ensure that the time of passage of the flue gas through the filter is taken into consideration. The CO analysers used are from the URAS series of Hartmann & Braun. It is also interesting to note that each MVA Dusseldorf incineration line is equipped with at least two multi-component Perkin Elmer analysers for process control and monitoring purposes. The measurement points are between the wet scrubber and the activated charcoal filter and between filter and stack.

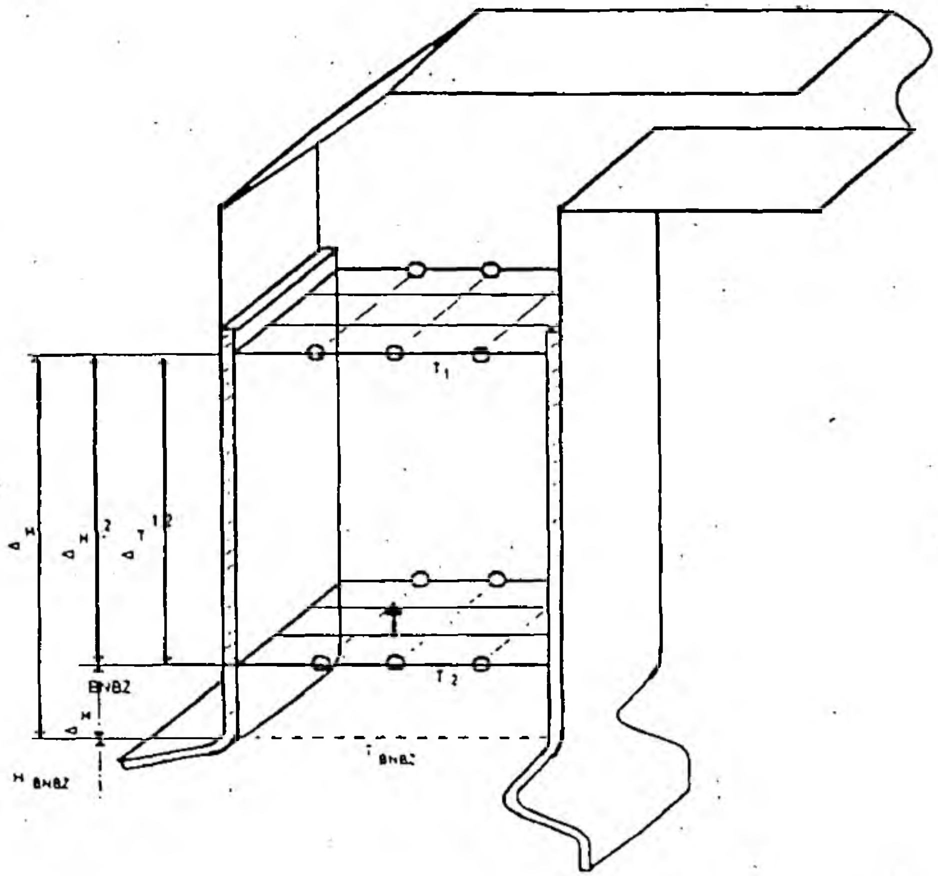
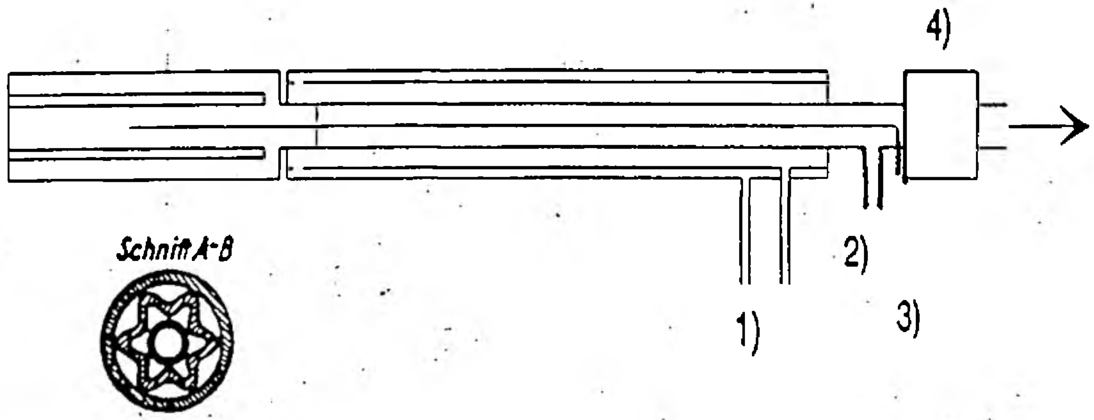


FIGURE 3.1

MEASUREMENT PLANES IN AN MWI FOR TEMPERATURE



1) Cooling water entrance and exit
2) Sample flow for gas analysis
3) Thermocouple cable exit for data processing
4) Controlled suction pump

FIGURE 3.2

SCHEMATIC REPRESENTATION SUCTION PYROMETER

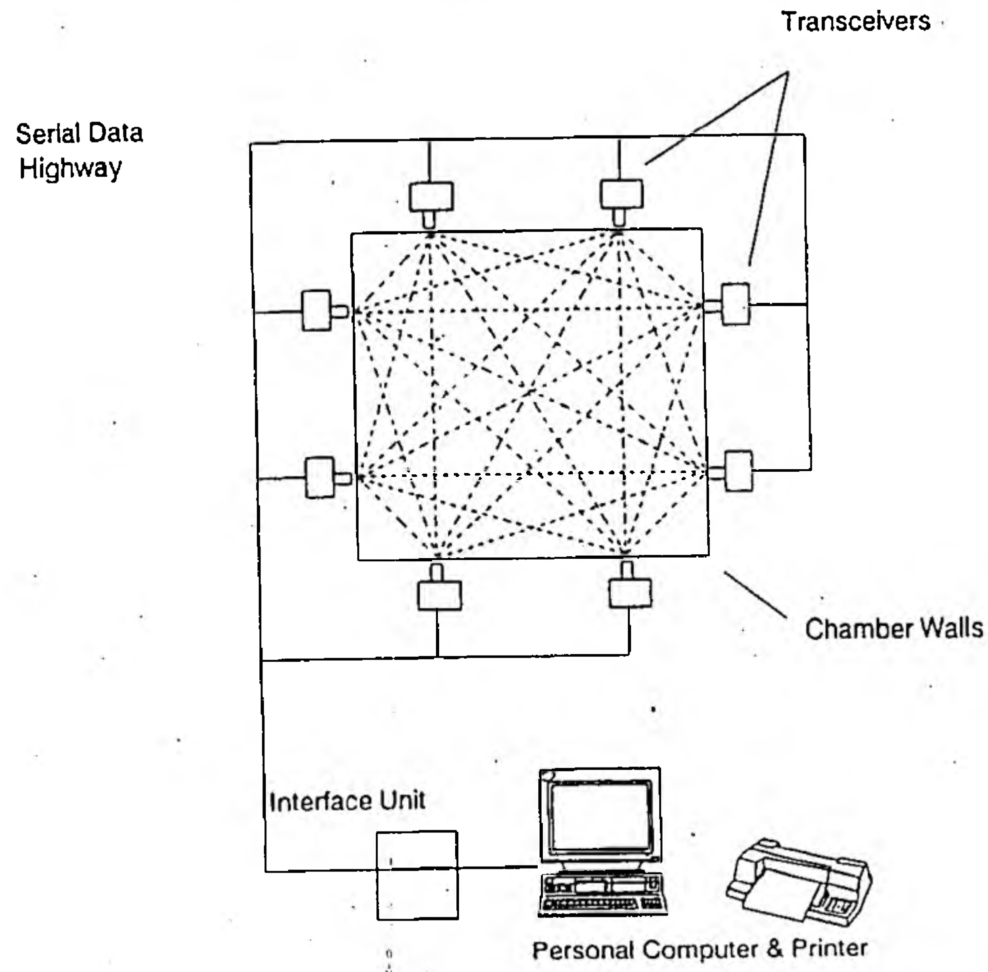


FIGURE 3.3

ACOUSTIC PYROMETER MULTIPATH ARRANGEMENT OF TRANSMITTERS & RECEIVERS

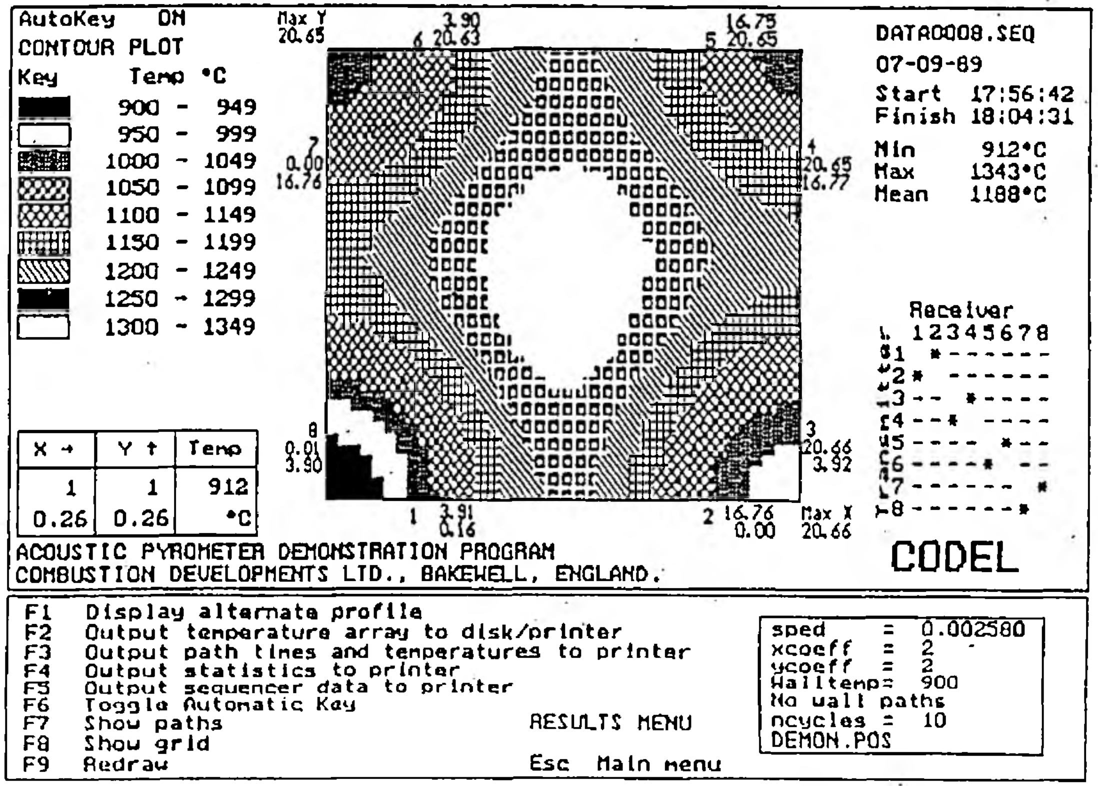


FIGURE 3.4

TWO DIMENSIONAL TEMPERATURE CONTOUR MAP (CODEL)

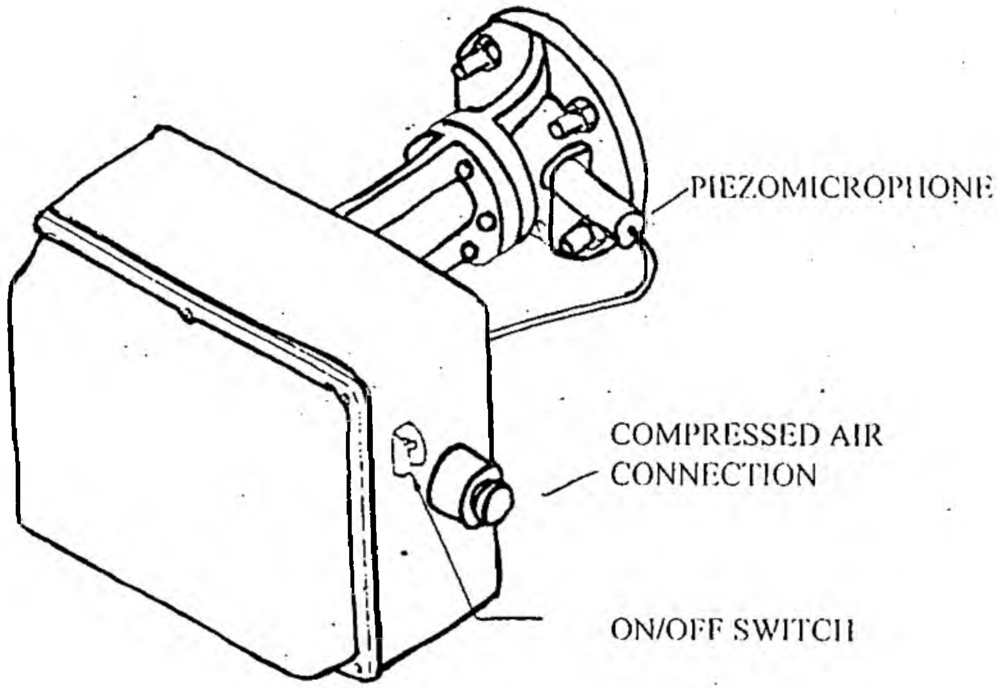


FIGURE 3.5

ARRANGEMENT OF ACOUSTIC PYROMETER SENDER/RECEIVER

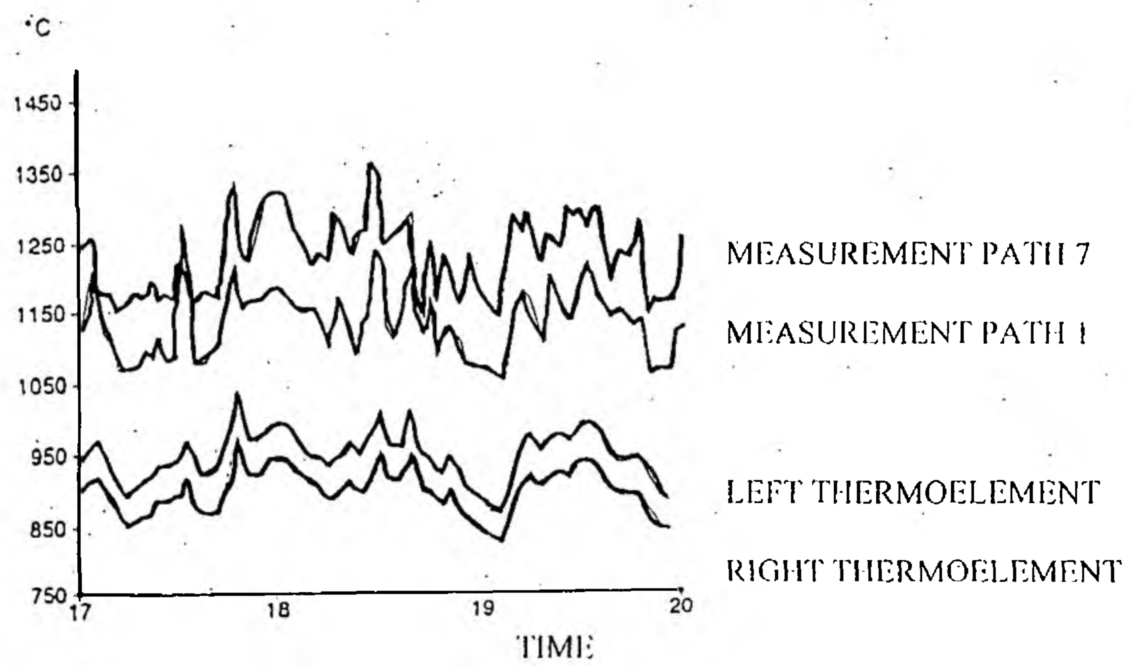


FIGURE 3.6

TEMPERATURE MEASUREMENT IN THE SCC OF AN HWI THERMOCOUPLE VS ACOUSTIC PYROMETRY

4.0 MONITORING OF EMISSIONS TO AIR

The technology for compliance with TA LUFT 86 type standards and that required for the new standards being developed in Europe, in particular Germany and the EU, are examined. The review concentrates on those areas of CEM technology that are specific to incinerators, i.e. HCl, multi-component systems (developed specifically for incinerators), particulate matter and organic carbon monitoring. The principal technologies used for continuous monitoring of SO_2, NO_x, particulate matter, CO and CO_2 are well documented in a previous HMIP - commissioned research report [Ref 4.1].

Available systems with incineration plant references have been reviewed, using where possible objective independent data on performance. Comments have been made on the history and current development status of individual systems and the companies that supply them.

4.1 CEMs and Incineration Processes

The combustion flue gas from an incineration process is a heterogeneous mixture of gases whose composition is constantly changing, due to variations in the composition of the waste incinerated and the specific combustion conditions. The composition of the gas exiting the stack is also influenced by the degree of flue gas treatment used. Until recently in the UK, treatment systems, in particular for MWIs, have involved flue gas cooling by water injection and relatively inefficient (cf Germany) particulate matter removal. The resulting flue gas in the stack was wet, chemically aggressive and associated with a high particulate matter burden. The recent installation of wet scrubbing systems to remove acid gases, for example at clinical waste incinerators and HWI, has, in many cases, compounded these problems, with the stack flue gas containing large amounts of water vapour, liquid droplet carry-over and salt aerosols. These flue gas conditions have placed a high technical burden on sampling and measurement systems installed and tested at UK plants.

These conditions, i.e. the difficult gas matrix and the absence of a clear legal/technical framework for CEMs, in addition to high R&D costs, have discouraged developments by indigenous UK companies of appropriate CEM technology. Many of the systems which have been installed and tested have been imported from mainland European manufacturers - mainly German. Due to the small size of the UK market many of these overseas suppliers have not developed, either through agents or UK subsidiaries, locally based technical expertise and the required specific service support - maintenance and spare parts - which would normally be available in the supplier's home market. Therefore equipment breakdown - due to the difficult application and poor regular maintenance - has resulted in expensive repairs and occasionally lengthy delays in obtaining spare parts from overseas.

In Germany, commencing in the late 1970s and early 1980s, both local licensing authorities and the federal government insisted on the installation of CEMs at operating incinerators. The requirement for CEM was first standardised with the issue of TA LUFT 86 which, in addition to emission limits which were later largely adopted in the EU Directive on new municipal waste incineration plant, demanded the mandatory continuous monitoring of particulate matter, HCl, SO_2, TOC and CO. At that time, 1986, there was also a standard legal/technical framework, developed in the early 1980s, for the use of CEMs at large combustion plants, which could be easily adapted to the requirements of incineration plant operation. Therefore, in 1986 German suppliers of CEM equipment were set a clear and precise task for the development of suitable technology and they were assured of a sizeable market into which the new CEM technology could be sold. German suppliers, most notably Hartmann & Braun, Siemens, Bran & Luebbe, Perkin Elmer - Bodenseewerk, Erwin Sick etc., set about the expensive but potentially rewarding task of developing and testing appropriate CEM technology, and submitting the systems for 'type approval' testing for independent verification of performance and limitations. Operators also installed these systems, as they were obliged to do under their operating licenses, and they developed regular maintenance programmes to ensure high availability.

In Germany the introduction of 17BImSchV in 1990 reduced incinerator emission limits dramatically. This initiated further work to produce CEM systems which could meet the required performance standards, in particular with regard to detection limit and calibration performance, which corresponded with the new emission limits. 17BImSchV was enacted in 1990, and defined a compliance schedule for existing plant commencing in 1994 and lasting until 1996. It was clear therefore in 1990 that a considerable amount of development work was required in the period 1990 - 1994 to perfect the new systems and that practically every incinerator plant in Germany would be forced to scrap the TA LUFT 86 CEM systems and replace them with systems capable of compliance monitoring to 17BImSchV. During 1993 and 1994 new CEM systems came onto the market to meet this demand. Legislation created the market and within a two to three year time span, the CEM suppliers developed appropriate systems.

All EU countries are now required to comply with the conditions of the directive on municipal waste incineration which specifies requirements for emission limits and CEM similar to TA LUFT 86. This is being superseded by the new EU Directive on Hazardous Waste Incineration and one to replace the municipal waste incineration directive. These two directives contain emission limits and CEM requirements that are similar to 17BImSchV.

CEMs which are incinerator specific, i.e. systems which have been specifically developed to address the unique problems associated with incinerators are reviewed below:

- HCl monitoring.
- Multi-component monitors (with and without HCl monitoring).
- Particulate matter monitoring.
- TOC monitoring.

4.2 <u>HCl Monitors</u>

The continuous monitoring of HCl is one of the most difficult challenges to CEM technology for incinerator applications. CEMs for the measurement of HCl in flue gases arising at MWIs have been on the market in Germany for over 10 years. These CEMs were originally developed for use at MWIs without acid gas removal systems and hence were designed with measurement ranges in the thousands of mg/m^3 for HCl. As the emission limit was reduced due to successive pieces of legislation, improvements were made to the measurement techniques employed to measure at lower concentration ranges. The measurement problems unique to monitoring HCl in MWI flue gases can be described as:

- The poor absorbtion of IR light by HCl. Attenuation of IR light is one of the fundamental techniques used for the determination of gas concentrations. The properties of HCl forced manufacturers of CEMs to use large measurement cells and the analysers displayed poor sensitivity. The special design of the measurement cells also resulted in high costs.

- HCl gas is very reactive and considerable problems were encountered with regard to the reliability of the gas sampling system. Sample loss was experienced by adsorption onto the sampling system construction materials and, with the introduction of wet scrubbing systems at MWIs, the existence of large amounts of water vapour in the flue gases resulted in the need to develop specialised and expensive sampling systems to ensure that the sample's gas temperature could be maintained above the flue gas dew point. Condensation of water vapour in the sampling system results in major sample loss and corrosion and fouling problems. A reliable method of removing the water vapour from the flue gas sample in a sample conditioning unit, without major loss of HCl sample occurring, has yet to be developed. This has resulted in sampling systems that maintain temperatures in excess of 180° C. If an IR measurement principle is used the measurement cell also has to be maintained at an elevated temperature.

- Working with HCl calibration gases is also difficult, again due to the reactivity of HCl. Standards are available from calibration gas suppliers, however, certification to +/- 5% is currently the best available and the stability of the gas is limited to six to 12 months. Adequate methods of instrument calibration have been the subject of much research.

CEMs which have overcome these difficulties are now available from a number of suppliers, the most established of whom are Bodenseewerk - Perkin Elmer, Bran & Luebbe and Woesthoff.

4.2.1 Bodenseewerk - Perkin Elmer

Bodenseewerk, a German subsidiary of the international Perkin Elmer Group, developed and introduced the Spectran 677 HCl monitor to the German incineration market in the early 1980s. The measurement principle is non-dispersive process photometer which is based on gas filter correlation in the IR range. The measurement is specific to HCl gas and is not influenced by other inorganic chlorides.

Independent testing was carried out by the TUV Norddeutschland during 1981 for the Spectran at various measurement ranges, the smallest of which was 0 - 200 mg/m^3 and the monitor was subsequently approved for this range.

Details of the operating performance of the Spectran were published by the VDI in 1992 [Ref 4.2] using results from the 1981 tests and information from the supplier. The detection limit for the 200 mg/m^3 measurement range was 2.1 mg/m^3 with interferences identified in particular from water vapour - up to 6% of the measurement range. Comments were also made on the requirement to adjust the calibration curve to the expected water concentration. Wide fluctuations in gas water vapour content could lead to measurement difficulties.

The Spectran was also subject to independent testing at an operating incinerator in the USA. Ref 4.3 describes site tests for a number of HCl monitors carried out by the USEPA in 1988. During the late 1980s and into 1990/91, the USEPA sponsored a number of field trials for available HCl monitoring equipment for incinerators. As described in Section 2, they were considering the promulgation of HCl monitoring performance standards for both BIF and MWI applications. The trials programme was terminated following a decision not to proceed with the promulgation of the HCl standard. No summary conclusions report was prepared, however, some of the individual test reports have been published. The test results from 1988 indicated that the Spectran 677 performed well with good agreement between the CEM data and data obtained by manual reference methods.

The Spectran 677 was installed at approximately 90 incinerators in Germany with MWI being the most common application. The ranges used were between 0 - 100 mg/m^3 and 0 - 3000 mg/m^3. The Spectran 677 was widely used for TA Luft compliance monitoring although not having the ideal minimum approved range (see Table 4.a). In most cases a fixed factor was used to convert from the wet concentration to the required dry concentration. Units were also installed at incinerator applications in Austria, Benelux, Switzerland, Scandinavia, Italy, France and two units in the UK/Ireland. The Spectran 677, although still available from Bodenseewerk, has been largely replaced in the incineration market place by the MCS multi-component system (see Section 4.3.1) which can measure a number of flue gas components in addition to HCl. At the time of the introduction of the MCS system the costs quoted for the multi-component version of the HCl monitor were similar to the costs quoted for the Spectran. The company itself has concentrated on the further development and marketing of the MCS, in particular for the monitoring of 17BImSchV type emission limits where water vapour data are required to compensate for interference, and also to derive the dry concentration from the wet concentration data.

4.2.2 Bran & Luebbe

Bran & Luebbe are a German company based in Hamburg with a full UK subsidiary in Northampton. They have been involved in the HCl monitoring market for incinerator applications since the 1970s, first through the Sensimeter range and subsequently through the Ecometer range.

Both monitors are based on potentiometric analysis, i.e. heated flue gas sampling system, automated contact between sample gas and an absorption solution and subsequent analysis by a chloride ion-selective electrode.

The Sensimeter G was tested by the TUV in 1979 with a minimum measurement range of 5 - 500 mg/m^3, however, the performance did not match the minimum requirements, in particular with regard to response time and reproducibility. The Ecometer HCl monitor was "type approved" in 1989 for incinerator applications with a minimum range of 0 - 200 mg/m^3.

Details of some of the operating characteristics of the Ecometer are given in a VDI guideline

.from 1992 (Ref 4.4). The data presented are based on the TUV approval report from 1989. The detection limit for the minimum measurement range is 3.2 mg/m^3. Other halides in the flue gas, i.e. F^-, I^- and Br^-, are reported to have a significant influence on the measurement result. The Ecometer measures all inorganic chlorides which enter the absorption solution, therefore any chloride salt aerosol which passes through the heated sampling system filter will also be registered as HCl.

The Ecometer has also been subjected to independent testing in the USA as part of the USEPA trials as described above. Ref 4.3 describes the performance of the Ecometer as good, however a negative bias was detected. In tests carried out at a HWI in 1990 (Ref 4.5), the Ecometer suffered from problems associated with other halides in the flue gas causing erratic measurement and increased response time.

The Ecometer has sold well in Germany and overseas for incinerator applications and would appear to be have been the only major competitor for Bodenseewerk - Perkin Elmer during the 1980s, both in Germany and overseas, for the monitoring of TA Luft type limits. Many installation sites are available with approximately five to six units sold in the U.K. - i.e. Rechem at Fawley and Pontypool, Fine Organics in Cleveland, Ciba Geigy in Manchester, Cleanaway in Ellesmere Port and Fibrogen. All the UK units have been sold with measurement ranges in excess of 100 mg/m^3.

Bran & Luebbe are currently working on a new version of the Ecometer with a measurement range and performance to match 17BImSchV. The system underwent TUV testing and approval in 1995.

4.2.3 Woesthoff

Woesthoff GmbH, based in Bochum in Germany, have developed an HCl monitor based on the change in conductivity of an absorbing solution following contact with the flue gas sample (hot wet extractive system). As described in Section 3.3.4, the Woesthoff system first measures the sum of acidic components (HCl + SO_2) and then SO_2 alone (following removal of the HCl from the sample gas by condensation on cooling). The difference between the measurement signals represents the HCl concentration.

The system was "type approved" for both HCl and combined HCl/SO_2 monitoring in 1989. The test report (Ref 4.6) indicated good performance with all performance characteristics well within the minimum requirements. The minimum range for HCl tested in 1989 was an average of 0.89 mg/m^3 for the measurement range 0 - 100 mg/m^3. The performance of the system indicated ideal suitability for the supervision of a HCl emission limit of 30 mg/m^3 - TA Luft.

In 1992, the Woesthoff HCl system was also approved for use at 17BImSchV applications with a measurement range of 0 - 15 mg/m^3, the first such approval in Germany, and at the time of compiling this report, still only one of two - the other is the MCS 100 HW from Bodenseewerk - Perkin Elmer. The test report indicated interference from HF if present in large quantities and also stated that the variation in H_2O content of the flue gas must also be taken into consideration if the variation is greater than +/-36 g/m^3.

Approximately 35 - 40 installation sites are available for the Woesthoff system either to measure the sum of HCl/SO_2 or HCl alone. A small number have now been sold at operating incinerators for full compliance monitoring with 17BImSchV. No utilisation is known in the UK and Woesthoff have no UK agent or subsidiary.

4.2.4 Others

A range of other systems have been developed for incinerator HCl monitoring.

The German company **Compur Monitors**, part of the Bayer group, developed an Ionotox monitor based on potentiometric analysis. Testing was carried out during 1993 by TUV, however no approval was received and the system has been withdrawn from the market.

Servomex in the U.K. developed an extractive (hot wet) NDIR monitor, the model 2510 for HCl measurement at incinerators. Development trials were carried out in the UK, however, no commercial installations are known (Instrument details are provided in Appendix I).

Severn Science in the UK developed and now market the Model SSI HCl monitor which is based on potentiometric measurement. The flue gas is contacted with the absorbing solution in the sampling probe and transported by means of an umbilical to the analyser. A number of UK and Far East sales have been made (instrument details are provided in Appendix I).

Tess-Comm Inc in the USA also developed and now market a HCl monitor based on the use of an ion selective electrode - similar to Bran & Luebbe and Severn Science. The Tess-Comm monitor also participated in the USEPA tests as described in Refs 4.4 and 4.5. The results from these tests were inconclusive with a number of operating problems reported including interference from other halides. In a second series of tests improved performance was reported following a change in the specification of the analyser solution. The analyser system can also be used for ambient air analysis for both HF and HCl. The bulk of the known installations are for HF analysis rather than for HCl measurement at operating incinerators (continuous HCl measurement is not a general requirement in the USA).

In the USA the market is small and German systems have predominated.

4.3 Multi-Component Analysers

In recent years, a number of systems have come onto the market which measure continuously or quasi-continuously a number of flue gas components. The most important of these are monitors from Bodenseewerk - Perkin Elmer and OPSIS.

4.3.1 Bodenseewerk - Perkin Elmer

Bodenseewerk - Perkin Elmer developed a series of multi-component monitors for the incineration market based on the Perkin Elmer MCS process photometer and the experience gained from the development and installation of the Spectran 677.

In 1989/1990, the company introduced the MCS 100 multi-component monitor to the market in two versions - CD and HW - both of which are extractive type monitors with facilities for zero and span adjustment using appropriate calibration gases. The MCS 100 can measure up to six components quasi-continuously. The CD version measures on a dry basis, i.e. the flue gas is subject to cooling and water vapour removal prior to analysis. The components which can be measured include; CO, NO, SO_2, CO_2, N_2O, CH_4 and a range of other organic/inorganic gases. The HW version maintains the sample gas temperature above 185°C at all times and hence can measure, on a wet basis, HCl, H_2O and NH_3, in addition to the components listed above.

The measurement principle is a combination of Non-Dispersive Infra-Red Gas Filter Correlation, NDIR GFC, and NDIR Dual Wavelength, i.e both gas filled cells and optical filters are used in the optical bench filter wheel. Both versions can be configured in a number of arrangements providing between two and six measured components per monitor. The measurements are made sequentially - moving measurement and reference filters into and out of the optical path in a predetermined sequence. One measurement value per component is obtained within the cycle time. For example, for a two component monitor HCl/H_2O, one measurement cycle takes approximately 10 seconds, for six components including HCl, the cycle time can be up to 84 seconds. (In Germany, the cycle time must be short enough to ensure that the CEM complies with the response time requirement of the type approval performance specification).

Compliance monitoring with TA LUFT type standards may be achieved using one MCS 100 HW which is configured to measure HCl, SO_2 CO and NO. The same monitor must also monitor H_2O and CO_2, both to compensate the measured pollutant concentration to dry values (H_2O concentration) and also to compensate electronically for the interference these two components cause to the other measurements, in particular HCl. Both H_2O and CO_2, which are present in the flue gas in the percentage range, are strong absorbers of IR. Full TA LUFT CEM standards would require the additional installation of an O_2 monitor and a Flame Ionisation Detector (FID) for TOC measurement.

Both the MCS 100 HW and CD were submitted to testing for 'type approval' in Germany during 1989 and were approved for use at incineration plant with the following minimum ranges in 1991;

		HW	CD
HCl	:	0 - 70 mg/m^3	-
SO_2	:	0 - 500 mg/m^3	0 - 100 mg/m^3
NO	:	0 - 200 mg/m^3	0 - 200 mg/m^3 (also NO_2 up to 80 mg/m^3)
CO	:	0 - 100 mg/m^3	0 - 100 mg/m^3

The measurement ranges for H_2O and CO_2 for the HW were up to 40% and 25% respectively.

To implement compliance monitoring using 17BImSchV CEM requirements, two MCS 100s are required - a HW version to measure HCl and H_2O (and possibly NH_3) and a CD version to measure SO_2, NO and CO. Separate O_2, TOC and particulate matter monitors are also required. To achieve the performance requirements for HCl, in particular a measurement range of 0 - 15 mg/m^3 and a detection limit of at least 0.3 mg/m^3, the MCS 100 HW can only measure a maximum of three components (instead of the six possible for TA LUFT 86 HW version). The MCS 100 HW was "type approved" in Germany in 1994 for the low HCl measurement range. The CD monitor is equipped with full flue gas conditioning and measures the other components with the approved measurement ranges, i.e. approval from 1991.

The MCS 100 has also been subject to independent testing in the USA. It was included in tests carried out by the USEPA during 1990 [Ref 4.5] as part of the programme designed to test available HCl monitoring technology. Although the monitor was a multi-component system, only the HCl measurement channel was tested. The measurement range was 0 - 500 ppm. The MCS 100 demonstrated the best performance of all the monitors included in the test in terms of relative accuracy, i.e. compared to the results obtained using EPA Method 26. The aims of the test programme and the other HCl monitors participating are described in Section 4.2. The relative accuracy over three test campaigns averaged approximately 23% for actual HCl concentrations in the range 3 - 86 mg/m^3 (see definition of relative accuracy in Section 2.4.3). Ref 4.5 discusses the relative accuracy test results and comments:

" The Mekos (MCS 100 HW) also measures the H_2O content and makes two corrections to the wet-basis HCl measurement data to convert to dry-basis readings. One is for the volume of H_2O in the gas sample, and the second for the H_2O influence on the HCl absorption coefficient. A correction factor is used in the microprocessor to account for the H_2O influence. This correction is determined at a single point within the HCl measurement range for the typical HCl and H_2O levels expected at the source. The correction factor for the instrument provided for the EPA evaluation was determined at 345 ppm HCl and 40% H_2O. According to the vendor, a more appropriate setting would have been determined at a lower concentration. The factor determined at 80 ppm and 40% H_2O, coupled with a manual calibration adjustment that could have been performed based on the Mekos responses to calibration gas injections during the calibration error tests would improve the relative accuracy results to 10% and 6% for the second and third test, respectively..... These results may better reflect the true performance capabilities of the Mekos. "

The basis of this comment, which has been confirmed by Bodenseewerk, highlights the importance of specifying as accurately as possible the expected flue gas conditions when ordering an MCS 100 system for HCl. These data are used for factory adjustment of the correction factor. If the source characteristics are changed dramatically then the calibration may need to be adjusted. This should also be considered if a portable system is used, i.e. moving from site to site with widely differing characteristics.

The Bureau of Air Management in the State of Connecticut also published data on certification tests on a number of MCS 100 CD systems installed at both scrubbing system inlet and outlet of an MWI facility [Ref 4.7]. The measured components were SO_2, CO, NO, CO_2 and H_2O. In general, the monitors performed well with excellent availability and relative accuracy results with the specified requirements. Problems were experienced with the CO measurement channel. The source was characterised by very rapid CO level fluctuations. The method against which the MCS 100 was being tested for CO measured on a continuous basis whereas the MCS 100 measured CO within the cycle time as described above. The MCS 100 therefore could not discern the fine detail on the CO level and achieved poor relative accuracy results. For CEM certification purposes an additional CO monitor was installed.

The MCS 100 series has been very successful in the market since its introduction. Several hundred units (September 1994 reference list) have been sold to the incineration market for both raw gas analysis - measurement ranges up to several thousand mg/m^3 - and emission analysis. For emission analysis the installation site list for 17BImSchV standards is currently quite small but is expected to grow rapidly as the German incineration market complies with the legislation. The main market has been Germany, however a significant number of units have been sold in North America, Scandinavia, the Benelux countries, Taiwan/Korea and France. Three have been sold in the UK - Shell Stanlow, City of Dundee MWI and a portable unit to the Department of Trade & Industry (DTI). The UK agent is Land Combustion Limited.

During a field trip to Germany, as part of this study, a number of MCS 100s were observed at operating incinerators, one MWI and two HWIs. The operators reported high availability, low maintenance and good performance. At MVA Dusseldorf, approximately six units were in operation monitoring in both the raw and cleaned gas.

4.3.2 OPSIS AB

The Swedish company OPSIS AB developed a multi-component monitor during the 1980s for ambient air quality measurement. The monitoring system was further developed for use as a multi-component stack emission monitor which could be used at a number of industrial sources including waste incinerators.

The A 600/620 system is a cross duct monitor which is based on the principle of Differential Optical Absorption Spectroscopy (DOAS) - computer based analysis of absorption spectra in the UV through to IR range. Light is passed through the duct from sender to receiver and then, by means of a fibre-optic cable, to the analysis unit. The absorption spectrum is then compared to factory prepared calibration curves. Normally no calibration gases are used for site adjustment of zero and span settings, however for the US market a manual site calibration system has been developed (necessary for compliance with USEPA performance standards). Manual zero and span adjustment (or drift calculation) is achieved by removing the sender and receiver from the duct and placing them at opposite ends of a calibration bench into which calibration cells can be introduced. The cells have transparent windows and calibration gas is passed through them. The system can be configured to measure between two and eight components in the flue gas from NO, NO_2, SO_2, H_2O, HCl, HF, NH_3 and Hg.

The measurement ranges achievable for each of the possible components will depend on both the measurement path, i.e. the distance between sender and receiver in the duct - recommended between one and five metres - and the signal processing or integration time.

Compliance monitoring for TA LUFT type standards may be achieved with one A 620 system to measure HCl, SO_2, NO/NO_2 and H_2O (the other possible components, e.g. CO_2, NH_3 etc. are optional). Full compliance with TA LUFT will require the installation of additional monitors for CO, O_2 and TOC. The A 620 was "type approved" in Germany during 1991 and 1992 for SO_2 (min. range 0 - 80 mg/m^3), NO (min. range 0 - 150 mg/m^3), NO_2 (min. range 0 - 20 mg/m^3) and H_2O (min. range 0 - 30%). The approved ranges ensure that the range required for these components under TA LUFT are adequately covered. No approval was obtained for HCl monitoring. The detection limit for HCl for the standard OPSIS system is given as 10 mg/m^3 (for a one metre path length and 30 second measurement time) which does not meet the German performance requirements, however, a number of systems have been installed (in particular in Scandinavia) with a measurement range for HCl down to 0 - 100/200 mg/m^3.

To monitor 17BImSchV type limits the approvals for SO_2 and NO_x from 1991/1992 are valid. For CO and HCl, the AR 650 OPSIS, which concentrates on the UV light range, has been subjected to intensive testing at an operating MWI in Hamburg during 1994. OPSIS hope that if the tests are successful they will be able to offer a full 17BImSchV system to the German market. This will comprise one sender/receiver set with two separate fibre-optic cables to be connected to a 600 series analyser for SO_2, NO_x NH_3 and Hg measurement and the other connected to a 650 unit for HCl, H_2O and CO. Both analysers will be housed in a single cabinet with one keyboard and VDU.

Ref 4.8 describes operating experience with the OPSIS system installed at the Hamburg MWI. The incinerator operator has used the system as the main form of compliance monitoring for SO_2, NO_x, NH_3 and Hg. The continuous monitoring of both NH_3 and Hg are not standard 17BImSchV requirements, however, OPSIS obtained type approval for both parameters in 1992 and 1994 with the following minimum measurement ranges

NH_3 0 - 10 mg/m^3
Hg 0 - 0.15 mg/m^3.

The availability of systems for the continuous monitoring of these parameters has encouraged individual licensing authorities to specify their use in operating licences.

The operating experience described for the Hamburg MWI [Ref 4.8] is generally positive with no major problems reported. The system was installed at an angle to the gas flow in the duct allowing a seven metre gas path length in a 2.1 m duct. Comments are made with regard to the regular maintenance required and the importance of compressed air required for purging of the sender and receiver units. The system was installed in late 1993. In the absence of the system's type approval for CO, a URAS 3 monitor from Hartmann & Braun was also installed.

The reference list for incinerator applications is concentrated in Scandinavia with versions used for both emission monitoring purposes and also raw gas monitoring - with HCl measurement ranges up to 0 - 10,000 mg/m^3.

The UK agents for OPSIS are Enviro Technology Services plc (company details are provided in Appendix I).

4.3.3 Others

A multi-component analyser for flue gas analysis was developed in Canada during the 1980s by a company (Bomem) which was subsequently taken over by the German company Hartmann & Braun. The technology employed was Fourier Transform Infra-Red (FTIR) analysis. The technology, which utilises a hot wet extractive system, could measure up to nine gas components, including HCl. This FTIR system was introduced to the European market for incinerator applications during 1994 - marketed as CEMAS in Germany and the H&B, 9100 FTIR CEM in the UK.

The model 9100 (as marketed in the UK) can measure SO_2, HCl, NO, NO_2, CO, HF, H_2O, CO_2, and NH_3 with minimum measurement ranges which would be acceptable for compliance monitoring purposes for TA LUFT type standards, e.g. 0 - 70 mg/Nm^3 minimum for HCl. The measurement is not continuous, but is based on the analysis of a sample of flue gas in the measurement cell followed by flushing of the cell and re-sampling - from a continuous hot wet bypass flow in the analyser. This mode of operation results in a long response time, i.e. T_{90} up to 150 seconds. However, the performance characteristics of the system, e.g. detection limits, interferences etc., are claimed to be within the minimum performance criteria for TA Luft CEM systems in Germany.

Incinerator references for the H&B FTIR system are practically non-existent for Europe. In Canada, one system has undergone extensive field trials at the MWI in Quebec City. The field trials were successful with good reliability and low maintenance. The performance was tested against the typical German performance standards and was found to meet or exceed them. The measurement ranges tested would qualify the system for supervision of TA Luft type emission limits, e.g. HCl : 0 - 70 mg/m^3.

It is significant that a company with such extensive experience in the design and marketing of CEM systems as H&B, should decide to invest the time and money that is required to sell the FTIR system to the German incineration market. It would appear, therefore, that they are confident that the future of CEMs for incineration applications in Europe lies in multi-component monitors and they have put their faith in FTIR as the most likely technology to succeed.

The US company KVB/Analect also developed an FTIR multi-component monitor for incinerator applications which was introduced to the market in the early 1990s. [Ref 4.9]. The performance and capabilities of the system are claimed to be similar to the H&B monitor.

The company claims five European installation sites incinerator applications - believed to be concentrated in Italy and a small number of units under test at US sites. KVB/Analect are represented in the UK by Hobre Instruments. No FTIR systems have been sold in the UK.

The UK company Procal Analytics Ltd. has developed both an in-situ (Pulsi 200 series) and an extractive (Pulsi 400 series) multi-component monitor based on NDIR GFC. The measurement principle is similar to that used by Bodenseewerk for the MCS system, i.e. multi-pass sample cell with measurement and reference filters (gas filled cells or optical filters) moved into and out of the optical path according to a predetermined sequence. The Pulsi 200 series uses a sample cell which is inserted into the stack or flue gas duct. The cell is protected by a sintered filter through which the flue gas components diffuse. The Pulsi 400 series is based on hot wet sampling of the flue gas and analysis in external photometer.

The Pulsi series can measure up to eight components, however for incineration applications four components would be usual, i.e. HCl, SO_2, NO or CO and H_2O (non-indicating correction channel). The minimum measurement range for HCl is given as 0 - 50 ppm (0 - 83 mg/Nm^3). Installation sites are available for both types of four component system at incinerator applications mainly in the UK, Italy and the Far East.

4.4 Particulate Matter

There are three main problems associated with the measurement of particulate matter on a continuous basis at incineration plants:

- Flue gases leaving a scrubbing system may be saturated with water vapour and may contain fine droplets and aerosols carried over from the scrubbing system. Traditional opacity monitors cannot distinguish between particulate matter and water droplets and hence cannot generally be used at sites where wet scrubbing systems are employed.

- There are no standard calibration gases for particulate matter monitors and the only way to relate the CEM response to particulate matter loading is to carry out a detailed site calibration, i.e. linear regression analysis for paired measurement data (see Section 2.2.3). This calibration is specific to the properties of the particulate matter that exist during the calibration. The response of a CEM to particulate matter is influenced to a greater or lesser degree by the characteristics of the particulate matter to be measured. The shape, colour and size distribution of the particles will alter the response of the analyser, resulting in different readings when the same mass loading of particulate matter is present but when the properties of the particulate matter have changed. At sites where the characteristics of the particulate matter do not change radically, the calibration curve derived remains reasonably valid. At incineration sites, the nature of the particulate matter can alter depending on the composition of the waste being incinerated. The lowering of limits for particulate matter emissions to levels around 10 mg/m^3 in 17BImSchV, RV89 and the EU Directive on Hazardous Waste Incineration have lessened the importance of this consideration. Particulate matter that passes through a scrubbing system which reduces the mass loading to low levels will usually result in a reasonably common set of particulate properties.

- The third problem is designing a CEM system that is sensitive enough to measure the low levels required.

There are three main types of CEMs currently being applied to particulate matter monitoring at incineration plants in Europe, i.e. Light Transmission, Light Scatter or Dispersion and Beta-Ray Measurement. Other CEMs include Optical Scintillation and Triboelectric systems.

4.4.1 Light Transmission (Photometric in-situ).

The concentration of particulate matter is measured by the attenuation of a light-beam which is passed through the flue gas duct or stack from the sender to a receiver. For any given light path length there is generally a linear relationship between the extinction of the light (defined as the logarithm of the light transmitted divided by the light received) and the concentration of particulate matter. The precise relationship between extinction and particulate matter concentration can only be determined on-site during calibration. The measurement ranges for these types of analysers are quoted therefore in terms of extinction.

CEMs of this type have found wide application in the power generation industry. Common features include light modulation to compensate for interference of light from other sources (the receiver only recognises light of the correct modulation frequency), air purge system to keep optical surfaces clean, and automatic zero compensation to compensate for dirt build up on the windows. A wide variety of optical arrangements are used; e.g. double pass types that use a reflector on the opposite side of the stack or duct so that the light is transmitted twice through the flue gas, increasing sensitivity.

CEMs of this type are supplied by a number of companies, including Erwin Sick, Durag, Codel, Anacon and Hartmann & Braun. They all have references at incineration plant with the German CEMs having obtained type approval for the application. Anacon received a German type approval for incineration plant during 1994. The Hartmann & Braun unit is a Codel system sold under the H&B name. These CEMs cannot be used for applications where a wet scrubber has been used and where there is no flue gas reheat. They also have range limitation when levels of particulate matter go below approximately 10 - 20 mg/m^3 (Ref 4.10).

CEMs of this type have proved successful in applications where a dry flue gas is subjected to TA Luft 86 compliance monitoring, i.e. limit value 30 - 50 mg/m^3. However, for lower limits or a wet flue gas other technologies have proved more successful.

4.4.2 Light Scatter or Dispersion

Light scatter analysers can be either extractive or in-situ. A beam of light is passed through the flue gas either in the duct or in an analyser working on a heated flue gas bypass system. The light is attenuated and scattered by the particulate matter. The CEM measures only the amount of scattered light at a pre-determined angle to the main beam. Measuring the small amount of scattered light is more sensitive than light transmission monitors as the scattered light does not have to be distinguished from a much larger amount of transmitted light.

CEMs of this type have been developed by Erwin Sick, Durag and Sigrist.

The Erwin Sick RM200 and the Durag DR300-40 measure in-situ and hence are influenced by water droplets and aerosols. Both have been "type approved" for incinerator applications with a minimum range of 0 - 15 mg/m^3 and are suitable for 17BImSchV compliance monitoring in dry flue gas. The KTNR CEM from Sigrist utilises an automatic heated isokinetic sampling system to obtain a sample gas flow where all droplets in the gas are evaporated. This permits operation in water saturated flue gas. The three systems have been installed at incinerators with the KTNR being particularly successful.

Sigrist are represented in the UK by Rosow Technical.

4.4.3 Beta Ray Measurement

The measurement principle is based on extracting a sample of flue gas in a heated sampling system and passing it through a filter paper which is on a continuous motorised reel to reel system. The area of the filter paper that is intercepting the particulate matter contained in the flue gas is subject to a beta ray source. The attenuation of the beta rays is measured and is a measure of the level of particulate matter build up on the filter. The filter paper moves according to a predetermined sequence, with fresh filter surface introduced to the flue gas at regular intervals. The filter paper reel is also available for subsequent metals analysis if required. CEMs of this type can operate on wet flue gas.

CEM systems are available from FAG and Verewa. Both systems have received type approval with a measurement range of 0 - 30 mg/m³ for the FAG CEM and 0 - 15 mg/m³ for the Verewa. Both have a limited number of systems installed at incinerator applications. Graseby Anderson are UK agents for Verewa. They have not been successful to date in the UK market. FAG do not have a UK agent.

4.5 Total Organic Carbon (TOC)

There is a huge range of organic compounds to be found in flue gas from incineration processes. The general emission limit for organic compounds is expressed as mg of organic carbon. This can be measured on a continuous basis by the use of a Flame Ionisation Detector (FID). A very small but measurable ion current is observed when an electric field is applied to a hydrogen flame. When air (or flue gas) containing organic molecules is fed to the flame the current increases approximately in proportion to the number of C-atoms introduced per unit time. FIDs have been used for many years as detectors for gas chromatography and also for measuring VOC emissions in air streams. The application of FID technology to incinerator gas commenced during the 1980s. The application of FID technology to incinerators is associated with a number of difficulties including:

- The FID is usually calibrated using either methane or propane. Other organic molecules display different response factors i.e. ion current not linearly responsive to the number of C-atoms. The published performance standards for FID for incineration processes in both Germany and Holland call for a maximum standard deviation of less than 15% of the calibration response for a range of compounds including cyclohexane, methyl benzene and butyl and ethyl acetate.

- All FID systems are extractive and where a wet flue gas is to be sampled considerable care and attention has to be invested in the design of the sampling system and the internals of the FID to avoid sample loss and corrosion/contamination in the measurement cell.

TA Luft 86 introduced an emission limit of 20 mg/m³. The first system to obtain a type approval for an FID to supervise this limit was the Fidas 2T in 1989. This approval was closely followed by a similar approval for the COMPUR FID from Bayer. Both of these CEMs had a measurement range of 0 - 50 mg/m³. The most widely used FID for TA Luft 86 was and is the Fidas CEM.

The introduction of lower limits for TOC., i.e. 10 mg/m³, resulted in a renewed round of development and research to develop a suitable system. Type approvals were received in Germany for FIDs from COMPUR (taken over by Hartmann & Braun in 1994), JUM, and Ratfisch. These CEMs have measurement ranges of 0 - 20/25 mg/m³ and have been approved for 17BImSchV applications.

4.6 Other Parameters

4.6.1 SO_2, NO_x and CO

For the continuous measurement of SO_2, NO_x and CO in incinerator flue gas there is a wide range of proven technologies available. CEM systems for these parameters are widely used in the utility boiler industry and the measurement ranges that are required for these parameters, whether for TA Luft 86 or 17BImSchV type emission limits, do not put undue strain on the capabilities of the employed technology.

The multi-component systems described in Section 4.2 will measure these components and both the Perkin Elmer - Bodenseewerk MCS 100 CEM and OPSIS have extensive incinerator reference lists for these parameters. Prior to the introduction of these CEMs to the market, the most successful CEM technology for incinerator applications was the extractive NDIR/NDUV. The German market has been dominated by Hartmann & Braun (Uras and Radas) and Siemens (Ultramat). Both companies have "type approved" systems for incinerators for both TA LUFT 86 and 17BImSchV type limits.

The NDIR/NDUV type CEM is described in Appendix I. There are a large number of suppliers of these systems, many of whom have approvals/references in the incineration market. The suppliers are listed in tabular form in Appendix I.

4.6.2 Hg and NH_3

In recent years there has been considerable interest internationally, but particularly in Germany, with regard to the monitoring of both Hg and NH_3 emissions from incinerators on a continuous basis.

Hg is present in flue gas as both mercury compounds - in particular $HgCl_2$ - and in metallic form. Three Hg CEM systems are currently available.

Verewa Mess- und Regeltechnik GmbH have developed an extractive total mercury CEM - the Total Mercury Analyser HM 1400. Sample flue gas is first passed through an IR oven (max 800°C) and two reactors to oxidise and disassociate all mercury compounds to the metallic vapour form. The treated sample is then analysed in a UV atomic absorption spectrometer. The development of the CEM was co-sponsored by the EU and it has been subject to type approvals testing for 17BImSchV. The minimum standard measurement range is 0 - 0.15 mg/m^3. The company can name two municipal waste incinerators and one hazardous waste incinerator installations, all in Germany. The company has recently appointed a UK representative - Graseby Andersen Ltd. (company details are provided in Appendix I).

The nuclear research establishment at Karlsruhe developed a continuous mercury CEM which is now manufactured and marketed by Seefelder Messtechnik as the Hg-Mat2. It is similar in concept to the Verewa unit and consists of a heated sampling system, a reactor for oxidation and vaporisation of all mercury compounds and an atomic absorption spectrometer. The minimum and maximum measurement ranges are 0 - 0.15/1.2 mg/m^3. A liquid analysis version of the analyser has also been developed and some work has been carried out at an MWI on the use of the analyser as a control signal input to a TMT 15 dosing system in the waste water treatment. Windsor Scientific Ltd. are the UK agents for the Seefelder Hg-Mat2.

OPSIS, as described in Section 4.3.2, can also measure metallic mercury vapour in incinerator flue gas. This cross duct system has a minimum standard Hg measurement range of 0 - 0.15 mg/m^3 with a detection limit of 0.005 mg/m^3. The system achieved "type approved" status for Hg in 1994. The OPSIS CEM does not measure total Hg, however, tests have been carried out to develop a correlation factor between metallic and total mercury in the flue gas after a wet scrubber. OPSIS have a large number of installations at incinerators.

Interest in NH_3 CEMs is due to the installation of NO_x control systems, either SCR or SNCR, at operating incinerators which utilise NH_3 injection into the flue gas for the reduction reaction of NO_x to N_2 and O_2. Unreacted NH_3 can cause problems in following flue gas treatment systems and also pose an additional emission problem. Optimisation of DENOX systems and the limitation put on NH_3 emissions in new operating licences in Germany have encouraged manufacturers to develop NH_3 CEMs.

Three systems have been developed commercially, two of which are multi-component systems.

Both the extractive Perkin Elmer - Bodenseewerk MCS 100HW and the cross duct OPSIS CEM can measure NH_3 as one of the components. The OPSIS has a "type approved" measurement range of 0 - 10 mg/m^3, whereas the MCS 100 HW successfully completed testing during 1994 for a minimum measurement range of 0 - 10 ppm. Both systems are being used extensively at incinerators including a limited number of units measuring NH_3.

Siemens developed the MIPAN NH_3 CEM and received type approval in 1993 for the measurement range 0 - 15 mg/m^3 . The MIPAN is based on micro-wave spectrometry.

4.6.3 Polychlorinated Dibenzo-p-dioxins and Dibenzofurans

Long-term sampling systems recently developed for monitoring of polychlorinated dioxins and furans are described in Refs 4.11 and 4.12.

4.7 Costs

The estimation of the cost of a full compliance monitoring system based on CEMs is associated with a number of difficulties and uncertainties. Costs will be site specific and there are numerous options available with regard to the basic technology employed and also with regard to the optional extras that are associated with any system.

During the course of the study cost information was obtained from UK suppliers, from German suppliers and from the literature - in particular a Dutch study carried out during 1991 which obtained quotations for full monitoring systems for compliance with RV 89 [Ref 4.13]. Wide discrepancies were noted between the costs quoted which can be attributed to market differences and also the degree of engineering and service elements associated with each cost quote. Costs have also been obtained from UK suppliers (and several German suppliers). Details are included in Appendix I.

Having regard to these uncertainties, costs for CEMs are discussed under two headings. The first is the installation of a system by UK suppliers for compliance with IPR 5/3 type standards - similar to TA LUFT 86, and the costs of complying with 17BImSchV/RV89 and the new EU Directive type standards based on the information obtained from suppliers in Germany and Holland. All costs should only be taken as an order of magnitude indication.

4.7.1 IPR 5/3 or TA LUFT 86 Compliance

For compliance monitoring to IPR 5 standards, separate analysis systems are required for particulate matter and TOC. For the other gaseous components several engineered options are available. All prices and options are given in a simplified form in Table 4.2.

Unless otherwise indicated, the costs do not include major site development costs, i.e. installation of access ladders, platforms, utility connections etc..

Particulate matter

For a dry flue gas, cross duct systems from companies such as Erwin Sick, Hartmann & Braun, Codel etc. would be suitable. These have an equipment cost in the range £7,500 - £8,500. A budget price including installation would be £10,000. If the flue gas is wet the price will increase substantially up to £30,000 to £35,000 for the Sigrist KTNR or the Verewa F-904.

TOC

An FID, suitable for use at an incinerator with wet scrubbing would cost in the region of £15,000 - £25,000 with an average of £20,000 including a heated sampling system.

Gas Components Option 1 - Individual Monitors

This option is based on an extractive system with one sampling probe and sample conditioning equipment set, i.e. filters and cooler. The CEM system is based on the use of NDIR monitors for SO_2 and CO, an NDUV monitor for NO_x, and an O_2 paramagnetic analyser. The HCl analyser is from either Bran & Luebbe or Woesthoff with a dedicated sampling system. The budget cost for this option is approximately £95,500.

Gas Components Option 2 - Multi-Component Systems

Bodenseewerk: One extractive MCS 100 HW for six components, SO_2, NO CO, HCl, CO_2 and H_2O. A separate paramagnetic O_2 analyser will also be required. The budget cost for this option is approximately £97,300.

OPSIS: One cross duct system for HCl, SO_2, NO, NO_2, CO_2 and H_2O. A separate CO analyser, e.g. cross duct from Codel, and a paramagnetic O_2 analyser will also be required. The budget cost is approximately £95,000.

H&B FTIR: This system which is new to the market is an extractive (hot-wet) analyser which can measure HCl, SO_2, NO, NO_2, CO_2 and H_2O. A paramagnetic O_2 analyser will be required. The budget cost is approximately £85,000.

The costs developed for the different systems available are all of the same order of magnitude and, given the uncertainties discussed earlier, and the fact that in a competitive situation costs are likely to be refined for particular jobs, it would appear that there is little to choose between the various options on price.

4.7.2 17BImSchV/RV89/EU Directive/IPC Guidance Note S2 5.01

The current market price for a full CEM compliance monitoring system as quoted recently in Germany is given in Table 4.3. The total price given is similar to the budgetary allocations allowed by several German operators who were visited as part of this study.

The range of figures quoted in 1991 [Ref 4.13] for a full compliance system for RV89 are given in Table 4.4.

Since the compilation of the figures in 1991, it is likely that Dutch costs will have come down in line with in Germany prices. However, it would appear that Dutch operators insist on a very high level of training and back-up for installed CEMs and the prices charged in Holland are structured to reflect this requirement.

TABLE 4.1A
EMISSION LIMITS AND CEM PERFORMANCE REQUIREMENTS
- TA LUFT 86/ OR 89/369/EEC - IPR 5/3 TYPE LIMITS

Pollutant	Limit Value mg/m^3	Allowable Measurement Range (Note 1) mg/m^3	Maximum Allowable Detection Limit (Note 2) mg/m^3	Maximum Allowable Interferences (Note 3) mg/m^3
HCl	30	0 - 90	1.8	3.6
Particulate Matter	30	0 - 90	1.8	3.6
TOC	20	0 - 60	1.2	2.4
SO_2	300	0 - 900	18	36
NO_x	350	0 - 1050	21	42

Notes:

Note 1 : The monitor range should be 2.5 to 3 times the emission limit
Note 2 : The detection limit should be a maximum of 2% of the measurement range.
Note 3 : The maximum interference by other flue gas components should be no greater than 4% of the measurement range.

TABLE 4.1B

EMISSION LIMITS AND CEM PERFORMANCE REQUIREMENTS - 17BIMSCHV TYPE LIMITS.

Pollutant	Limit Value (Note 1) mg/m^3	Measurement Range (Note 2) mg/m^3	Detection Limit (Note 3) mg/m^3	Interferences (Note 4) mg/m^3
HCl	I - 10 II - 60	0 - 15 0 - 90	0.3	0.6
Particulate matter	I - 10 II - 30	0 - 15 0 - 45	0.3	0.6
TOC	I - 10 II - 20	0 - 15 0 - 30	0.3	0.6
SO_2	I - 50 II - 200	0 - 75 0 - 30	1.5	3
NO_x	I - 200 II - 400	0 - 300 0 - 600	6	12

Notes:

Note 1 : The emission limits are expressed as 24 hour averages (limit I) and 30 minute averages (limit II).

Note 2 : The monitor measurement range for 17BImSchV is given as 1.5 times the limit value for the 30 minute average, i.e. for HCl 0 - 90 mg/m^3. However, the minimum performance criteria should be assessed for a measurement range corresponding to 1.5 times the 24 hour average limit. Therefore, in particular for HCl, dual range monitors are being offered by suppliers with either automatic switching or continuous recording of two range channels.

Note 3 : The detection limit is a maximum of 2% of emission limit range I.

Note 4 : The maximum interference by other flue gas components should be no greater than 4% of the emission limit range I.

TABLE 4.2: COST ANALYSIS FOR IPR 5/3 TYPE STANDARDS

Gas Analysis		Option 1	Option 2		
		Individual Analysers	Bodenseewerk	Opsis	H&B FTIR
Analyser Costs	SO_2	£8,500			
	NO	£10,000	£65,000 Note 7	£75,000 Note 10	£85,000
	HCl	£30,000			
	CO	£7,000		£10,000	
	O_2	£6,000	£5,000	£5,000	
	Sampling Systems	£10,000 Note 1	£20,000 Note 8		
Ancillary Equipment	Sample conditioning	£4,000 Note 2	£1,500		
	Cubicles, Racks and Engineering	£15,000 Note 3	£800 Note 9		
	Installation Costs	£5,000 Note 4	£5,000 Note 4	£5,000 Note 4	
	Sub-totals	£95,500	£97,300	£95,000	£85,000 Note 11
Particulate Matter	dry flue gas	£10,000 Note 5	£10,000 Note 5	£10,000	£10,000
	wet flue gas	£35,000 Note 5	£35,000 Note 5	£35,000	£35,000
TOC		£25,000 Note 6	£26,000 Note 6	£25,000	£25,000
Totals	dry flue gas	£130,500	£132,300	£130,000	£120,000
	wet flue gas	£155,500	£157,300 Note 7	£155,000	£145,000

Note 1: includes one sampling probe and short length of heated sample line
Note 2: filters, coolers, flow valves etc.
Note 3: the cost of system design and installation in a cubicle/rack system
Note 4: a standard allowance for site based installation and commissioning
Note 5: includes commissioning
Note 6: includes sampling and commissioning
Note 7: inclusive costs for HCl, NO and SO_2 and CO
Note 8: sampling for O_2 from gas exit from MCS 100 HW
Note 9: most engineering costs in analyser costs, additional costs associated with O_2
Note 10: inclusive costs for HCl, NO and SO_2, an additional CO analyser is required
Note 11: all inclusive cost

General: costs not considered include calibration gases (hardware), containers or housing, access, platforms, welding, service, datalogging, utilities.

TABLE 4.3
GERMAN PRICE QUOTE - COMPLIANCE WITH 17BImSchV

No.	Item	Price
1	MCS 100 HW - HCl, NH_3 and H_2O Sampling System with heated line	£86,000 £6,250
2	MCS 100 CD - SO_2, CO and NO	£31,250 £11,000
3	Compur Multi-FID - TOC	£14,000 £4,000
4	Oxygen Analyser	£6,000
5	Itabar Averaging Pitot - Flue gas flow measurement	£12,000
6	Sigrist Particulate Matter Measurement	£35,000
7	Data-logger, printer	£17,000
8	Control Cubicle	£6,500
9	Calibration gas system	£15,000
10	CEM container - walk-in container, heated for all CEMs	£20,000
11	Delivery and Installation	£9,000
13	Commissioning	£4,000
14	Engineering and Documentation	£18,000
	Total	**£255,000**

Note: Original prices in DM, exchange rate £1 - DM 2.4

TABLE 4.4 - DUTCH FULL SYSTEM PRICES - 1991 (Ref 4.13)

Prices quoted by Dutch Systems Builders in NGL, 1991 exchange rate £1 = 3.2DG

For system details see notes

Supplier	H&B	Multi Instruments	Rosemount	Van [illegible] en Heurvens	Siemens [13]	Enviro
Particulate matter	96,000	116,000	112,000	55,000	136,000	83,000
HCl	129,000	167,000	150,000	123,000	168,000	250,000 [8]
CO	30,000	146,000 [1]	33,000	22,000	[3]	59,000
SO_2	23,000	[1]	28,000	22,000	[3]	[5]
NO	34,000	[1]	34,000	36,000	[3]	[5]
O_2	15,000	19,000	13,000	18,000	[3]	7,000
Total CO, SO_2, NO and O_2	102,000	165,000	108,000	98,000	236,000	Incl. HCl 316,000
C_xH_y and temperature measurement	94,000	73,000	58,000	35,000	90,000	50,000
Sampling of CO, SO_2, NO, O_2 and C_xH_y	[7] 36,000	[7]	85,000	62,000	[7]	[7]
Total analyzing equipment and sampling system	457,000	521,000	513,000	373,000	630,000	449,000
Data processing	99,000	95,000	60,000	20,000	22,000	[6]
Housing [10]	113,000	135,000	46,000	64,000	70,000	36,000
Calibration gas	19,000	14,000	13,000	24,000	[4]	30,000
Engineering	51,000	20,000	79,000	39,000	84,000	25,000
Assembly/start-up	100,000	53,000	24,000	52,000	30,000	12,000
Total basic system	839,000	838,000	735,000	572,000	836,000	552,000
Options						
Flow rate	21,000	34,000	20,000	54,000	33,000	33,000
Moisture	4,000 [11]	[2]	5,000 [12]	24,000 [12]	38,000 [12]	9,000 [10]
Static pressure	5,000	4,000	5,000	7,000	5,000	3,000
HF	140,000	154,000	166,000	197,000	141,000	13,000 [10]
NH_3	177,000	19,000	208,000	248,000	194,000	13,000 [10]
CO/O_2	101,000	76,000	137,000	71,000	60,000	66,000
Total inclusive options	1287,000	1125,000	1276,000	1173,000	1307,000	689,000

Notes to Table 4.4:

1) SO_2, NO_x and CO combined in Bodenseewerk MCS 100 CD.
2) Moisture measurement in Bodenseewerk MCS 100 HW.
3) Siemens gives one price for combined measurement of CO, SO_2, NO_2 and O_2.
4) Siemens did not submit a price for calibration gases.
5) SO_2 and NO_x combined with HCl (OPSIS AR 620).
6) Data processing integrated in OPSIS AR 620.
7) Sampling included in price of measuring system.
8) The Enviro OPSIS system combined the analysis of a number of components. The basic price can be found under the HCl component. The CO and SO_2 components are included in this price. The optional components H_2O, HF and NH_3 are also measured with this system so that only an extension to the existing system will be required.
9) The assembly costs for the data processing systems are included and amount to NLG 2000.-- up to NLG 22,000.--.
10) Combined with HCl, SO_2 and NO_x in the OPSIS AR 620 (see also note 8).
11) By means of temperature measurement in saturated flue gas.
12) By means of psychometric method.
13) Siemens offered for 1993 a price which is about NLG 100.000,-- lower for the total basic system and about NLG 170.000,-- lower for the total equipment inclusive options.

5.0 MONITORING OF RELEASES TO WATER AND SOLID RESIDUES

5.1 Monitoring of Releases to Water

In the case of Germany, the Netherlands and the European Union there are no specific regulations on incineration for continuous monitoring of releases to water. Most German and Dutch plants are moving to wastewater free operation.

However, in the USA discharges to 'navigable' water from incineration processes are covered by NPDES permits. The NPDES permit programme is primarily based on an "end-of-the-pipe" control approach which focuses on specifying effluent limitations guidelines or concentration limits for individual pollutants in permits. Concentration limits are applied to "conventional pollutants" such as Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS) and pH.

In the UK, the Environment Agency's IPC Process Guidance Notes include general advice on continuous monitoring of releases to controlled water and sewers:

Environment Agency Monitoring Requirements -

Where relevant, continuous monitoring of process effluents released to controlled waters and sewers should be made for:

- Flowrate.
- pH.
- Temperature.

Monthly analysis of representative monthly bulk samples should be made for:

- Suspended Solids.
- Dioxins.
- Prescribed Substances (where relevant).
- Any determinands released to controlled waters and required by the licensing body, and maxima for the period reported.

Continuous monitoring and flow proportional sampling is always preferable but the use of a fixed interval or time proportional sampler for smaller flow rates of less than one litre per second may be acceptable. Spot sampling may additionally be used for audit or enforcement purposes. In addition to monitoring single substances, there are some wider testing methods to characterise effluents.

BOD is in general use for assessing overall organic contamination in water. An alternative is TOC (Total Organic Carbon), which may be a quicker and more reliable test than BOD and can be automated for continuous monitoring. There is often a reliable, though non-linear, relationship between BOD and TOC for a particular effluent. In some situations, COD (Chemical Oxygen Demand) may be an acceptable alternative.

The traditional determinand of suspended solids may also be replaced where appropriate by turbidity, which is more amenable to continuous monitoring.

Continuous Monitoring Parameters

Appendix II contains details of equipment suppliers providing CM instrumentation for the following parameters:

- Flow measurement.
- Temperature.
- TOC.
- Suspended Solids/Turbidity.
- pH.

In addition, details have also been obtained for liquid effluent sampling systems.

A comprehensive listing of equipment suppliers and general principles of measurement are included in the Effluent Processing Club's manual - Volume 3 "Wastewater Characterisation Instrumentation and Monitoring" August 1993. This provides an overview of methods available for determining the wide range of individual physical and chemical parameters necessary for wastewaters. On-line instrumentation is investigated as a means of monitoring discharges for compliance with consents, if a suitably sensitive procedure is available.

The Effluent Processing Club (EPC) was set up several years ago to provide its members with a comprehensive state-of-the-art technology manual covering all aspects of liquid effluents, treatment and monitoring.

EPC details can be obtained from:-

- Effluent Processing Club, AEA Technology, 404 Harwell Laboratory, Didcot, Oxfordshire, OX1 0RA

5.2 Releases to Land

A review of legislative requirements relating to releases to land from incineration processes was undertaken in Section 2.0 covering the UK, Germany, the Netherlands, USA and the European Union. In all cases there are no specific regulations on incineration for continuous monitoring of releases to land.

In the U.K., the Environment Agency requires that waste for disposal from IPC regulated processes is quantified by weighing each load. Also, analysis of each waste stream should be undertaken for prescribed substances. The frequency of such analysis will be site specific but should not be less frequent than annually.

As a result of there being no legislative requirements for continuous monitoring of releases to land from incineration processes no information has been gathered relating to CM instrumentation.

6.0 CONCLUSIONS

This report has examined the use of continuous monitors for incineration processes under the following headings:-

- Legal and Technical Framework.
- Process Parameter Monitoring.
- Monitoring of Emissions to Air.
- Monitoring of Releases to Water and Solid Residues.

The conclusions under each of these headings can be summarised as follows.

6.1 Legal and Technical Framework

The best developed legal and technical framework reviewed in this report for the use of continuous monitors at incineration processes exists in Germany. The framework includes a clear legal requirement with regard to the use of continuous monitors; the existence of a type approval system for CEMs; a clear methodology for on-site calibration and verification of the CEMs and the data they produce; and clear guidelines with regard to data handling and reporting formats.

The framework in other European countries, and the European Commission, has been and continues to be heavily influenced by the experience, to date, in Germany.

The laws and licensing practice for incinerators and the use of continuous monitors in the USA, have evolved along different lines and in a much more diverse format than is the norm in Europe. The requirement for continuous monitoring is not as "standardised" as in Europe and much of the framework is currently based on state rather than federal laws. The system for calibration and verification of CEMs is based on the methodologies widely used in the USA for CEMs at large combustion plant.

6.2 Process Parameter Monitoring

This section has concentrated on the continuous measurement of gas temperature in the incineration process, the technical/legal definition and measurement of residence time and the use of continuous monitors for other flue gas parameters, e.g. O_2, flow etc..

With a few exceptions (e.g. work by HMIP in the late 1980s) the subject of the accuracy and reliability of gas temperature measurements using thermocouples in large scale incinerators has been largely ignored by both the incineration industry and legislators.

Work both in the UK and more recently in Germany has highlighted the difficulties encountered using thermocouples. The alternative, acoustic pyrometers, are expensive. The use of these pyrometers might in certain circumstances be justified from the technical point of view by better control of the process and hence better economic performance.

The question of legal definitions of residence time in an SCC and the technically correct way of assessing this has been taken to address the new proposed German methodology, while not being an issue for serious consideration elsewhere. The methodologies are associated with high costs.

The continuous measurement of O_2 in incinerator flue gas is now state-of-the-art. Different systems exist including both extractive and in-situ approaches.

Systems are available for flue gas flow monitoring and several systems have been installed at operating incinerators. Flue gas water vapour monitoring is offered by a number of CEMs including as an option on two multi-component systems, OPSIS and the Perkin Elmer MCS.

A combined HCl/SO_2 monitor has been used in Germany for activated carbon depletion monitoring.

6.3 Monitoring of Emissions to Air

This section has concentrated on those CEMs which have been specially developed for the incineration market, i.e. HCl, multi-component, particulate matter and total organics.

The performance of the available CEMs has been reviewed. This review has, in general, relied upon data from German approvals testing, and tests carried out by the USEPA. These are the only objective sources of information on the performance of CEMs systems. The German type approval reports, which test performance against a minimum standard, are probably the only available database on which objective comments on the performance of a CEM can be based. Although, information is available from incineration plant operators on experience with individual systems, the lack of controlled and comparable conditions at each plant prevents the drawing of objective conclusions on the relative merits of individual systems.

On the basis of this report it is not possible to draw conclusions about the relative merits of different approaches, for example, cross duct versus extractive, NDIR GFC versus conductometric (for HCl). It is recognised that direct comparison trials will probably be the only way to obtain such information.

The technology exists and has been proven for monitoring TA LUFT 86 type standards. This technology has been applied to a wide range of European plants over the last nine to 10 years and, given sufficient maintenance and technical back-up from the supplier, proved reliable.

A new generation of CEM technology to monitor extremely low concentrations of pollutants has been developed in recent years in Germany to achieve compliance monitoring with the new 17BImSchV regulations.

The current state of the German CEM market to meet 17BImSchV has led to expensive systems, in excess of DM 500,000 (£200,000) per incinerator unit regardless of plant size. The development of these new systems has been accomplished in parallel to significant improvements in flue gas treatment technology which results in emissions which are barely above the detection limits of the CEMs when the scrubbing system is working. However, CEMs are required to alert to the significant emissions which could occur should the abatement technology malfunction.

6.4 Monitoring of Releases to Water and Solid Residues

There are no legislative requirements for continuous monitoring of releases to land from incineration plants. There are, some requirements for continuous monitoring of releases to water, for example, in the USA and UK.

GLOSSARY OF TERMS

BATNEEC	-	Best Available Techniques Not Entailing Excessive Cost.
BMU	-	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BOD	-	Biochemical Oxygen Demand.
BPEO	-	Best Practicable Environmental Option.
BSI	-	British Standards Institution.
CAA	-	Clear Air Act 1990 (USA).
CAAA	-	Clean Air Act 1990 Amendments (USA).
CEM	-	Continuous Emission Monitor (relating to releases to atmosphere).
CEN	-	European Body for Standardisation.
CFR	-	Code of Federal Regulations (USA).
CM	-	Continuous Monitoring (relating to releases to all environmental media).
COD	-	Chemical Oxygen Demand.
EPA 1990	-	Environmental Protection Act 1990.
EPC	-	Effluent Processing Club.
ESP	-	Electrostatic Precipitator.
EU	-	European Union.
FID	-	Flame Ionisation Detector.
FTIR	-	Fourier Transform Infra-Red.
GFC	-	Gas Filter Correlation.
HMIP	-	Her Majesty's Inspectorate of Pollution.
HWI	-	Hazardous Waste Incinerator.

GLOSSARY OF TERMS (Continued).....

IPR	-	Process Guidance Note (HMIP).
L/G Ratio	-	Ratio of liquid flowrate to gas flowrate (wet flue gas scrubbing system).
ISO	-	International Standards Organisation.
MWI	-	Municipal Waste Incinerator.
NDIR	-	Non Dispersive Infra-Red.
NDUV	-	Non Dispersive Ultra-Violet.
NESCAUM	-	North-East States for Co-ordinated Air Use Management (USA).
NPDES	-	National Pollution Discharge Elimination System (USA).
NRA	-	National Rivers Authority.
NSPS	-	New Source Performance Standard (USA).
PCDD	-	Polychlorinated Dibenzo-p-dioxin.
PCDF	-	Polychlorinated Dibenzofuran.
PID	-	Photo-ionisation Detector.
PLC	-	Programmable Logic Controller.
RATA	-	Relative Accuracy Test Audit.
RCRA	-	Resource Conservation and Recovery Act 1976 (USA).
Richlijn Verrbranden (RV89)	-	Dutch 1989 Incineration Guideline.
SCC	-	Secondary Combustion Chamber.
SCR	-	Selective Catalytic Reduction.
SNCR	-	Selective Non-Catalytic Reduction.
SRM	-	Standard Reference Method.

GLOSSARY OF TERMS (Continued).....

TA LUFT 86	-	1986 Technische Anleitung zur Reinhaltung der Luft (Technical Instructions on Air Quality Control)
TOC	-	Total Organic Carbon.
TSS	-	Total Suspended Solids.
TUV	-	Technishe Ueberwachungs Vereine - Independent Bodies Recognised by the Licensing Authority to Conduct Calibration and Verification Checks, Germany.
US EPA	-	United States of America Environmental Protection Agency.
VDI	-	German Standards Organisation.
WG	-	Working Group.
17BImSchV	-	17th Regulation of the Federal Air Quality Law (Germany) 1990.

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APPENDIX I

CONTINUOUS MONITORS FOR EMISSIONS TO AIR

APPENDIX I(A)

CONTINUOUS MONITORS FOR EMISSIONS TO AIR:

EQUIPMENT SUPPLIERS DETAILS

APPENDIX I (a)

CONTINUOUS MONITOR (CEM) SUPPLIERS

COMPANY	ADDRESS	TELEPHONE	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	NO. OF EMPLOYEES	TURNOVER
ABB KENT-TAYLOR LTD.	Oldens Lane, Stonehouse, Gloucestershire, GL10 3TA.	(01453) 826661	(01453) 821478	Manufacture of industrial instruments including gas analysers.	British	600 in UK	£15 million (total), £1 million (gas analysis).
ACAL AURIEMA LTD.	442 Bath Road, Slough, SL1 6BB.	(01628) 604353	(01628) 603730	UK agency for a range of industrial electronics and instrumentation including process and gas analysers. Agents for Ametek (USA) and Tess Comm (USA).	USA	60	£4 million (total UK), £0.75 million (gas analysis).
ALLISON ENGINEERING LTD.	Allison House, Capricorn Centre, Cranes Farm Road, Basildon, Essex SS14 3JA.	(01268) 526161	(01268) 533144	UK agency for a range of gas instrumentation. Agents for FCI INC (USA) and representation for RBR-Ecom (Germany) - portable emission monitors.	British USA	21	£4 million (UK total), £3 million gas flow instrumentation.
ANACON CORPORATION LTD.	Goodsons Industrial Mews, Wellington Street, Thame, Oxfordshire OX9 3BX.	(01844 260460)	(01844) 217220	Manufacture, supply and installation of industrial instrumentation.	British	10	£0.7 million (total).
ANALYTICAL DEVELOPMENT CO. LTD.	Pindar Road, Hoddesdon, Hertfordshire, EN11 OAQ.	(01992) 469638	(01992) 444567	Manufacture, supply and installation of industrial and gas analysis instrumentation.	British	70 - 75	£4 million (total).
ANATROL LTD.	Unit 1A, Hampton Heath Industrial Estate, Hampton Heath, Cheshire SY14 8BB.	(01948) 820271	(01948) 820282	Gas analysis system builder and agent for M&C GmbH (Germany). Also agents for Rosemount.	Germany, Holland, UK, Denmark and USA	12	£0.85 million.
BRAN & LUEBBE (GB) LTD.	Scaldwell Road, Brixworth, Northampton NN6 9UD.	(01604) 880751	(01604) 880145	Supply of monitoring and analysis equipment. UK agents for parent company.	Germany	Sales and Maintenance UK 50	£14 million.

APPENDIX I (a)

CONTINUOUS MONITOR (CEM) SUPPLIERS (Continued)

COMPANY	ADDRESS	TELEPHONE	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	NO. OF EMPLOYEES	TURNOVER
BRUEL & KJAER	Harrow Weald Lodge 92 Uxbridge Road Harrow HA3 6BZ	(0181) 9542366	(0181) 9549504	Design of analyser systems, sales and marketing	Denmark	80	£3 million
CODEL LTD.	Station Building, Station Road, Bakewell, Derbyshire DE4 1GE.	(01629) 814351	(01629) 814619	Manufacture and supply of continuous stack emission monitoring systems.	British	45	£5 million.
DRAEGER LTD.	Ullswater Close, Kitty Brewster Industrial Estate, Blyth, Northumberland, NE24 4RG.	(01670) 352891	(01670) 356266	Supply of gas alarm and analysis equipment. UK agents for parent company.	Germany	8,000 (worldwide)	£23 million (UK), £400 million (worldwide).
EMISSION TECHNOLOGY INSTRUMENTATION LTD (ETI LTD)	Units 9 CDE Alstone Lane Industrial Estate Alstone Lane Cheltenham Gloucestershire GL51 8HF	(01242) 233330	(01242) 242353	Supply of environmental monitoring and control instrumentation	UK, France	16	£2 million
ENOTEC UK LTD.	The Redhouse, 84 High Street, Buntingford, Hertfordshire SG9 OAJ.	(01763) 272069	(01763) 273594	Sale and installation of flue gas analysers. Agents for DURAG GmBH (Germany) and ENOTEC GmbH (Germany). System builders.	Germany	4	£0.25 million.

APPENDIX 1 (a)

CONTINUOUS MONITOR SUPPLIERS (Continued)

COMPANY	ADDRESS	TELEPHONE	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	NO. OF EMPLOYEES	TURNOVER
ENVIRO TECHNOLOGY SERVICES Plc	Environment House, Dunbridge Road, Stroud, Gloucestershire GL5 3EE.	(01453) 751641	(01453) 757596	Supplier of a wide range of continuous monitoring systems. Agents for OPSIS (Sweden), API (USA) and Instrumatic (Denmark).	Sweden, USA and Denmark	28	£3 million.
ENVIRONMENT TECHNOLOGY RESEARCH LTD.	Stowe Castle Business Park, Buckingham, Buckinghamshire, MK18 5AB.	(01280) 822155	(01280) 822299	Design, manufacture and supply of continuous dust measurement systems for industrial processes.	British	17	-
ERWIN SICK LTD	Waldkirch House 39 Hedley Road St Albans Hertfordshire AL1 5BN	(01727) 831121	(01727) 856 767	Supply, installation and maintenance of flue gas monitoring systems. UK agents for parent company .	Germany	120 (Germany)	£8 million (UK)
FIELD ELECTRONICS	Gill house Conway Street Hove, East Sussex BN3 3LW	(01273) 729361	(01273) 726595	Manufacture, supply and installation of industrial electronics and instrumentation.	British	15	£1 million

APPENDIX I (a)

CONTINUOUS MONITOR (CEM) SUPPLIERS (Continued)

COMPANY	ADDRESS	TELEPHONE	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	NO. OF EMPLOYEES	TURNOVER
FLUID DATA LTD.	Unit B4 Chaucer Business Park, Watery Lane Kemsing, Sevenoaks, Kent TN15 6QY	(01732) 763968	(01732) 763969	Manufacture, supply and installation of a range of industrial instrumentation. Agents for ENOTEC (Germany), Temac (Denmark), and Oldham (France).	Germany and Denmark France	130 (worldwide)	$26 million (parent company), $20 (gas analysis).
GRASEBY ANDERSON LTD.	River House, 97 Cray Avenue, St Mary Cray, Orpington, Kent OR5 4AA.	(01689) 877767	(01689) 876661	Supply of environmental systems. UK agents for Graseby STI (USA).	USA	115 (Graseby STI)	£10 million (Graseby STI).
HARTMANN AND BRAUN (UK) LTD.	Moulton Park, Northampton, NN3 1TF.	(01604) 646311	(01604) 491027	Supply and installation of industrial instrumentation. UK agents for parent company.	Germany and UK	55 (UK)	£100m worldwide £5.5m UK
HOBRE INSTRUMENTS (UK)	Unit 2, Prince Rupert House, Cavaliers Court, Bumpers Way, Chippenham, Wiltshire SN14 6NQ.	(01249) 444133	(01249) 444107	UK agents for a range of industrial instrumentation. Agents for Analect (USA).	USA	9 (UK) 26 (Hobre Holland)	£1.8 million
HOENZTSCH GMBH	Postfach 1324, D-Waiblingen 4, Germany.	00 49 7151 17160	00 49 7151 58402	Manufacture, supply and installation of gas flow instrumentation.	Germany	-	-
HORIBA INSTRUMENTS LTD.	Kyoto Close, Summerhouse Road, Moulton Park, Northampton NN3 6FL.	(01604) 671166	(01604) 671080	Supply and installation of gas analysis instrumentation and systems.	UK and Japan	35	£9 million

APPENDIX 1 (a)

CONTINUOUS MONITOR (CEM) SUPPLIERS (Continued)

COMPANY	ADDRESS	TELEPHONE	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	NO. OF EMPLOYEES	TURNOVER
KDG MOBREY LTD.	190/196 Bath Road, Slough, Berkshire SL1 4DN.	(01753) 534646	(01753) 823589	Manufacture and supplier of industrial instrumentation. Agents for Dietrich Standard (USA).	USA	500 (KDG), 100 (Dietrich Standard)	-
LAND COMBUSTION	Stubley Lane, Dronfield, Sheffield S18 6DJ.	(01246) 417691	(01246) 290274	Manufacture, supply and installation of combustion gas analysers. Agents for Perkin Elmer (Bodenseewerk Germany). Division of Land Instruments International Ltd.	UK and Germany	50 (UK) 30 (USA)	£5 million (Land Combustion), £18 million (Land Group).
McQUEEN CAIRNS INTERNATIONAL	PO Box 2047, 8 Clarence Terrace, Regents Park, London NW1 4RD.	(0171) 723 2266	(0171) 402 5739	Sales and Marketing of specialist electronics and instrumentation.	Germany	250 (Ultrakust) 6 (UK)	DM 30 million
MONITOR LABS LTD	2 Airfield Way Christchurch Dorset BH23 3TE	(01202) 485420	(01202) 476503	Market various Monitor Labs & United Sciences Inc. particulate monitors, gas analysers and flow measurement systems.	USA, UK	5 in UK	£500million Bowthorpe plc
ORBITAL GAS SYSTEMS LTD.	Maer Lane Industrial Estate, Market Drayton, Shropshire TF9 1QS.	(01630) 658123	(01630) 655735	Systems builders. Supply and installation of flue gas analysis equipment. Exclusive agents for Siemens (AG) gas analysers. Also offer ECO Physics and Bovar analysers.	Germany	25	£3 million.
PANAMETRICS LTD.	Unit Two, Villiers Court, 40 Upper Mulgrave Road, Cheam, Surrey SM2 7AS.	(0181) 643 5150	(0181) 643 4225	Supply and installation of process instrumentation. Parent company: Panametrics INC (USA).	USA and Ireland	10 (UK) 60 (Ireland) 500 (USA)	-
POLLUTION CONTROL AND MEASUREMENT (EUROPE) LTD. (PCME)	Stonehill, Stukely Meadows Industrial Estate, Huntingdon, Cambridgeshire PE18 6EL.	(01480) 455611	(01480) 413500	Manufacture, supply and installation of emission monitors.	UK	30	£2.2 million.

APPENDIX I (a)

CONTINUOUS MONITOR (CEMs) SUPPLIERS (Continued)

COMPANY	ADDRESS	TELEPHONE	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	NO. OF EMPLOYEES	TURNOVER
PROCAL ANALYTICS LTD.	5 Maxwell Road, Woodston, Peterborough PE2 OHU.	(01733) 232495	(01733) 235255	Manufacture, design, supply and installation of gas liquid analysers.	UK	15	£2 million (total), £1.6 million (gas analysers).
QUANTITECH LTD.	Unit 3, Old Wolverton Road, Old Wolverton, Milton Keynes MK12 5NP.	(01908) 227722	(01908) 227733	Agents for a range of instrumentation companies. UK agents for AAA Italy, Bernath Atomic - Germany, ETG - USA.	Italy	15	£2 million.
ROSOW TECHNICAL LTD.	1 Pembroke Avenue, Waterbeach, Cambridge CB5 9QR.	(01223) 860595	(01223) 861819	Supply of industrial measurement systems. Agents for Sigrist (Switzerland) and MIP (Finnish).	Switzerland Finland	4 (UK) 50 - 70 (Switzerland) 8 - 9 (Finland)	£0.5 million.
ROTORK ANALYSIS LTD.	Regal Way, Faringdon, Oxon SN7 7BX.	(01367) 242660	(01367) 242700	Manufacture, supply and installation of industrial gas analysis systems.	British	50	£4.5 million.
SAMAC LTD.	PO Box 43, Hove, East Sussex BN3 6UU.	(01273) 563109	(01273) 566270	UK agents for KURZ Instruments Inc.	USA	7	£0.35 million.
SERVOMEX PLC	Jarvis Brook, Crowborough, Sussex TN6 3DU.	(01892) 652181	(01892) 662253	Manufacture, supply and installation of industrial gas analysis systems.	UK	350 (worldwide)	£20 million.
SEVERN SCIENCE (INSTRUMENTS) LTD.	Unit 4, Short Way, Thornbury Industrial Estate, Thornbury, Bristol BS12 2UT.	(01454) 414723	(01454) 417101	Primarily a manufacturing company. Sales and marketing of instruments handled by Severn Science Ltd (SSL).	British	25	SSL £2.3 million.

APPENDIX I (a)

CONTINUOUS MONITOR (CEM) SUPPLIERS (Continued)

COMPANY	ADDRESS	TELEPHONE	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	NO. OF EMPLOYEES	TURNOVER
SIEMENS ENVIRONMENTAL SYSTEMS LTD.	Sopers Lane, Poole, Dorset BH17 7ER.	(01202) 782000	(01202) 782335	Manufacture and supply of emission monitoring systems.	USA and UK	70	£7 million.
SIGNAL INSTRUMENTS CO. LTD.	Standards House, 1 Doman Road, Camberley, Surrey GU15 3DW.	(01276) 682841	(01276) 691302	Manufacture, supply and installation of industrial gas analysis systems.	UK	50	£2.5 million.
SYSCO ANALYTICS LTD.	Broadway, Market Lavington, Devizes, Wiltshire SN10 5RQ.	(01380) 818411	(01380) 812733	Analysis systems builder for the process industry. Agents for Bovar GmbH (Canada).	Canada, Germany	30	£2 million
TELEDYNE BROWN ENGINEERING ANALYTICAL INSTRUMENTS LTD.	The Harlequin Centre, Southall Lane, Southall, Middlesex UB2 5NH.	(0181) 571 9596	(0181) 571 9439	Supply of process and gas analysers.	USA	5 (UK)	-
THERMO ELECTRON LTD.	910 Birchwood Boulevard, Birchwood, Warrington, Cheshire WA3 7QN.	(01925) 813600	(01925) 812138	Supplier of monitoring instrumentation. UK subsidiary of US parent company.	USA	30 (UK)	£4 million
VEREWA GMBH	Postfach 102238, D-43330 Muelheim a.d., Ruhr 1, Germany.	00 49 8161 12480 (Int. sales)	00 49 8161 7262 (Int. sales)	Manufacture and supply of flue gas monitoring systems.	Germany	14	DM3.2 million.
WOESTHOFF GMBH	D-4630 Bochum 1, Max-Greve-StaBe 30, Germany	00 49 234 51814	00 49 234 583393	Manufacture and supply of gas analysers and gas pumps	Germany	-	-

APPENDIX I(B)

CONTINUOUS MONITORS FOR EMISSIONS TO AIR:

CONTINUOUS MONITOR PRINCIPLES OF MEASUREMENT

APPENDIX I (b)

CONTINUOUS MONITOR (CEM) PRINCIPLES OF MEASUREMENT

Company	SO2	NOX	Particulate	HCl	HF	C02	CO	Velocity	O2	Water Vapour	Organic Carbon
ABB KENT-TAYLOR LTD	-	-	-	-	-	-	-		In-situ ZrO2	-	-
ACAL AURIEMA LTD	-	-	-	Extractive Potentiometric	Extractive Potentiometric	-	-	-	Extractive ZrO2	-	-
ALLISON ENGINEERING LTD	-	-	-	-	-	-	-	Thermal Dispersion	-	-	-
ANACON CORPORATION LTD	-	-	Average Light Intensity	-	-	-	-	-	-	-	-
ANALYTICAL DEVELOPMENT CO LTD	Extractive NDIR	Extractive NDIR	-	Extractive NDIR	-	Extractive NDIR	Extractive NDIR	-	Extractive Paramagnetic Thermo-magnetic	-	-
ANATROL LTD	UV/IR	IR/UV/ Chemilum.	Optical	Specific ion	Specific ion	IR	IR/Electro-chemical	-	Paramagnetic/electrochem./ ZrO_2	IR	FID
BRAN & LUEBBE (GB) LTD	-	-	-	Potentiometric Analysis	-	-	-	-	-	-	-
BRUEL & KJAER	Photo Acoustic Spectroscopy	Photo Acoustic Spectroscopy	-	Photo Acoustic Spectroscopy	Photo Acoustic Spectroscopy	Photo Acoustic Spectroscopy	Photo Acoustic Spectroscopy	-	Magneto acoustic	Photo Acoustic Spectroscopy	Photo Acoustic Spectroscopy
CODEL LTD	Cross Duct NDIR	Cross Duct NDIR	Cross Duct Transmiss-ometer	Cross Duct NDIR	-	Cross Duct NDIR	Cross Duct NDIR	Time of Flight IR	-	Cross Duct NDIR	Cross Duct NDIR

APPENDIX I (b)

CONTINUOUS MONITOR (CEM) PRINCIPLES OF MEASUREMENT (Continued)

Company	SO_2	NOX	Particulate	HCl	HF	CO_2	CO	Velocity	O_2	Water Vapour	Organic Carbon
DRAEGER LTD	Multi-component Electro-chemical Cell	Multi-component Electro-chemical Cell	-	-	-	-	Multi-component Electro-chemical Cell	-	Multi-component Electro-chemical Cell	-	-
ETI LTD	1) Multicomp - gas filter correlation IR (GFC IR) 2) UV fluorescence	1) Multicomp - gas filter correlation IR (GFC IR) 2) chemilum.	BETA 5M	Multicomp - gas filter correlation IR (GFC IR)	Wet system with ion specific monitor	Multicomp - gas filter correlation IR (GFC IR)	Multicomp - gas filter correlation IR (GFC IR)	Automated pitot with backflush	Multicomp - gas filter correlation IR (GFC IR) - with O_2 by ZrO_2/paramag	Multicomp - gas filter correlation IR (GFC IR)	1)Multicomp - gas filter correlation IR (GFC IR) 2)FID/PID
ENOTEC UK LTD	-	-	1) Cross Duct Transmiss-ometer 2) In-situ Light Scatter	-	-	-	-	-	In-situ ZrO_2	-	-
ENVIRO TECHNOLOGY SERVICES PLC	1) Cross Duct Multi-component OPSIS (DOAS) 2) Extractive UV fluorescence (dil)	1) Cross Duct Multi-component OPSIS (DOAS) 2) Extractive chemilum. (dil)	-	Cross Duct Multi-component OPSIS (UV-IR DOAS)	Cross Duct Multi-component OPSIS (UV-IR DOAS)	Cross Duct Multi-component OPSIS (UV-IR DOAS)	1) Cross Duct Multi-component OPSIS (IR DOAS) 2) Extractive IR GFC (dil)	-	Zirconia	Cross Duct Multi-component OPSIS (UV-IR DOAS)	Cross Duct Multi-component OPSIS (UV-DOAS) (individual voc's)
ENVIRONMENT TECHNOLOGY RESEARCH LTD	-	-	Particle impingement probe Optical modulation (opacity)	-	-	-	-	-	-	-	-

APPENDIX I(b)

CONTINUOUS MONITOR PRINCIPLES OF MEASUREMENT (Continued)

Company	SO2	NOX	Particulate	HCl	HF	C02	CO	Velocity	O2	Water Vapour	Organic Carbon
ERWIN SICK LTD	Multi-component Cross Duct Photometry	Multi-component Cross Duct Photometry	1) Cross Duct Transmiss-ometer 2) In-situ Light Scatter 3) By-pass system for moisture laden gases	-	-	-	Cross Duct NDIR	Time of Flight Ultrasonic	In-situ Zr02	-	-
FIELD ELECTRONICS LTD	-	-	In-situ Transmiss-ometer	-	-	-	-	-	-	-	-
FLUID DATA LTD	Extractive NDIR Electrolytic Cell	Extractive NDIR Electrolytic Cell	-	1) Multi-component IR gas using filter correlation 2) Electrolytic Cell	Multi-component IR gas using filter correlation	Extractive NDIR Multi-component Electrolytic Cell	Extractive NDIR Multi-component Electrolytic Cell	-	In-situ ZrO2 Extractive Paramagnetic Thermo-magnetic	-	FID

APPENDIX I (b)

CONTINUOUS MONITOR (CEM) PRINCIPLES OF MEASUREMENT (Continued)

Company	SO2	NOX	Particulate	HCl	HF	C02	CO	Velocity	O2	Water Vapour	Organic Carbon
GRASEBY ANDERSON LTD	Extractive UV Fluorescence (dil)	Extractive Chemilumin. (dil)	-	-	-	-	Extractive NDIR (dil and non-dil)	-	-	-	FID
HARTMANN & BRAUN (UK) LTD	1) Extractive NDIR 2) Multi-component NDIR 3) NDUV	1) Extractive NDUV 2) Multi-component NDIR 3) Multi-component FTIR	-	Multi-component FTIR	Multi-component FTIR	1) Extractive NDIR 2) Multi-component NDIR 3) Multi-component FTIR	1) Extractive NDIR 2) Multi-component NDIR 3) Multi-component FTIR	-	Extractive Paramagnetic Thermo-magnetic	Multi-component FTIR	Multi-component FTIR
HOBRE INSTRUMENTS (UK) LTD	Multi-component FTIR	Multi-component FTIR	-	Multi-component FTIR	Multi-component FTIR	Multi-component FTIR	Multi-component FTIR	-	-	-	-
HOENNTSCH GMBH	-	-	-	-	-	-	-	Vortex Shedding Flow Meter	-	-	-
HORIBA INSTRUMENTS LTD	1) Extractive NDIR 2) Extractive NDUV	1) Extractive NDIR 2) Extractive Chemilumin.	-	-	-	Extractive NDIR	Extractive NDIR	-	Magneto-pneumatic	-	FID
KDG MOBREY LTD	-	-	-	-	-		-	Averaging Pitot: Annubar.	-	-	

APPENDIX I (b)

CONTINUOUS MONITOR (CEM) PRINCIPLES OF MEASUREMENT (Continued)

Company	SO2	NOX	Particulate	HCl	HF	C02	CO	Velocity	O2	Water Vapour	Organic Carbon
LAND COMBUSTION	1) Multi-component Extractive NDIR 2) Extractive photodiode array	1) In-situ Electro-chemical Cell 2) Multi-component Extractive NDIR 3) Extractive photodiode array 4) Extractive electro-chemical cell	Cross Duct Transmiss-ometer	1) Extractive NDIR 2) Multi-component Extractive NDIR	-	Multi-component Extractive NDIR	1) Cross Duct IR 2) Multi-component Extractive NDIR 3) Extractive Electro-chemical Cell	-	1) Extractive Electro-chemical Cell 2) In-situ zirconia cell	Multi-component Extractive NDIR	-
McQUEEN CAIRNS INTERNAT-IONAL	-	-	-	-	-	-	-	-	-	Bounce Jet Psychrometry	-
ORBITAL GAS SYSTEMS LTD	Extractive NDIR	Extractive NDIR Chemilumin.	Cross Duct Transmiss-ometer	-	-	1) Extractive NDIR 2) Multi-component NDIR	1) Extractive NDIR 2) Multi-component NDIR	-	Extractive Paramagnetic Thermo-magnetic	Extractive NDIR	FID
PANAMETRICS LTD	-	-	-	-	-	Thermal conductivity	-	Time of Flight Ultrasonic	1) Extractive ZrO2 2) Thermal conductivity	-	-
POLLUTION CONTROL AND MEASURE-MENT (EUROPE) LTD (PCME)	-	-	1) In-situ Particle Impingement 2) Optical Scintillation	-	-	-	-	-	In-situ ZrO2	-	-

APPENDIX I (b)

CONTINUOUS MONITOR (CEM) PRINCIPLES OF MEASUREMENT (Continued)

Company	SO2	NOX	Particulate	HCl	HF	CO2	CO	Velocity	O2	Water Vapour	Organic Carbon
PROCOL ANALYTICS LTD	Multi-component in-situ NDIR	Multi-component in-situ NDIR	-	Multi-component in-situ NDIR	Multi-component in-situ NDIR	Multi-component in-situ NDIR	Multi-component in-situ NDIR	-	-	Multi-component in-situ NDIR	Multi-component in-situ NDIR
QUANTITECH LTD	1) Multi-component Cross Duct NDIR. 2) Multi-component Cross Duct Ultraviolet	1) Multi-component Cross Duct NDIR 2) Multi-component Cross Duct Ultraviolet	Multi-component Cross Duct NDIR	1) Multi-component Cross Duct NDIR 2) Ion mobility spectroscopy	1) Ion mobility spectroscopy 2) Multi-component Cross Duct NDIR	Multi-component Cross Duct NDIR	Multi-component Cross Duct NDIR	-	In-situ ZrO2	Multi-component Cross Duct NDIR	FID
ROSEMOUNT LTD	Extractive NDUV	1) Extractive NDIR/NDUV 2) Extractive Chemilumin.	-	-	-	Multi-component Extractive NDIR	Extractive NDIR	-	1) In-situ ZrO2 2) Extractive Paramagnetic Thermo-magnetic	-	-
ROSOW TECHNICAL LTD	-	-	Extractive Light Scatter	-	-	-	-	-	-	-	-
ROTORK ANALYSIS LTD	Extractive NDIR	Extractive Chemilumin.	-	-	-	Extractive NDIR	Extractive NDIR	-	Extractive ZrO2	Extractive dual ZrO_2 (wet and dry)	FID
SAMAC LTD	-	-	-	-	-	-	-	Thermal Dispersion	-	-	
SERVOMEX PLC	Extractive NDIR	1) Extractive Chemilumin. 2) Extractive NDIR (GFC)	-	Extractive GFC	-	Extractive NDIR	Extractive GFC NDIR	-	1) In-situ ZrO2 2) Extractive Paramagnetic Thermo-magnetic	NDIR	-

APPENDIX I (b)

CONTINUOUS MONITOR (CEM) PRINCIPLES OF MEASUREMENT (Continued)

Company	SO_2	NOX	Particulate	HCl	HF	CO_2	CO	Velocity	O_2	Water Vapour	Organic Carbon
SEVERN SCIENCE (INSTRU-MENTS) LTD	-	-	-	Extractive Electro-chemical	Extractive Electro-chemical	-	-	-	-	-	-
SIEMENS PLESSEY CONTROL LTD	1) Multi-component in-situ 2) Extractive UV Fluorescence (dil)	1) Multi-component in-situ NDUV 2) Chemilumin. (dil)	Transmiss-ometer	-	-	NDIR (dil)	NDIR (dil)	-	In-situ ZrO_2	In-situ NDIR	FID
SIGNAL INSTRUMENTS CO LTD	1) Extractive NDIR 2) Extractive NDUV	Extractive Chemilumin	-	-	-	Extractive NDIR	Extractive NDIR	-	Extractive Paramagnetic Thermo-magnetic	-	FID
SYSCO ANALYTICS LTD	Extractive NDUV	Multi-component Extractive NDUV	-	-	-	-	-	-	-	-	-
TELEDYNE ANALYTICAL INSTRUMENTS LTD	Extractive NDUV	Extractive Chemilumin	-	-	-	Extractive NDIR	Extractive NDIR	-		-	FID

APPENDIX I (b)

CONTINUOUS MONITOR (CEM) PRINCIPLES OF MEASUREMENT (Continued)

Company	SO2	NOX	Particulate	HCl	HF	C02	CO	Velocity	O2	Water Vapour	Organic Carbon
THERMO ELECTRON LTD	Extractive UV pulsed Fluorescence (dil)	Extractive Chemilumin (dil)	Cross Duct Transmiss-ometer	Extractive Gas Filter Correlation IR	-	Extractive GFC IR	Extractive GFC IR	Ultrasonic	-	-	FID and PID
VEREWA GMBH	-	-	Extractive Beta Absorption	-	-	-	-	-	-	-	-
WOESTHOFF GMBH	Extractive Conducto-metric	-	-	Extractive Conducto-metric	-	-	-	-	-	-	-

APPENDIX I(C)

CONTINUOUS MONITORS FOR EMISSIONS TO AIR:

CONTINUOUS MONITOR COSTS. REFERENCE PLANT AND APPROVAL DETAILS FOR:

SULPHUR DIOXIDE
NITROGEN OXIDES
PARTICULATE MATTER
CARBON MONOXIDE
CARBON DIOXIDE
HYDROGEN CHLORIDE
HYDROGEN FLUORIDE
OXYGEN
WATER VAPOUR
FLUE GAS FLOW
MULTI-COMPONENT
TOTAL ORGANIC CARBON

APPENDIX I (c)

SULPHUR DIOXIDE

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES: 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ANALYTICAL DEVELOPMENT CO LTD	Model 7000 Series RF Extractive NDIR	£13,000 including sampling system with permeation dryer	1) 0 - 200ppm 2) 0 - 100%	No information	Customer references available
ANATROL LTD	BINOS 1, 4, 1000, 1004 (Rosemount)	£8,000 - £12,000	1) 0 - 200 ppm 2) 0 - 100%	No information	Worldwide
BRUEL & KJAER	Model 3425	£12,500	0.3ppm, 30000ppm	International Instruments Users Group	Extensive references available
CODEL LTD	Model 1021, 2021 and 3020 Series Cross Duct NDIR	1021 : £10,000 2021 : £5,400 3020 : £12,000 ex works	1) 0 - 50ppm, 0 - 50 mg/Nm^3 2) 0 - 9999ppm, 0 - 9999mg/Nm^3 Fully selectable	Model 1021 tested by Nuclear Electric in 1991 and certified as complying with CEGB Standard 500115 for LCP applications	Over 90 customer references on LCPs and industrial applications
ENVIRO TECHNOLOGY SERVICES	Model 152 (API) Dilution Extractive UV Fluorescence	No information	1) 0 - 0.5ppm (analyser) 2) 0 - 10ppm (analyser) Fully selectable	No information	No information
ERWIN SICK LTD	Model GM30 series (simultaneous in-situ measurement of SO_2, NO, dust, opacity)	£26,000 - £41,000	1) 0 - 30mg/m^3 2) 0 - 300mg/m^3 3) 0 - 2,000mg/m^3 4) 0 - 20,000mg/m^3	TUV approved for incineration plant in 1993	No information
ETI LTD	Model AF21M (UV fluorescence) (dil)	Dil £10,000	Dil 1) 0 - 0.1ppm, 3) 0 - 10ppm	No information	No information
GRASEBY ANDERSON LTD	Model AR 200 series (STI) Dilution extractive UV Fluorescence	No information on ind. analysers. Costs for complete system for CO, NOx, SO2 and O2 with dil. sampling system given at £55,000	1) 0 - 12.5ppm 2) 0 - 1,000ppm	Complies with US EPA requirements	North American references available for LCP applications

APPENDIX I (c)

SULPHUR DIOXIDE (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
HARTMANN & BRAUN (UK) LTD	Model URAS 3 G&E Extractive NDIR	£4,500 - £8,000	1) 0 - 100ppm 2) 0 - 100% 3) 0 - 286mg/m^3	TUV approved for LCP applications in 1986	Extensive German and worldwide references available at LCP applications
HORIBA INSTRUMENTS LTD	Model ENDA-U113OL/U123OL Extractive NDUV Usually supplied as part of system with O2 measurement (paramagnetic)	No information	1) 0 - 10ppm 2) 0 - 2,000ppm	No information	No information
HORIBA INSTRUMENTS LTD	Model ENDA 1130/913 Extractive NDIR Usually supplied as part of monitoring system 900/1000 series	No information	1) 0 - 50ppm 2) 0 - 5,000ppm	No information	No information
LAND COMBUSTION	Model PDA 350 (extractive photodiode array)	£40,000	0 - 500ppm	No information	No information
ORBITAL GAS LTD	Model Ultramat 5 (SIEMENS AG) Extractive NDIR & Ultramat 21 range	£5,500 analyser Ultramat 21 £3,000 - £4,000	1) 0 - 50ppm 2) 0 - 100% 3) 0 - 100mg/m^3 Ultramat 21 low ppm - 100%	TUV approved systems	Extensive German and worldwide references available at LCP applications
ROSEMOUNT LTD	Model Binos 4/1004 Extractive NDUV	No information	1) 0 - 100ppm 2) 3) 0 - 3,000mg/m^3	A version of this monitor, the SO2-UV-Binos received TUV approval in 1985 for LCP applications	No information
ROTORK ANALYSIS LTD	Model Emirak Modular Analyser Extractive NDIR dual beam	No information	1) 0 - 100ppm 2) 0 - 500ppm	No information	Reference list provided

APPENDIX I (c)

SULPHUR DIOXIDE (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
SERVOMEX PLC	Model 1490 Extractive NDIR	£5,500 for analyser £3,00 to 15,000 for sampling system	1) 0 - 200ppm	Has successfully undergone US EPA certification testing at LCP applications	Extensive references available
SERVOMEX PLC	Model 2500 Series Extractive NDIR Alternative Model 1490	No information	1) 0 - 100ppm (for 2500) 1) 0 - 200ppm (for 1490)	The model 2500 is the replacement for the model 402PSA which was approved by the CEGB for LCP applications including FGD	Drax FGD
SIEMENS PLESSY CONTROLS LTD	Model ML 9850 Dilution Extractive UV Fluorescence	No information	Autoranging: 0 - 20ppm (analyser) System range will depend on analyser range and dilution ratio	Should meet US EPA requirements	No information
SIGNAL INSTRUMENTS LTD	Model 1100M Extractive NDUV	£8,900 analyser	1) 0 - 500ppm 2) 0 - 5,000 ppm	No information	Limited LCP references available
SIGNAL INSTRUMENTS LTD	Model 2000 Series Extractive NDIR	£5,200 - £6,100 analyser	1) 0 - 100ppm 2) 0 - 1,000ppm	No information	Limited LCP references available
SYSCO ANALYTICS LTD	Models 721, 910, 920, 922 (Bovar Western Research) Extractive NDUV	£12,000 Model 721 £50,000 Model 910 inc. sampling system and flow measurement provision £45,000 Model 920 inc. sampling system £15,000 Model 922	Wide range available	US EPA	References available. Thousands installed.
TELEDYNE BROWN ENGINEERING	Model 691 Extractive NDUV	£12,000 - £15,000	1) 0 - 150ppm 2) 0 - 100%	conforms to USA EPA requirements CFR 40 Part 60	Installations worldwide

APPENDIX I (c)

SULPHUR DIOXIDE (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
THERMO ELECTRON LTD	Model 43B, 40B Dilution Extractive UV Fluorescence Supplied as part of Model 200 system	£11,000 analyser exclusive of dilution sampling system	43B 1) 0 - 0.1ppm 2) 0 - 100ppm 40B 1) 0 - 10ppm 2) 0 - 5000ppm	Meets requirements of US EPA	Extensive references with US utility companies for system 200 dilution monitoring system
WOESHOFF GMBH	Model MIKROGAS-SO2 TE Extractive Conductometric	DM31,000 analyser DM25,000 sampling system	1) 0 - 50mg/m^3 2) 0 - 100g/m^3 3) 0 - 400mg/m^3	TUV approved for LCP applications in 1988	Approximately 45 references at LCP applications

APPENDIX 1 (c)

NITROGEN OXIDES

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ANALYTICAL DEVELOPMENT CO LTD	Model 7000 Series RF Extractive NDIR	£13,000 including sampling system	1) 0 - 200ppm	No information	Customer reference list available
ANATROL LTD	Rosemount 951 A (chemilum.) Rosemount Binos 1004 (IR/UV)	£11,500 - £14,000	1) 0 - 1ppm 2) 0 - 100%	No information	Worldwide
CODEL LTD	Models 1030, 2030, 3030 Cross Duct NDIR	1030 : £10,000 2030 : £5,400 3030 : £12,000 ex works	1) 0 - 50ppm 2) 0 - 9,999ppm Fully selectable	1030 approved for use at LCPs by the CEGB in 1987. Approval No. 5142A3075	Approximately 100 customer references for LCP and industrial applications.
ENVIRO TECHNOLOGY SERVICES	Model 252 (API) Dilution Extractive Chemiluminescence	No information	1) 0 - 0.5ppm (analyser) 2) 0 - 10ppm (analyser) Other ranges available	No information	No information
ERWIN SICK LTD	Model GM 30 series (simultaneous in-situ measurement of SO_2, NO, dust, opacity)	£2,600 - £41,000	1) 0 - 30mg/m³ 2) 0 - 300mg/m³ 3) 0 - 500mg/m³ 4) 0 - 5,000mg/m³	TUV approved for incineration plant in 1993	No information
ETI LTD	Model AC31M (dil)	Dil £10,000	Dil 1) 0-0.1ppm, 2) 0 - 10ppm	No information	No information
GRASEBY ANDERSON LTD	Model AR 300 Series (STI) Dilution Extractive Chemiluminescence	No information on analysers. Costs for a complete system including dil. sampling system for CO, NOx, SO2 and O2 given as £55,000	1) 0 - 25ppm 2) 0 - 1,000ppm	Complies with US EPA requirements	North American references available at LCP applications
HARTMANN & BRAUN (UK) LTD	Model Radas 2 Extractive NDUV	£8,000 - £11,000	1) 0 - 75ppm 2) 0 - 100% 3) 0 - 125mg/m³	TUV approved for LCP applications in 1986, TUV approved for 17 BIMSchV	Extensive German and worldwide references available and LCP applications

APPENDIX I (c)

NITROGEN OXIDES (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
HORIBA INSTRUMENTS LTD	Model ENDA 912/1120 Extractive NDIR Usually supplied as part of monitoring system 900/1000 series	No information	1) 0 - 25ppm 2) 0 - 500ppm	No information	No information
HORIBA INSTRUMENTS LTD	Model ENDA-C1120/C1220 Extractive Chemiluminescence Usually supplied as a system with O2 measurement	No information	1) 0 - 20ppm 2) 0 - 2,000ppm	No information	No information
LAND COMBUSTION	Model PRONOX 3000 In-situ Electrochemical Cell	£25,000	1) 0 - 100ppm 2) 0 - 3,000ppm	Complies with US EPA requirements and has received certification	Over 40 references supplied in North America and Europe, including LCP applications
ORBITAL GAS LTD	Model Ultramat 5 and Ultramat 21 range (SIEMENS AG) Extractive NDIR and range of analysers from ECO Physics (Switzerland) Chemiluminescence	£5,500 for analyser (Ultramat 5) £3,000 - £4,000 (Ultramat 21 range) ECO Physics analysers £7,555 - £18,500	Ultramat 5 1) 0 - 100ppm 2) 0 - 100% 3) 0 - 250mg/m³ (smallest) Ultramat 21 range - low ppm - 100%	TUV approved systems	Extensive European and worldwide references available at LCP applications
ROSEMOUNT LTD	Model 951A Extractive Chemiluminescence	No information	1) 0 - 10ppm 2) 0 - 10,000ppm 3) 0 - 300mg/m³ (smallest)	TUV approved for LCP applications in 1977	No information
ROSEMOUNT LTD	Model Binos 1004 Extractive NDIR (NO)	No information	1) 0 - 300ppm 2) 3) 0 - 400mg/m³ (smallest)	TUV approved for LCP applications in 1987	No information
ROTORK ANALYSIS LTD	Model Emirak Modular Analyser Extractive Chemiluminescence	No information	1) 0 - 100ppm 2) 0 - 1,000ppm	No information	Reference list provided

APPENDIX I (c)

NITROGEN OXIDES (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
SERVOMEX PLC	Model 1491 Extractive Chemiluminescence	£8,500 for analyser with converter Sampling systems range from £3,000 to £10,000	1) 0 - 5ppm 2) 0 - 2,500ppm	Has successfully undergone US EPA certification testing at LCP applications	Limited number of North American references available
SIEMENS PLESSY CONTROLS LTD	Model ML 9841 Dilution Extractive Chemiluminescence	No information	Auto ranging: 0 - 20ppm (analyser) System range depends on analyser range and dilution ratio	Conforms to the requirements of the US EPA	No information
SIGNAL INSTRUMENTS LTD	Model 4000 Extractive Chemiluminescence	£11,000 - £14,000	1) 0 - 4ppm 2) 0 - 10,000ppm	No information	UK references for gas turbine, mobile labs and combustion research facilities
SYSCO ANALYTICS LTD	Models 910, 920, 922 (Bovar Western Research) multicomponent measurement with SO_2	£50,000 Model 910 inc. sampling system and flow measurement provision £45,000 Model 920 inc. sampling system £15,000 Model 922	Fully selectable	No information	References available
TELEDYNE BROWN ENGINEERING	Model 911 Extractive Chemiluminescence	£7,000 - £15,000	1) 0 - 10ppm 2) 0 - 10,000ppm	Conforms to US EPA requirements	Installations worldwide
THERMO ELECTRON LTD	a) Model 42 Dilution Extractive Chemiluminescence b) Model 42H Supplied as part of Model 200 dilution monitoring system	£12,000 (analyser) Dilution system not included	a) 1) low ppb 2) 0 - 20ppm (analyser) b) 1) 0 - 10ppm 2) 0 - 5000ppm System range depends on analyser range and the dilution ratio	Meets US EPA requirements	Extensive references at US utilities as part of the System 200 monitoring system

APPENDIX I (c)

PARTICULATE MATTER

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ANACON CORPORATION LTD	Models 406, 406 T1, 406 T2 Average Light Intensity	Model 406 :£2,800 to £3,500 Model 406 T1 : £3200 Model 406 T2 : £3750	Standard: 0.1 - 999.9mg/m³	T1, T2 TUV approved for LCP, working towards approval for incineration plant	500 customer references in a wide range of industrial applications including incinerators. T1, T2 - 30 references in Germany
ANACON CORPORATION LTD	Model 336 Average Light Intensity	£2200 - £2500	0.1 - 3500mg/m³	None	Worldwide 250, 25 UK
ANATROL LTD	OPM 2000	£13,000*	0 - 100% opacity	None	USA, Europe (new model 1994)
CODEL LTD	Models 100 and 200 Series Cross Duct Transmissometers	Model 100 : £1,300 to £3,500 Model 200 : £8,500 ex works	1) 0 - 10% opac. (0.05 ext) 2) 0 - 100% opac. (2.00 ext) 3) Fully selectable	A version of the Model 200, the Intrans D, marketed by Hartmann & Braun, received TUV approval in 1989. Also approved by CEGB.	Extensive references for the 100 series. Over 80 customer references for the model 200.
ENOTEC UK	Models D-R 280-10 and D-R 216 (DURAG AG) Cross Duct Transmissometers	280-10 : £6,875 216 : £2,150	1) 0 - 0.1 ext (280-10) 2) 0 - 1.6 ext (280-10) 3) 0 - 0.1 ext (smallest, 280-10) Standards on 216: 0 - 100% opacity	280-10 approved by the TUV (1978-1982) for LCP applications	Extensive German reference list available
ENOTEC UK	Model D-R 300-40 (DURAG AG) In-situ Light Scatter	£7,940 ex works	1) 0 - 2mg/m³ 2) 0 - 100mg/m³ 3)	TUV approved in 1992 for LCP applications	No information
ENVIROMONITOR LTD	Model FH 62 E-N (FAG KUGELFISCHER) Extractive Beta Ray Absorption	£36,000 excluding installation and commissioning	1) 2) 3) 0 - 30mg/m³	TUV approved in Germany for LCP and incineration applications with wet scrubbers in 1990	17 German references at incineration plants. References in Holland, Italy, France, Poland, Austria and Switzerland
ENVIRONMENTAL TECHNOLOGY RESEARCH LTD	Alpha system - cross stack optical modulation, Omicron particle impingement probe	Alpha : single location measurement £3,495, 4 location measurement £9000. Omicron : £1100	0 - 1, 0 - 10, 0 - 100, 0 - 1000mg/m³	No information	UK references available for industrial applications

APPENDIX 1 (c)

PARTICULATE MATTER (continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ERWIN SICK LTD	Models RM61-03, RM41-03 and OMD 41 Cross Duct Transmissometers	RM61-03 : £3,000 RM41-03 : £7,800 OMD 41 : £6,000	1) 0 - 0.08 ext (RM41) 2) 0 - 1.6 ext (RM41) 3) 0 - 0.9 ext (RM41) min. on RM61: 0 - 20% opacity. OMD 41 : opacity 0 - 100%, extinction 0 - 0.3 ext. units and 0 - 2 ext. units. Opacity & extinction values available on same instrument simultaneously	RM41-03 TUV approved for LCP applications in 1978 RM61-03 approved for flue gas opacity in 1984	No information
ERWIN SICK LTD	Model RM200 In-situ Light Scatter	£8,700 excluding installation and commissioning. Also used on heated by-pass when gases are water saturated. Budget price £31,000 for by-pass + RM200	1) 0 - 0.5 mg/m³ 2) 0 - 20mg/m³ (and higher) 3) 0 - 7mg/m³	1993 TUV approved for incineration processes.	No information
ETI LTD	BETA 5 M	£20,000	2 - 40,000 mg/m³	No information	No information
FIELD ELECTRONICS LTD	Model Serop Series III In-situ Transmissometers	£8,000	2) 0 - 0.3 ext	Approved by the CEGB, approval No. 5126 A2	UK LCP and MSW references
HARTMANN & BRAUN (UK) LTD	Model Intrans D (CODEL) Cross Duct Transmissometers	£7,500	1) 0 - 0.05 ext 2) 0 - 2.6 ext 3) 0 - 0.02 ext (min)	TUV approved for LCP applications in 1989	European reference list available for LCP applications

APPENDIX I (c)

PARTICULATE MATTER (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
LAND COMBUSTION	Model 4100 and 4500 Cross Duct Transmissometers	£3,000 - £6,000	Opacity: 0 - 100% (user selectable) Dust: 0 - 10, 0 - 100, 0 - 1000 mg/m³	No information	Customer list available
ORBITAL GAS LTD	Models M52081 and M52083 (SIEMENS AG) Cross Duct Transmissometers (Versions of the DURAG D-R 280-10 and 216)	No information	1) 0 - 0.1 ext 2) 0 - 1.6 ext 3) 0 - 0.1 ext	TUV approved for LCP applications	No information
POLLUTION CONTROL AND MEASUREMENT (EUROPE) LTD (PCME)	Models DT100, DT150, DT200 and D770 In-Stack Particle Impingement SC600 In-Stack Optical Scintillation	£2,500 to £4,000	Selectable in range: 0 - 0.1mg/m³ to 0 - 1,000 mg/m³	Independent tests carried out by Warren Springs Laboratory	UK reference list available for industrial applications
ROSOW TECHNICAL LTD	Model KTNR Extractive Light Scatter	£45,000 - £50,000	1) 0 - 0.1mg/m³ 2) 0 - 1,000mg/m³ 3) 0 - 0.05mg/m³	TUV approved in 1992 for flue and waste gases following wet scrubbing	Approximately 70 German references with others in the UK Sweden and Switzerland. LCP incineration and other industrial applications
SEVERN SCIENCE (INSTRUMENTS) LTD	SSI Flue Dust monitor Impacimeter	£9,000	Standard: 0 - 15% obscuration per minute	No information	One unit in operation at Rugeley Power Station
SIEMENS PLESSY CONTROLS LTD	Model MC2000 (LEAR SIEGLER) Cross Duct Transmissometer	No information	Standard : 0 - 100% opacity	Conforms to the requirements of the US EPA	US references available
THERMO ELECTRON LTD	Model 400 Cross Duct Transmissometer	£10,000 to £18,000	Standard : 0 - 100%	Conforms to US EPA requirements	Approximately 25 US customer references supplied
VEREWA GMBH (UK distributor for Graseby Anderson Ltd)	Model F-904 Extractive Beta Ray Absorption	DM65,000 to DM85,000	1) 0 - 1mg/m³ 2) 0 - 500mg/m³ 3) 0 - 15mg/m³	TUV approved for incineration applications following wet scrubbing	Extensive Germany reference list available

APPENDIX I (c)

CARBON MONOXIDE

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ANALYTIC DEVELOPMENT COMPANY LTD	Model 7000 Series Extractive NDIR	£7,000 including simple sampling system	1) 0 - 30ppm Typical : 0 - 500ppm	No information	No information
ANATROL LTD	Binos 100, 1000 AMS & Bigler & Lang (electrochem)	£3,500 - £9,000	1) 0 - 100ppm 2) 0 - 100%	No information	Worldwide
BRUEL & KJAER	Model 3425	£12,500	0.16, 16000ppm	International Instrument Users Group	Extensive references available
CODEL LTD	Models 1010, 2010, 3010 Cross Duct NDIR	1010 : £9,400 2010 : £5,000 3010 : £11,500 ex works	1) 0 - 50ppm 2) 0 - 9,999ppm 3) Fully selectable	1010 CEGB approval No. 51042A3074 1987	Approximately 250 customer references supplied both in the UK and abroad.
ENVIRO TECHNOLOGY SERVICES	Model API 300 Series Dilution Extractive NDIR	No information	Selectable between 0 - 1,000ppm	US EPA approval	No information
ERWIN SICK LTD	Model GM 910 Cross Duct NDIR Version of Land Model 9000	£9,000	1) 0 - 800mg/m^3 2) 0 - 5,000mg/m^3	TUV approval tests carried out summer 1995	No information
ETI LTD	CO 11M	£7,000	0-200ppm	No information	No information
GRASEBY ANDERSON LTD	Model AR 400 series (STI) Dilution Extractive NDIR	No information on analysers. Cost for complete system for CO, NOx, SO2 and O2 with dil. sampling system given as £55,000	1) 0 - 50ppm	Complies with US EPA requirements	North American reference list available for LCP applications
HARTMANN & BRAUN (UK) LTD	Model Uras 4 G Extractive NDIR	£4,500	1) 0 - 100ppm 2) 0 - 100% 3) 0 - 250mg/m^3	TUV approved in the stated ranges for LCP applications in 1981 and 1987 TUV approved for 17 BIMSchV	Extensive industrial and LCP reference list in Europe and UK

APPENDIX I (c)

CARBON MONOXIDE (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
HORIBA INSTRUMENTS LTD	ENDA 915/1150 Extractive NDIR Usually supplied as part of monitoring system 900/1000 series	No information	1) 0 - 25ppm 2) 0 - 50%	No information	No information
LAND COMBUSTION	Model 9000/9200 Cross Duct NDIR	Model 9000 : £8,000 Model 9200 : £10,000	1) 0 - 500mg/m³ 2) 0 - 12,500mg/m³ 3) 0 - 625mg/m³	A version of the Model 9200 was TUV approved as the Erwin Sick Model GM900 in 1992	Extensive worldwide references for the Model 9000. Over 50 Model 92000 units sold in Germany through Erwin Sick
LAND COMBUSTION	Model FGA 900 Extractive Electrochemical Cell	£4,750	1) 0 - 100ppm 2) 0 - 500ppm	No information	No information
ORBITAL GAS LTD	Ultramat 5 (Siemens) Extractive NDIR	Analyser : £5,500	1) 0 - 20PPM 2) 0 - 100% 3) 0 - 150mg/m³ (smallest)	TUV approved for the stated range for LCP applications in 1989	Extensive industrial and LCP reference list in Europe
ROSEMOUNT LTD	Binos 100 Extractive NDIR	£4,500 analyser	1) 0 - 1,000ppm	A CO system from Binos (Binos 1004) was given TUV approval in 1985 for the min. range 0 - 200mg/m³	No information
ROTORK ANALYSIS LTD	Model 401 Extractive NDIR	No information	1) 0 - 500ppm	No information	No information
ROTORK ANALYSIS LTD	Model Emirak Modular Analyser Extractive dual beam	No information	1) 0 - 50ppm 2) 0 - 1,000ppm	No information	Reference list provided
SERVOMEX PLC	Model 1490 Extractive NDIR (alternative - Model 2510)	£5,500 for analyser	1) 0 - 10ppm (for 1490) 1) 0 - 100ppm (for 2510)	Has undergone successful US EPA certification testing	Extensive reference list available at LCP and industrial applications in North America

APPENDIX I (c)

CARBON MONOXIDE (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
SIEMENS PLESSY CONTROLS LTD	Model EX4700A (LEAR SIEGLER) In-situ NDIR	No information	1) 0 - 250ppm 2) 0 - 500ppm	No information	No information
SIEMENS PLESSY CONTROLS LTD	Model ML 9830 (LEAR SIEGLER) Dilution Extractive NDIR	No information	1) 0 - 1ppm 2) 0 - 200ppm analyser ranges (dilution will determine actual measurement range)	No information	No information
SIGNAL INSTRUMENTS LTD	Model 2100 Extractive NDIR	£5,000 approx for analyser	1) 0 - 100ppm 2) 0 - 100%	No information	General references available at combustion sources
TELEDYNE BROWN ENGINEERING	1) Series 9300 Flue Gas Analyser Extractive NDIR 2) Series 9100 Flue Gas Analyser (extractive electrochemical cell)	£3,000 - £15,000 depending on version	1) 0 - 500ppm 2) 0 - 20%	No information	No information
THERMO ELECTRON LTD	Model 48 Dilution Extractive GFC IR Model 48H	£10,000 analyser	Model 48 1) 0 - 5ppm 2) 0 - 2,000ppm Model 48H 1) 0 - 50ppm 2) 0 - 20,000ppm analyser range (system range determined by dilution ratio)	Meets with US EPA requirements	North American references available

APPENDIX I (c)

CARBON DIOXIDE

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ANALYTICAL DEVELOPMENT CO LTD	Model 7000 Series RF/DB/SB Extractive NDIR	Analyser : £6,000	2) 0 - 100%	No information	No information
ANATROL LTD	Rosemount 880 Binos 100, 1000 series (Rosemount)	£3,700 - £9,000	50ppm to 100%	No information	Worldwide
BRUEL & KJAER	Model 3425	£12,500	1.5ppm, 150,000ppm	International Instrument Users Group	Extensive references available
CODEL LTD	Model 3080	£11,500	1) 0 - 2% 2) 0 - 20% 3) Fully selectable	No information	No information
HARTMANN & BRAUN LTD	Model Uras 4 Extractive NDIR	£5,000	1) 0 - 0.01% 2) 0 - 100%	No information	No information
HORIBA INSTRUMENTS LTD	Model ENDA 914/1140 Extractive NDIR Sold as part of ENDA 900/1000 emission monitoring systems	No information	1) 0 - 5% 2) 0 - 50%	No information	No information
ORBITAL GAS	Model Ultramat 21 (NDIR) Model Ultramat 5 (NDIR)	£3,000 - £6,000	0 - 1ppm, 0 - 100%	No information	No information
PANAMETRICS LTD	Model TMO2-TC (thermal conductivity)	£2,200 - £3,500	0 - 5%, 0 - 30%, 95 - 100%	No information	20, European references provided at industrial applications. Extensive USA references available
ROTORK ANALYSIS LTD	Model Emirak Modular Analyser Extractive single beam NDIR	No information	1) 0 - 10% 2) 0 - 20%	No information	Reference list provided
SERVOMEX PLC	Model 1490 Extractive NDIR (alternative Model 2500)	Analyser : £5,500	1) 0 - 10ppm 2) 0 - 100% 2500 - 1)0 - 10ppm, 2) 0 - 100%	No information	No information

APPENDIX I(c)

CARBON DIOXIDE (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
SIEMENS PLESSY CONTROLS LTD	Model M9820 (LEAR SIEGLER) Dilution Extractive NDIR	No information	Autoranging 0 - 3,000ppm	Should comply with US EPA specification	No information
SIGNAL INSTRUMENT CO LTD	Model 2200 Extractive NDIR	Analyser : £4,200 to £5,200	1) 0 - 100ppm 2) 0 - 100%	No information	No information
THERMO ELECTRON LTD	Model 41 Dilution Extractive NDIR Model 41H	Analyser : £10,000	Model 41 1) 0 - 0.2ppm 2) 0 - 2,000ppm Model 41H a) 0 - 5ppm 2) 0 - 2000ppm	Meets US EPA requirements	Extensive use in installed Model 200 systems

APPENDIX I (c)

HYDROGEN CHLORIDE

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ACAL AURIEMA LTD	Model Tess-Comm 745 Extractive Potentiometric	£30,000 including heated sampling system	Standard : 0 - 50ppm	No information	44 references provided in North America and worldwide. One UK industrial application. Also used as ambient air analyser
ANALYTICAL DEVELOPMENT COMPANY LTD	Model 7000 RF HCl Extractive NDIR with permeation dryer	£15,000 to £17,000 including sampling system	1) 0 - 500ppm	No information	System under test/development
ANATROL LTD	In development	£14,000 - £18,000	0 - 100ppm to 0 - 1000ppm	No information	No information
BAYER PLC (COMPUR)	Model Ionotx HCl Extractive Potentiometric	£30,500 analyser approx. £6,000 for sampling system depending on application	1) 0 - 10mg/m³. dilution probe used	TUV testing carried out during 1993 for the minimum measurement range for waste incinerator applications	6 references supplied in Germany at waste incinerator and industrial applications
BRAN & LUEBBE (GB) LTD	Monitor 90 Ecometer HCl Extractive Potentiometric	£30,000 analyser £7,500 to £15,000 for sampling system	1) 0 - 30mg/m³ 2) 3) 0 - 200mg/m³	TUV approved in 1994 for waste incineration applications with wet scrubbing	Widely used at waste incinerators in Germany and worldwide. In use at UK merchant incinerators
BRUEL & KJAER	Model 3425	£12,500	0.4ppm, 40,000ppm	International Instrument User Group	Extensive references available
CODEL LTD	Models 1040 and 3040	1040 : £18,000, 3040 : £20,000	1) 0 - 20ppm 2) 0 - 9999ppm 3) Fully selectable	3040 is USA EPA compliant	References in UK, France and Denmark
HARTMANN & BRAUN	CEMAS FT-IR	£6,500	1) 0 - 30ppm 2) 0 - 200ppm	TUV testing in progress	No information
LAND COMBUSTION	Model MCS 100 (PERKINS ELMER, BODENSEEWERK) Extractive NDIR	£40,000 to £45,000 including sampling system	1) 0 - 100mg/m³ 2) 0 - 3,000mg/m³ or greater 3) 0 - 200mg/m³	TUV approved in 1989 for waste incineration applications with wet scrubbing	In excess of 250 references, concentrated in Germany and Scandinavia at waste incineration applications
PROCAL ANALYTICS LTD	Model Pulsi 400 Extractive NDIR	No information	1) 0 - 300ppm 2) 0 - 100%	No information	No information

APPENDIX I (c)

HYDROGEN CHLORIDE (continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
SERVOMEX PLC	Model 2510 Extractive GFC	£14,500 analyser min £7,000 for sampling system	1) 0 - 150mg/m³ 2) 0 - 1,500mg/m³	No information	Site trials carried out. Commercial references not available
SEVERN SCIENCE (INSTRUMENTS) LTD	Model SSI HCl Extractive Potentiometric	£16,000	0.5 - 1,000ppm	Tested and used by PowerGen plc. Used by incineration plants in UK and overseas.	12 references supplied. Three at incinerators in the Far East, three in UK
THERMO ELECTRON LTD	Model 15 Dilution Extractive NDIR	£40,000 - £50,000	1) 0 - 5ppm 2) 0 - 5,000ppm System range depends on analyser range and dilution ratio	Tested by US EPA. TUV testwork completed, awaiting final report	Customer references available in Austria, Hungary and Czech Republic, some systems have been in continuous operation for 18 months.
WOESTHOFF GMBH	Model Mikrogas-HCl TE Extractive Conductometric	DM90,000 analyser DM30,000 sampling system	1) 0 - 100mg/m³ 2) 3) 0 - 100mg/m³	TUV approved in 1989 for waste incineration applications	No references for HCL measurement alone. Sold mainly as combined analyser for SO2 and HCL (see below)
WOESTHOFF GMBH	Model Mikrogas-SO2+HCl TE Extractive Conductometric measures combined SO2 + HCl	DM35,000 analyser DM30,000 sampling system	1) 0 - 15mg/m³ (HCL+SO2) 2) 3) 0 - 15mg/m³ (HCL + SO2)	TUV approved in 1992 for the low range	26 references provided concentrated in Germany. Waste incineration applications

APPENDIX I (c)

HYDROGEN FLUORIDE

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ACAL AURIEMA LTD	TESS-COMM 745 Extractive Potentiometric	£30,000 including sampling system	Standard : 0 - 50ppm	Approved by the US EPA for air quality monitoring	44 references (HF and HCL measurement) provided in North America and worldwide for industrial applications. 1 UK reference
ANATROL LTD	A-AL-1994	£15,000 - £18,000	0 - 1 to 0 - 100ppm	Under licence from Alcan	Alcan
BAYER PLC (COMPUR)	IONOTOX HF Extractive Potentiometric	Analyser: £30,500 Sampling system: approx £6,000 depending on application	1) 0 - 1mg/m³ 2) 3) 0 - 10mg/m³	TUV approved for the stated range in 1990	21 references provided at ceramic, glass and chemical industry applications in Germany
BRAN & LUEBBE	ECOMETER HF Monitor 90 Extractive Potentiometric	Analyser: £30,000 Sampling system: £7,500 to £15,000 depending on site requirements	1) 0 - 10mg/m³	TUV tested 1995	Numerous references especially HF acid manufacturers, aluminium smelters and glass manufacturers
BRAN & LUEBBE	SENSIMETER G HF Extractive Potentiometric	Analyser: £30,000 Sampling system: £7,500 to £15,000 depending on site requirements	1) 0 - 5mg/m³ 2) 3) 0.5 - 50mg/m³	TUV approved in 1980 for the stated range	No references supplied. However, has been used in Germany at industrial applications. Not sold in the UK. Has been superseded in many applications by the Ecometer
BRUEL & KJAER	Model 3425	£12,500	0.4ppm, 40,000ppm	International Instrument Users Group	Extensive references available
ETI LTD	Model TES 747	£25,000	1)0 -10ppb, 2) 0 - 1%	No information	No information
SEVERN SCIENCE	Model SSI HF Extractive Potentiometric	£18,000	0.5 - 1000mg/m³	No information	Tested and used by Ceram Research organisations in UK and Europe
HARTMANN & BRAUN	CEMAS FT - IR	£65,000	1) 0 - 20ppm 2) 0 - 200ppm	TUV testing in progress	No information

APPENDIX I (c)

HYDROGEN FLUORIDE (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
THERMOELECTRON LTD	Model 745	£20,000 - £25,000	1) 0 - 100ppb 2) 0 - 10000ppm	US EPA	Customer references in USA, Europe

APPENDIX I (c)

OXYGEN

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ABB KENT TAYLOR LTD	ZF92, ZGP2, ZMT	£2500 - £6000	0 - 25%	CEGB, Lloyds	No information
ACAL AURIEMA LTD	Ametek Thermox WDG IV & IVC Extractive Paramagnetic/Thermomagnetic	£7,500 to £9,500 depending on application	0 - 21%	Evaluated in 1979 by SIREP on behalf of the CEGB	No information
ANALYTIC DEVELOPMENT COMPANY LTD	7000 Series Extractive Paramagnetic/Thermomagnetic	£6,000 including simple sampling system	Selectable in the general range 0 - 100%	No information	No information
ANATROL LTD	M&C PMA 30 (Extractive Paramagnetic/Thermomagnetic)	Analyser: £4,000 - £4,500	1) 0 - 3% 2) 0 - 100% 3) 0 - 10% 0 - 30%	TUV approved for the stated ranges for LCP applications in 1991	European wide
BRUEL & KJAER	Model 1311 (CO_2, O_2, organic carbon monitor)	£11,000	0 - 25% O_2	None	Extensive references available
ENOTEC UK	Oxitec O2 In-situ ZrO2	£3,500	Programmable : 0 - 1 to 0 - 25%	TUV approval for LCP applications	PowerGen, National Power, ICI, etc.
ENVIRONMENTAL TECHNOLOGY SERVICES	Oxydan (various zirconia models)	No information	No information	No information	No information
ERWIN SICK LTD	LU2 O2 (Asea Brown Boveri AG) In-situ ZrO2. Others offered : ABB Kent ZFG2 probe + ZMT analyser	LU2O2 £5,800 to £7,000 depending on application ZFG/ZMT £4,000	3) 0 - 21%	TUV approved in the stated range in 1991	No information
FLUID DATA LTD	Oxor 6N (Maihak AG) Extractive Paramagnetic/Thermomagnetic	Approximately £7,000 including simple sampling system	1) 0 - 2.5% 2) 0 - 25% 3) 0 - 10% 0 - 25%	TUV approved in stated range for LCP applications in 1992	References at LCP applications in Germany

APPENDIX I (c)

OXYGEN (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
HARTMANN & BRAUN	Magnos 6 Extractive Paramagnetic/Thermomagnetic Usually supplied as part of monitoring system 900/1000 series	No information	1) 0 - 1% 2) 0 - 100% 3) 0 - 10% 0 - 21%	TUV approved in the stated ranges for LCP applications in 1990	Extensive industrial and LCP reference list in Europe and UK. The Magnos 6 is a microprocessor version of the Magnos 3 which has been extensively used
HORIBA INSTRUMENTS LTD	ENDA 916/1160 Extractive Paramagnetic/Thermomagnetic Usually supplied as part of monitoring system 900/1000 series	No information	1) 0 - 5% 2) 0 - 25%	No information	No information
LAND COMBUSTION	Model 1100 In-situ ZrO_2	£2,500 - £3,500	Standard : 0 - 25%	No information	36 references supplied in UK and worldwide at LCP and industrial applications
LAND COMBUSTION	Model FGA 930 (extractive electro-chemical cell)	£5,250	No information	No information	No information
ORBITAL GAS LTD	Oxymat 5 (Siemens) Extractive Paramagnetic/Thermomagnetic	Analyser : £4,000	1) 0 - 1% 2) 0 - 100% 3) 0 - 25%	TUV approved for the stated range for LCP applications in 1989	Extensive industrial and LCP reference list in Europe
PANAMETRICS LTD	Series 300 In-situ ZrO_2	£3,000	Standard : 0 - 21%	None	Approximately 60 European references provided at industrial applications. USA references also available
PANAMETRICS LTD	TM02 and FGA series 300 Extractive Paramagnetic/Thermomagnetic	Analyser : £3,500 Sampling system : £4,000	1) 0 - 1% 2) 0 - 25%	None	Approximately 20 European references provided at industrial applications. Extensive USA references available
ROSEMOUNT LTD	Oxynos 100 Extractive Paramagnetic/Thermomagnetic	No information	1) 0 - 1% 2) 0- 100% 3) 0 - 25%	TUV approved in the stated range for LCP applications in 1992	No information

APPENDIX I (c)

OXYGEN (continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ROTORK ANALYSIS LTD	Model Emirak Modular Analyser Extractive ZrO2	No information	1) 0 -25%	No information	Reference list provided
SERVOMEX PLC	700B In-situ ZrO2	£4,000	1) 0 - 2.5% 2) 0 - 25%	TUV approved for LCP applications in 1989	Extensive reference list available
SERVOMEX PLC	Models 1420 and 1100H Extractive Paramagnetic/Thermomagnetic	1420 : £3,000 1100A : £5,000	1) 0 - 2% 2) 0 - 100%	Model 540 using the same measurement cell as the 1420 and 1100A approved for use at LCP applications in Germany	Extensive references available for both analyssers
SIEMENS PLESSY CONTROLS LTD	Dynatron 401 (Lear Siegler) In-situ ZrO2	No information	Standard : 0 - 21%	Meets US EPA requirements for 02 monitoring	No information
SIGNAL INSTRUMENTS LTD	Model 8000M Extractive Paramagnetic/Thermomagnetic	Analyser : £4,000 - £5,000	1) 0 - 5% 2) 0 - 25%	None	No information
TELEDYNE BROWN ENGINEERING	Series 9000 Extractive Electrochemical Cell	£4,000 - £5,000	1) 0 - 5% 2) 0 - 25%	Californian Air Resources Board. Conforms to US EPA requirements.	Installations worldwide

APPENDIX I (c)

WATER VAPOUR

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ANATROL LTD	Binos 1004 (Rosemount)	£12,000	0 - 1 to 0 - 50%	None	Limited application
BRUEL & KJAER	All models (at no extra cost)	-	Fully selectable	International Instrument User Group	Extensive references available
CODEL LTD	Models 1050, 2050, 3050	1050 : £9,500, 2050 : £5,000, 3050 : £11,500	1) 0 - 10% 2) 0 - 25% 3) Fully selectable	No information	Various sites UK and abroad
HARTMANN & BRAUN	CEMAS FT - IR	£65,000	1) 0 - 1 vol% 2) 0 - 30 vol%	TUV testing in progress	No information
McQUEEN CAIRNS INTERNATIONAL	Hygrophil-H 4220/PO25 (Ultrakust Elektronic)	£10,500 - £13,000	Specific Humidity : 1 - 1,000g/kg	TUV approved for aggressive gases at high temperature	UK and German references available (power and combustion plant
ORBITAL GAS	Ultramat 5F (heated version)	£6,500 - £9,000	ppm - 100%	TUV approved	No information
ROTORK ANALYSIS	Emirak Modular Analyser	No information	0 - 30%, 0 - 100%	No information	Reference list provided
SERVOMEX PLC	Model 2500	No information	0 - 500ppm	No information	No information

APPENDIX I (c)

FLUE GAS FLOW

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ALISON ENGINEERING LTD	Model MT91 (FCI INC) Thermal Dispersion	Site specific e.g. 2*2m duct, 2 probes with 2 sensors each : £8,800	Standard : 0.08 - 4.7m/s	TUV testing at LCP in Stuggart due for completion in early 1993. Participated in US EPA testing programme for LCP applications. Should meet requirements in 40CFR Pt75	Numerous UK references supplied for FCI gas glow meters in industrial applications. Four German references supplied at LCP applications
CODEL LTD	Series 500 Time of Flight, Infrared	£9,000	1) 0 - 1m/s 2) 0 - 50m/s 3) Fully selectable	No information	Many reference sites UK and abroad
ERWIN SICK LTD	Model VMA2 & VELOS Time of Flight, Ultrasonic	£10,000	1) 0 - 16m/s VMA2, 0 - 20m/s VELOS 2) 0 - 48m/s VMA2, 0 - 60 VELOS	VMA2 TUV approved 1986	No information
HOENTZSCH GMBH	Model Vortex VA Vortex Shedding	Site specific	1) 0 - 25m/s 2) 3) 0 - 25m/s	TUV approved in 1992 for LCP applications	No information
KDG MOBREY LTD	Model DSF Annubar (DIETRICH STANDARD) Averaging Pitot	Site specific. For large duct at LCP application costs up to £25,000 for full system, including installation	3) 0 - 17.5m/s	TUV approved for LCP applications in 1989. Restricted to gases that are not saturated with water vapour	Eight references supplied in North America. Five LCPs and three waste incineration
PANAMETRICS LTD	Model CEM 68 Time of Flight Ultrasonic	£10,000 (site specific)	Standard : 0.3 - 45m/s	TUV evaluation during 1993. Meets US EPA requirements for flow measurement (40CFR Pt75)	It is stated that a number are operating in North America and Europe at LCP applications
SAMAC LTD	CEM Thermal Dispersion (Kurz Instruments)	No information	No information	Should meet the US EPA requirements (40CFR Pt75)	No information
THERMOELECTRON LTD	Model 220 Ultrasonic stack gas flow meter	£20,000 - £30,000	Standard 0 - 50m/s	No information	Several US customers

APPENDIX I (c)

MULTI-COMPONENT

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ANATROL LTD	NGA - 2000 Series (Rosemount)	Depends on application	CO, CO_2, O_2, SO_2, NO - (NO_x)	New product	Ford Motor Co.
BOMEM HARTMANN & BRAUN	Model 9100 Extractive FT-IR Up to 20 components	£50,000 to £70,000 for system	SO2 : 0 - 500ppm CO : 0 - 200ppm CO2 : 0 - 25% HCL : 0 - 200ppm H2O : 0 - 20% NO : 0 - 200ppm	No information	Canadian references available at LCP applications. Units under trial/test
BRUEL & KJAER	Model 1301 (any seven from HCl, HF, SO2, NOx, CO, CO2, H2O, org C)	£33,000	As for individual instruments	As for individual instruments	References available
BRUEL & KJAER	Model 1302 (any five from HCL, HF, SO2, CO, CO2, org C) (NOx and H2O are standard on all)	£27,000	As for individual instruments	As for individual instruments	References available
CODEL LTD	3000 Series for CO, NO_x, SO_2, CO_2, H_2O and opacity	£30,000 for 6 parameters	Same specification as for individual analysers	USA EPA compliant	No information
DRAEGER LTD	Model MSI 5600 Extractive Electrochemical Cells 5 components	No information	O2 : 0 - 25% CO : 0 - 100/500ppm NO : 0 - 100/500ppm NO2 : 0 - 100/200ppm SO2 : 0 - 100/1,000ppm	TUV approval for gas and light oil fired LCPs for O2, CO and NO only in 1992	No information
ENVIRO TECHNOLOGY SERVICES	Model AR600/610/620 (OPSIS) + IR DOAS AR650 (Differential Optical Absorption Spectroscopy - DOAS) up to 40 gases	£40,000 for basic system	SO2 : 0 - 5,000mg/m^3 NO : 0 - 2,000mg/m^3 HCL : 0 - 10,000 mg/m^3 H2O : 0 - 100% CO2 : 0 - 100% NH3 : 0 - 1,000mg/m^3 Hg : 0 - 1mg/m^3	US EPA, TUV approval, SIREP, Swedish EPA	References available for process and emission control applications. 350 systems worldwide.

APPENDIX I (c)

MULTI-COMPONENT (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ERWIN SICK LTD	Model GM 21 Cross Duct Transmissometer 2 components, particulate and SO2	£20,000 (site specific)	Particulate : 0 - 0.18 ext (min) SO2 : 0 - 0.18 ext (min) Ranges depend on measurement span	TUV approved in 1980 for particulate (0 - 0.9 ext min) and SO2 (0 - 3,000mg/m³) for LCP applications	No information
ERWIN SICK LTD	Model GM30 Cross Duct Transmissometer 3 components, particulate, SO2 and NO Model GM30-2P, In-situ probe version SO2 + NO combined analyser	GM30 £35,000 to £40,000 (site specific) GM30-2P £27,000	GM30 Particulate : 0 - 0.1 ext (min) SO2 : 0 - 300ppm NO : 0 - 300ppm GM30-2P SO2 : 0 - 100 mg/Nm³, 0 - 5000 mg/Nm³ NO : 0 - 150 mg/Nm³, 0 - 5000 mg/Nm³	TUV approved in 1990 for particulate (0 - 0.18 ext min), SO2 (0 - 200mg/m³) at LCP applications	No information
ERWIN SICK LTD	GM30 -5 (cross stack) GM30 -5P (insitu probe version)	GM30-5 : £42,000 GM30-5P : £37,000	NH3 : 0 - 50 and 0 - 100mg/m³ NO : 0 - 60 and 0 - 200mg/m³ SO2 : 0 - 100 and 0 - 300mg/m³		
ETI LTD	MIR 9000 (IR GFC) up to 10 components SO2, NO, HCl, CO, CO2, org C, H2O, O2, NH3, N2O	from £7,000	SO2 0-1%, 0-150ppm, NO 0-1%, 0-150ppm, HCl 0-1%, 0-600ppm, CO 0-5%, 0-30ppm, CO2 0-100%, org C 0-25ppm, H2O 0-1%, O2 0-25%, NH3 0-1%, 0-100ppm, N2O 0-1%	No information	No information
FLUID DATA LTD	Model Temac - Tecomb 3000 series SO_2, NO_x, CO, CO_2, HCl, HF, O_2	£2,400 - £20,000	Wide range	No information	No information
HARTMANN & BRAUN (UK) LTD	Model Uras 10 E/P Twin Beam Path Multidetector NDIR (3/4 components) Electrochemical Cell for O2	£18,700 for SO2, NO, CO and O2 Analyser including high specification sampling system	SO2 : 0 - 1,000mg/m³ NO : 0 - 650mg/m³ CO : 0 - 300mg/m³ O2 : 0 - 10%, 0 - 25%	TUV approved in early 1993 for the parameters and ranges given for LCP applications	No information

APPENDIX I(c)

MULTI-COMPONENT (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
HOBRE INSTRUMENTS (UK) LTD	Model Analect FT-IR Extractive FT-IR Maximum 10 components	£80,000 analyser £10,000 sampling system	Can measure to low ppm for SO2, NO, NO2, CO, HCL and water vapour	USA EPA tested for individual systems.	No information
LAND COMBUSTION	Model MCS 100 CD/HW (Bodenseewerk/Perkin Elmer) Extractive Single Beam NDIR SO2, NO, NO2, CO, CO2, HCl and H20	£80,000 for six components	SO2 : 0 - 70mg/m³ (min approved) NO : 0 - 200mg/m³ NO2 : 0 - 80mg/m³ CO : 0 - 100mg/m³ HCL : 0 - 70mg/m³ CO2 : 0 - 25% H20 : 0 - 40%	TUV approved for the stated minimum ranges in 1991 for LCP and incinerator applications	Approximately 90 references for the 100 HW mainly at incinerator applications. Approximately 50 references for the 100 CD at LCP, incineration and cement applications
ORBITAL GAS SYSTEMS LTD	Model Ultramat 22P Extractive Single Beam Dual Detector NDIR 2 components from SO2, NO, CO and CO2 and option for O2. Also Ultramat 5 range	£4,200 analyser	SO2 : 0 - 2,500mg/m³ NO : 0 - 1,500mg/m³ CO : 0 - 250mg/m³	TUV approved for the stated ranges in 1989 for LCP and incinerator applications	No information
PROCAL ANALYTICS LTD	Model Pulsi 200/400 In-situ Single Beam NDIR up to 5 components including SO2, NO, CO and HCl	No information	SO2 : 0 - 1,000ppm NO : 0 - 500ppm CO : 0 - 300ppm	No information	No information

APPENDIX I (c)

MULTI-COMPONENT (Continued)

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
QUANTITECH LTD	Model IMA 207/307/407 Series Cross Duct NDIR from 1 to 6 components including SO2, NO, CO, CO2, HCL, H2O	£35,000 to £40,000 for six components	S02 : 0 - 1,500ppm m (min) NO : 0 - 1,500ppm m CO : 0 - 480ppm m CO2 : 0 - 90ppm m HCI : 0 - 900ppm m H2O : 0 - 90ppm m Ranges depend on measurement span	Stated to meet US EPA requirements	References in the USA, Asia and Italy
ROSEMOUNT LTD	Binos 1001 Extractive NDIR· 2 components CO, CO2	No information	No information	No information	No information
ROTORK ANALYSIS LTD	Model 450 Series Cross Duct NDIR up to 3 components including SO2, NO, CO	£13,000	SO2 : 0 - 2,000ppm NO : 0 - 1,000ppm CO : 0 - 1,000ppm	No information	16 customer references
SIEMENS PLESSY CONTROLS LTD	Model SM8100A (LEAR SIEGLER) In-situ NDUV 2 components, SO2, NO	No information	SO2 : 0 - 208ppm NO : 0 - 208ppm	Stated to meet US EPA requirements	No information
SYSCO ANALYTICS LTD	Model 900 (WESTERN RESEARCH) Extractive NDUV 2 components SO2, NO	£10,000 analyser and £18,000 for high specification sampling system	SO2 : 0 - 500ppm NO : 0 - 300 NOx	No information	Scandinavian references available

APPENDIX I (c)

TOTAL ORGANIC CARBON

COMPANY	MODEL & TYPE	BUDGET COSTS	RANGES 1) MIN: 2) MAX: 3) APP:	APPROVALS/TESTING	REFERENCES
ANATROL LTD	Model 400A (Rosemount)	£5,000 - £6,500	0 - 1ppm to 0 - 10,000ppm	None	Worldwide
BRUEL & KJAER	Model 3425	£12,500	0.11ppm, 110,000ppm	International Instrument User Group	References available
CODEL LTD	Model 3060	£12,000	0 - 50ppm, 0 - 9999ppm, fully selectable	USA EPA compliant	No information
FLUID DATA LTD	Fluid Data 8280	£10,000 - £30,000	0 - 5ppm to % levels	No information	No information
ORBITAL GAS	Model Fidamat 5 seies	No information	low ppm - 100%	TUV approved	No information
QUANTITECH LTD	Models 3001/3003/3005 (Bernath Atomic)	No infomation	No information	No information	No information
ROTORK ANALYSIS	Emirak Modular Analyser, extractive heated FID	No information	0 - 10/10,000ppm	Currently undergoing European testing	References available
SIGNAL INSTRUMENTS LTD	Models 3000AM, 3000M, 3000PM	£4,700, £7,900, £10,000 respectively	1) 0 - 4ppm, 2) 0 - 10,000ppm	No information	Mobile laboratories, Combustion research
TELEDYNE BROWN ENGINEERING	Model 402 R (extractive FID)	£4,000 - £10,000	1)0 - 1ppm, 2)0 - 10,000ppm	No information	Instruments worldwide
THERMOELECTRON LTD	a) Model 51 Heated Total Hydrocarbon Analyser (FID)	£10,000 - £13,000	Autoranging	No information	Extensive US/European user base

APPENDIX II

CONTINUOUS MONITORS FOR RELEASES TO WATER

APPENDIX II(A)

CONTINUOUS MONITORS FOR RELEASES TO WATER:

EOUIPMENT SUPPLIERS DETAILS

APPENDIX II (a)

CONTINUOUS MONITOR SUPPLIERS (WATER)

COMPANY	ADDRESS	TELEPHONE	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	NO. OF EMPLOYEES	TURNOVER
ABB Kent-Taylor Ltd	Oldends Lane Stonehouse Gloucestershire GL10 3TA	(01453) 826661	(01453) 826358	Manufacturers of instrumentation for analytical, process and flow applications throughout a broad range of industries	UK	560	£40m
Acal Auriema Ltd	442 Bath Road Slough SL1 6BB	016286 04353	01628 669359	Instrument sales	USA UK Europe Japan	-	-
Applikon Analysers (UK) Ltd	Farnborough Business Centre Eelmoor Road Farnborough Hants GU14 7QN	01252 372303	01252 372628	On-line analysers for process and environmental monitoring	USA (TOC) Holland	6	£600K
Danfoss Ltd	Mayflo House Ebley Road Stonehouse Gloucestershire GL10 2LU	01453 828891	01453 824013	Temperature and flowmeter manufacturer	UK and Denmark	14000	£1,000m
ELE International	pHOX Systems Division Eastman Way Hemel Hempstead Hertfordshire HP2 7HB	01442 218355	01442 252474	Analytical instruments for industrial applications	UK	130	£17m
Fluid Data Ltd	Unit B4 Chaucer Business Park Water Lane Kemsing Sevenoaks Kent TN15 6QY	01732 763968	01732 763969	Manufacturers of analysers, supply of sampling systems. Representing various equipment manufacturers	USA Denmark France Germany Italy	170 worldwide plus agents	£14m worldwide

APPENDIX II (a)

CONTINUOUS MONITOR SUPPLIERS

COMPANY	ADDRESS	TELEPHONE	FAX	COMPANY ACTIVITY	NATIONAL ORIGIN OF HARDWARE	NO. OF EMPLOYEES	TURNOVER
Horiba Instruments Ltd	Kyoto Close Moulton Park Northampton NN3 6FL	01604 671166	01604 671080	Design. Manufacture of analysers and systems and laboratory instrumentation	Japan/UK	37	£8.4m
Montec International Ltd	Pacific Way Salford Manchester M5 2 DL	0161 8721487	0161 8487324	Flowmonitoring and sampling equipment manufacturers	UK	116	£8m
Sirco Controls Ltd	Sweynes Industrial Estate Ashingdon Road Rochford Essex	01702 545125	01702 546873	Manufacturers of samplers	UK	35	£1m

APPENDIX II(B)

CONTINUOUS MONITORS FOR RELEASES TO WATER:

CONTINUOUS MONITOR PRINCIPLES OF MEASUREMENT

APPENDIX II (b)

CONTINUOUS MONITOR (WATER) PRINCIPLES OF MEASUREMENT

Company	Flow Measurement	Liquid Effluent Sampling	Temperature	Total Organic Carbon	Suspended Solids	pH
ABB Kent-Taylor Ltd	Electromagnetic	-	-	-	Scattered light	-
Acal Auriema Ltd	Yes	-	-	-	Yes	-
Applikon Analyses (UK) Ltd	-	-	-	Elevated temperature UV/persulphate oxidation with infra-red detection of CO_2	-	-
Danfoss Ltd	Electromagnetic	-	-	-	-	-
ELE pHOX	-	-	Yes	Ultraviolet light	Yes	-
Fluid Data Ltd	-	-	-	• VOC stripper and FID • Thermo-catalytic oxidation to CO_2 with infra-red detection	-	-
Horiba Instruments Ltd	-	-	-	-	Forward scattering/transmitting method with condenser system	-
Montec International	Yes	Yes	-	-	-	-
Sirco Controls Ltd	-	Yes	-	-	-	-

APPENDIX I(C)

CONTINUOUS MONITORS FOR EMISSIONS TO AIR:

CONTINUOUS MONITOR COSTS. REFERENCE PLANT AND APPROVAL DETAILS FOR:

SULPHUR DIOXIDE
NITROGEN OXIDES
PARTICULATE MATTER
CARBON MONOXIDE
CARBON DIOXIDE
HYDROGEN CHLORIDE
HYDROGEN FLUORIDE
OXYGEN
WATER VAPOUR
FLUE GAS FLOW
MULTI-COMPONENT
TOTAL ORGANIC CARBON

APPENDIX II (c)

CONTINUOUS MONITORING PARAMETERS

FLOW MEASUREMENT

Company	Model & Type	Budget Costs	Ranges of Instruments	Approvals/Testing	References
ABB Kent-Taylor Ltd	Magmaster (Electromagnetic flowmeter)	£900 - £20,000	15mm - 2,000mm bore	• NAMAS accredited (0255B) • CENELEC safety • BS5750, ISO9001, EN29001 (cert No. FM21106)	Available
	Aquamag (Battery powered flowmeter)	£1,450 - £7,300	50 - 600mm bore	As above	
	Aquaprobe (Insertion meter)	£2,100 - £2,500	300 - 8000mm bore	As above	
	Dall tubes	£2,000 - £15,000	150 - 1,500mm bore	As above	
Acal Auriema Ltd	Monitek MSI/MTI	-	0.01 - 10 m/s	-	-
Danfoss Ltd	Mag 3100/2500	£1,000 - £1,600 (50mm - 250mm)	50mm - 2,000mm bore	BS5750	Extensive use by all UK water Plc's
Montec International Ltd	3510	£2,840	Full and partially full pipe survey flow monitor	IS Certification	-
	3020 3520	£2,600 £3,000	Full and partially full pipe, open channel flow monitor		
	2020	£1,300	Flume and weir flow monitor		
	3034 3530	£1,300 £1,650	Full pipe flow meter		

APPENDIX II (c)

TEMPERATURE

Company	Model & Type	Budget Costs	Ranges of Instruments	Approvals/Testing	References
ELE/pHOX	36 4 series	£400 £400	-5 to + 45°C -5 to + 45°C	-	-

APPENDIX II (c)

TOTAL ORGANIC CARBON

Company	Model & Type	Budget Costs	Ranges of Instruments	Approvals/Testing	References
Applikon Analysers (UK) Ltd	3500 on-line TOC	£12,500	Multi-stream & multi-range options available	-	-
ELE/pHOX	OPM 500 Ultraviolet light type	£5,500	0 - 215 mg/l BOD 0 - 475 mg/l COD 0 - 120 mg/l TOC	-	-
Fluid Data Ltd	ASE TOC Thermo-catalytic oxidation to CO_2 with infra-red detection	£19,000 - £22,000	0 - 3 mg/l 0 - 30 mg/l	-	-
	8280 and 8285 VOC stripper column and FID	£10,000 to £30,000	ppb to 2%		

APPENDIX II (c)

SUSPENDED SOLIDS

Company	Model & Type	Budget Costs	Ranges of Instruments	Approvals/Testing	References
ABB Kent-Taylor Ltd	4670/71	£2,000	-	-	New instrument
Acal Auriema Ltd	Monitek	-	0 - 30%	-	-
ELE/pHOX	Series 74	£2,200	1,000 - 6,000 mg/l 5,000 - 10,000 mg/l	-	-
Horiba Instruments Ltd	WATA - 100	£6,000	0 - 200ppm	None	BNFL

APPENDIX II (c)

pH MEASUREMENT

Company	Model & Type	Budget Costs	Ranges of Instruments	Approvals/Testing	References
Horiba Instruments	K-8	£1200 - £2400	0-14, 0-10 2-14, 4-14 0-8, 3-11 6-14, 4-10 or 0 - ±700 mV 0 - 1000 mV	-	-
	Alpha - 900	£800 - £1500	0-14, 0-10 2-12, 4-14 0-8, 3-11 6-14, 4-10 Interval Selection or ± 1400 mV ± 700 mV ± 350 mV 0 - 1400 mV 0 - 700 - 1400 - 0 -700 - 0 0 - 1000 mV Interval Selection	-	-
ELE International (pHOX)	40/96	£325	0-14	Numerous systems via various contractors	
	40/144	£625	0-14 2-12		
	Series 4	£550	0-14		

APPENDIX II (c)

LIQUID EFFLUENT SAMPLING

Company	Model & Type	Budget Costs	Ranges of Instruments	Approvals/Testing	References
Montec International Ltd	1011 1021 1022 1012 1023 1030 1511	£1,200 £1,400 £1,000 £1,200 £3,500 £3,100 £3,130	12 variations 9 variations 2 variations 1 model 1 product 2 variations 12 variations	-	-
Sirco Controls Ltd	Genie - M Genie - B	£2,467 £1,800	-	ISO9002	-

MANAGEMENT AND CONTACTS:

The Environment Agency delivers a service to its customers, with the emphasis on authority and accountability at the most local level possible. It aims to be cost-effective and efficient and to offer the best service and value for money.

Head Office is responsible for overall policy and relationships with national bodies including Government.

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For general enquiries please call your local Environment Agency office. If you are unsure who to contact, or which is your local office, please call our general enquiry line.

ENVIRONMENT AGENCY GENERAL ENQUIRY LINE

0645 333 111

The 24-hour emergency hotline number for reporting all environmental incidents relating to air, land and water.

ENVIRONMENT AGENCY EMERGENCY HOTLINE

0800 80 70 60

ENVIRONMENT AGENCY

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