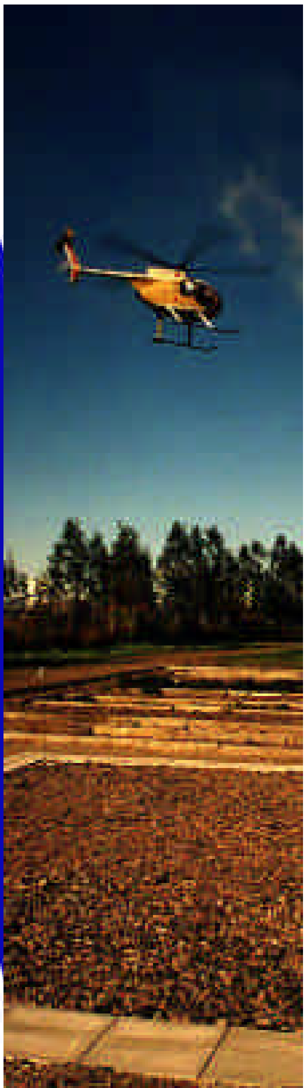
Report SGC 110

STATE OF THE ART OF TECHNOLOGIES FOR REMOTE DETECTION OF NATURAL GAS



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FOREWORD

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Summary and conclusions

There is an increasing awareness of the need to detect and survey gaseous fugitive emissions from production and distribution systems, industrial and energy processes, transportation systems for dangerous goods, leaks from landfill bodies, and from natural sources. Leaks may influence the function of production and distribution systems, or may be hazardous to human life or environment.

It is important to be able to detect the leak source of gases, survey and quantify gaseous and fugitive emissions, and to visualise and map the spatial distribution of the gas plume. Most gases are not detectable by human sensor systems, and traditional surveying techniques and methods have poor accuracy, are labour intensive, and are normally not cost-efficient.

Modern remote sensing techniques like high resolution thermography and powerful laser systems have opened up new possibilities to develop accurate, stable and cost-efficient handhold, land-mobile and airborne gas detection systems for a wide variety of applications.
During the last decade research activities of remote gas detection have been performed in different high tech industrial countries round the world in order to meet the requests for remote gas detection technologies expressed by different civilian and military end users.

In April 1996 a first meeting of a group of international researchers and end users was hold in Orlando, USA, in order to discuss the interest and the possibilities using passive and active remote sensing technologies for remote gas detection. The consensus of this meeting was that there is a need for highly sensitive and flexible remote gas detection techniques for detection of leaks from different gas sources, with ability to detect leak plumes at a sensitivity from 1 -5 ppm and upwards, at an operating range from a few meters up to 500 m (1500 feet) or more, and with a geometric resolution from 1 mm^2 for small scale surveying, up to 10-100 mm^2 for large scale surveying. Furthermore, there is a need for cost-efficient operative methods that define the advantages and limitations of the remote gas detection techniques developed for specific gas applications. R&D to produce accurate, operative and cost-efficient remote gas detection technologies and methods are complicated and costly, and motivate international co-operation.

In December 1997 an extended group of international researchers and gas producers and distributors were gathered at the Gas Research Institute (GRI) in the US to discuss and plan for mutual research activities within remote gas detection technologies. An agreement was made to establish an international R&D group of scientists and end users with the aim to form a base of mutual exchange of experiences, provide information for research priorities, and to create mutual criteria for testing and evaluation of gas detection technologies.

An international reference group and working group were formed, gas detection problems were defined, and project goals was established. A charter outline was written, and the working group was given the task to survey state-of-the-art of remote gas detection technologies for evaluation and prioritisation for future development of remote sensing of natural gas. According to project goal the survey is concentrated on methane gas, but the technologies and methods developed are expected to be useful for other gases as well, for instance biogas, with a lower methane content than natural gas, and petroleum-related hydrocarbons, etc.

In 1998 a world-wide survey of state-of-the-art of remote gas detection technologies was performed by the international working group consisting of researchers and representatives from gas production and distribution companies. The survey is mainly limited to civilian research, but includes also military research.

In this report is presented the outline and performance of the survey, the end users requests and performance criteria, results from the evaluation of technologies selected, conclusions, and suggestions of main future goals of the international R&D-group. The survey encom-passes two out of five steps of project development described in the charter outline, step I the actual survey, and step II technology evaluation and selection. In the charter outline is also given the guidelines for the survey, technologies of prime interest, and evaluation criteria. The performance criteria was later upgraded by the international working group, and the reference group during an evaluation meeting performed in Malmoe, Sweden September 1998. A final classification and evaluation of the technical reports and technologies gathered from the international survey, and the writing of this report has been performed during January-June 1999. The report is handed over as a final document to the international reference group.

Conclusions:

Based on the results of the evaluation of the international survey of state-of-the-art of remote gas detection technologies the working group has agreed to the following conclusions:

1. A consensus was reached by the end users regarding measurement requirements. (Table 2a, 2b).
2. Technologies that potentially meet the requirements of the end users were recognised.
3. A consensus was reached for a protocol to compare technologies for specific applications.

Finally it is agreed that that the international R&D-group should remain as a researchers and end users forum with the aim to form a base of mutual exchange of experiences, provide information for research priorities, and to create mutual criteria for testing and evaluation of gas detection technologies.

The reference group, responsible for this report consists of the following delegates:

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CONTENTS

1. Introduction

Gas emissions appear from a large range of sources related to production and distribution systems, industrial and energy processes, transportation systems for dangerous goods, leaks from landfill bodies or natural sources like peat mosses, etc. Some of the gases are potentially explosive or poisonous, others are harmless if not mixed with other material, like oxygen or hydrogen. Leaks may influence the function of production and distribution systems, or may be hazardous to human life or environment. Different gases have different gas characteristic; flow, pressure, spatial distribution, and absorb light in different absorption bands.

It is for several reasons important to be able to detect the leak source for gases, and to visualise and map the spatial distribution of the gas plume. Most gases are not detectable by human sensor systems, and traditional surveying techniques and methods have poor accuracy, are labour intensive, and are normally not cost-efficient.

There is a need for highly sensitive and flexible gas imaging techniques for detection of leaks from different gas sources, with ability to detect leak plumes at a sensitivity from ppm levels and upwards, at an operating range from a few meters up to 500 m (1500 feet) or more, and with a geometric resolution from 1 mm^2 for small scale surveying, up to 10-100 mm^2 for large scale surveying. There is also a need for cost-efficient operative methods that define the advantages and limitations of the gas imaging techniques for a specific gas application.

Modern remote sensing techniques like high resolution thermography and powerful laser systems have opened up new possibilities to develop accurate, stable and cost-efficient handhold, land-mobile and airborne gas detection systems for a wide variety of applications.

During the last decade research activities of gas detection have been performed in different high tech industrial countries round the world. For example, the Gas Research Institute (GRI) in the US has through different contractors performed a substantial research of active remote sensing in order to develop gas detection techniques, mainly for gas production and distribution system applications. The Royal Institute of Technology, Centre of Built Environment (KTH-BMG), and the Lund Institute of Technology, Division of Atomic Physics, Sweden have performed research devoted mainly to passive remote sensing techniques for a wider variety of applications, including gas production and distribution systems, landfill bodies, transportation of dangerous goods, industrial production, environmental and health related problems. The Fundamental Technology Research Institute, Tokyo Gas Co., Ltd, Japan, and Japan Gas Association have supported research and development of both active and passive gas imaging remote sensing technologies. The All-Russian Scientific- Research Institute of Natural Gases and Gas Technologies, VNIIGAZ, GASPROM, has performed and supported research for development of active gas detection technologies. However, so far there are no scientifically proven operational gas detection techniques or methods on the market.

To our knowledge there has been an increasing awareness of the need to detect and survey gaseous fugitive emissions from different manmade and natural sources. However, the R&D of accurate, operative and cost-efficient gas detection technologies and methods are complicated and costly. There is a need for international co-operation in the field of R&D, as well as in testing and evaluation of remote gas detection technologies and methods.

1.1 Forming of an international R&D-group

In December 1997 an international group of researchers and gas producers and distributors were gathered at the Gas Research Institute (GRI) in the US, in order to discuss and plan for mutual research activities. An agreement was made to establish an international R&D group of scientists and end users with the aim to form a base of mutual exchange of experiences, provide information for research priorities, and to create mutual criteria for testing and evaluation of gas detection technologies. An international reference group and working group was formed, gas detection problems were defined, and project goals were established.

1.2 Define problem

Detection of natural gas emissions with traditional technologies provides inadequate coverage and is not cost-efficient.

1.3 Projects goals

The evaluation and prioritisation for future development of advanced remote sensing for detection of natural gas.

Remote sensing is here taken to mean systems capable of detecting gaseous emissions at a distance of 5 m (15 feet) to 500 m (1500 feet).

Although the project will initially concentrate on methane gas, the technologies and methods developed are expected to be useful for other gases as well.

Furthermore, the technologies developed as a result of this project shall provide the tools necessary for accurate and cost-efficient gas detection for the end user.

2. Project description

The international working group was given the task to make a survey of state-of-the-art of technologies for remote sensing of natural gas emissions. The survey was to be performed according to criteria specified in a charter outline by the international reference group, at the GRI-meeting December 1997. It was decided that the survey should be executed by the members of the international working group, starting in January 1998, and ending up with a report to the international reference group by December 1998.

2.1 Project limitation

The project is limited to a world wide survey and evaluation of performed and ongoing research and development of stationary, land-mobile and airborne remote sensing technologies and methods for gas detection and visualisation of natural gas from manmade and natural sources. The investigation is mainly delimited to civilian research, but include also military research, as far as possible.

2.2 Project criteria

The project encompasses two out of five steps of project development described in the charter outline. The project goals will be achieved according to the following steps in the charter outline:

Step I Survey of the state-of-the-art of natural gas and methane detection technologies and methods.

A working group will be established to gather and evaluate current gas detection technologies. The working group shall consist of specialists in the various gas detection fields and the potential end users of these technologies.

When obtaining technology information the working group members should keep the project goals in mind. Some simple guidelines are:

1. Purely theoretical concepts should receive less consideration.

2. Technologies of prime interest are:
   - Passive and active gas imaging
   - DIAL and LIDAR technologies
   - FTIR or DOAS technologies
   - Active and passive Line-Scan technologies

But other interesting technologies should also be considered. All relevant information should be copied and distributed to the working group members.

Step II Technology evaluation and selection

a) The working group shall establish evaluation criteria for the technologies of step I.

Some examples of evaluation criteria might be:
- Gas detection sensitivity (concentration, leak rate.)
- Range
- Detection speed
- Field-of-view and resolution
- Size and weight (stationary or mobile platforms)
- Historical uses/applications
- Safety issues
- Reliability issues (accuracy, stability, repeatability, service life, etc.)
- Quantitative or Qualitative measurement capability

Note: There may be different criteria for the different end user applications

b) Based on these evaluation criteria the working group shall select those technologies best satisfying the project goal for development. The working group should be open to new technical approaches as well as to further development of current technologies; however, technology maturity and cost will be given high priority.

Recommendations of who is to be responsible for development of the selected technologies should be made by the working group. Special consideration shall be given to organisations in which state-of-the-art for each of the selected technologies resides.

A report summarising the evaluation criteria and technology development recommendations will be written by and distributed among the working group.

For further information about the content of the charter outline, see appendix (1).

2.3 Project execution

The gathering of information of the state-of-the-art of remote gas technologies has been performed by the members of the international working group, and co-ordinated by the Royal Institute of Technology, Centre of Built Environment, Gaevle (KTH-BMG) Sweden.

The information gathered has been transferred to KTH-BMG, Sweden by electronic mail, and is transformed and classified according to technical criteria's established by the reference and working group. Preliminary evaluation of the information has been performed by KTH-BMG, and presented for the international working group. The final evaluation of the information was performed by the working group, and presented for approval by the international reference group, who is responsible for the content of the final report. The writing of the report is co-ordinated by KTH-BMG.

2.4 Steps of investigation

- Creation of an investigation charter, (approved by the working group).

7. Test of safety of transference of information by electronic mail.
8. Start of the investigation & inventory phase.
9. Storage and classification of information.
10. Evaluation of information content.
11. Complementary investigation & inventory, picking up loose ends.
12. Compilation and evaluation of the "final" information (technical reports).
13. Presenting a preliminary report.
14. Evaluation of the preliminary report by the international working group.
15. Final evaluation of the report by the international reference group.
16. Final report.

2.5 Allocation of countries

The members/organisations of the international working group have been allocated the following countries:

KTH-BMG	Australia, New Zealand, China and Europe and the Baltic states, except for Russia, the former Soviet Union states, and the East European states
GAZPROM/Russia	Russia, the former Soviet Union states, the East European states, and the Arab states
Tokyo Gas/Japan	Asia, except China
GRI/USA	GRI, North and South America, Israel, Africa, including South Africa

2.6 Project organisation
The project has a traditional research organisation with one **working group** with responsibility to execute the inventory, and one **reference group** with scientists, end users, and project financiers who have the possibility and responsibility to influence, and to give approval of the final product and report.

The organisation and responsibilities of the working group is established according to the organisation schedule in appendix (2). Every key-person of the working group is responsible for their specific part of the survey to the international reference group.

2.7 Time schedule
The planning and organising of the international survey started the 12th of January 1998. The actual world-wide survey started at the beginning of February, and the main part of the survey was finished by August, 1998. A working and reference group meeting for classification and evaluation of technical reports gathered was held the 24 - 26 of September 1998, in Malmoe Sweden. Selection and priority of technologies best suited for further development according to the project goal was performed by the working group during January - March, 1999. A draft report was written February-March 1999, and was revised according to input from sub-working group meetings held at SANDIA National Laboratories (SNL), Livermore, USA, and at Northwest Recycling Co. (NSR, Landfills), Sweden, April - May 1999.

2.8 Budget
The cost for the investigation is estimated to 54 500 USD, covering 8 - 10 month work for one specialist, including cost for administration, computer and travelling expenses.

This investigation differs from a traditional inventory of published scientific reports as it also includes a search for information from not published, ongoing and past civilian and military research, and development within private manufacturers. According to the experiences from researchers within the international reference group this investigation could take about one year to perform. However, having support from an international working group with members in the research frontier in both civilian and military research, and with specialists from some of the worlds most outstanding organisations of gas producers and distributors, it has been possible to speed up, and perform this investigation to estimated cost and time budget.

3. Results

The results presented in this report are based on the information from the technical reports from the world-wide survey of state-of-the-art of remote gas detection technology, looked upon from the end users needs for cost-efficient remote gas detection technologies, expressed by the delegates of the international working and reference group, September 1998, Sweden.

The two main questions addressed in this report are: (1) What are the present and what will be the future needs for remote gas detection technologies? And (2), how does the technologies described in the technical reports meet the requests of the end users?

In order to evaluate the technical reports from the world-wide survey evaluation criteria's for different technologies, applications, and technical priorities have been developed by the international working group (table 2a-b).

3.1 Technical reports

The world-wide survey gave 59 reports, presented in appendix (3). In two of the reports were described 2 different technologies, which means that the 59 reports include description of 61 technologies. The survey has been performed according to criteria's stated in the charter outline (appendix 1). The information gathered has been listed in the technical reports, and classified according to step I in the charter outline. Purely theoretical concepts have received less consideration**.** Technologies of prime interest and numbers of technical reports gathered are presented in table 1.

Technique	**Number of reports**
Passive gas imaging (real time)	7
Passive gas imaging (sequential storage)	2
Active gas imaging (laser + IR combined)	7
Active gas detection (laser, IR separated)	6
DIAL	12
LIDAR	8
FTIR	5
Others (acoustic, photo-acoustic, resistance meter)	12
Total:	**59**

Table 1. Technologies and reports of prime interest, from the world-wide survey, Passive & active gas imaging 22 reports, Atmospheric systems 25 reports, Others 12 reports.

Definition & explanation of technologies of prime interest presented in table 1, and in Charter Outline:

Passive gas imaging - A method imaging gas plumes using ambient thermal radiation. The spectral response of a passive imager may or may not be restricted using filters, and the gas is imaged by adding or attenuating infrared radiation in the image.

Active gas imaging (also called Backscatter Absorption Imaging (BAGI)) - A method of imaging gas plumes in which a scene is illuminated by infrared laser radiation as it is being imaged in the infrared. Gases are visualized as they attenuate the backscattered radiation.

LIDAR (Light Detection and Ranging) - A method of remote sensing physical or chemical properties by projecting laser pulses to a remote location and sensing some aspects of the return signal.

DIAL (Differential Absorption Lidar) - A LIDAR method that measures absorption of gases by projecting two laser beams (one turned to the gas absorption and one detuned from it) and measuring the ratio of their return signals.

FTIR (Fourier Transform Infrared) - A method of spectroscopy that uses a Michelson interferometer to measure the spectrum of an infrared light beam. The signal from the interferometer is called an interferogram– it is subsequently Fourier transformed to generate an intensity spectrum. Gas concentrations are determined by measuring the attenuation or addition of infrared spectral intensity that they cause. In passive detection, for example, gases can attenuate radiation from a remote surface or they can radiate additional spectral radiation above that from the remote surface, depending on their relative temperature to that of the surface. This occurs at distinctive wavelengths, allowing the gas to be detected.

Note:

1. Passive and Active gas Imaging technologies generate information as real time images. It is possible to simultaneously detect gas emissions and measure their spatial distribution and movement. Passive imaging requires a temperature difference between the plume and the background, while active does not. The laser power required for active imaging increases as the stand-off range is increased; passive detection can operate at virtually unlimited range.

2. LIDAR, DIAL, and FTIR systems are absorption-based techniques used to identify and measure gases along a single line-of-sight. By scanning this line, measurements may be accumulated to characterise gases in two or three dimensions. This may then allow some degrees of plume mapping, however not at the rate of real-time imagery.

3.2 Evaluation of search routines & procedures

The world wide survey has been performed through literature search on the Internet, and via electronic mail, fax- and phone contacts with civilian and military research institutes, through end users organisations, embassy authorities, and by personal contacts within the research frontier of the delegates of the working group.

The potential contributors where given written information about the aim of the world wide survey, the international reference & working group, the commitments and organisation of the working group, and was also informed about the remaining work of the international reference and working group after the survey, according to the charter outline.

Because the survey included many different types of remote gas detection technologies the search for documents become rather time and resource consuming. It is well known by people within the research frontier of Remote Sensing Technologies that research for development of for example DIAL, LIDAR, and FTIR has been going on for quite long, and that there is an extensive production of research reports, published and unpublished. While, R&D within remote gas imaging has proceeded for about a 10-year period, with few published reports.

It is worth mentioning that the search for state-of-the-art of remote gas detection technologies for Europe has given a 1 meter pile of documents, with only 5 technical reports from R&D within remote passive and active gas imaging technologies, and with the remaining part of the reports dealing with research for development of technologies for survey of atmospheric pollutants, as for example LIDAR technologies, etc.

3.3 Missing technologies and documents

During the process of the survey there are indications that we have been missing information about some ongoing military and civilian research and development, mainly within the field of passive and active gas imaging & detection technologies. At the present we don't know how many they are, nor type or state of technology. Regarding ongoing military R&D the conclusion from the working group is that we probably have enough information to guide the choice of direction of future development of remote gas detection technology.

Regarding missing information of civilian R&D it is probably caused by confidential and commercial reasons. As one example it can be mentioned that we have been contacted by representatives of commercial organisations who at first where willing to inform us about their products and concepts within remote passive and active gas imaging technologies, but that they withdraw their offer when they understood that we couldn't guarantee 100 % confidentiality. A second example is the French company Bertin, who first wasn't willing to contribute with information to our project, but after performing a test with CH_4 gas leak simulation at the test site at Malmoe, Sweden, August 1998, changed their mind and contributed with a report of their system. A third example is another French system, which is reported in our technical reports, but will be treated as strictly confidential until permission is given to do otherwise.

Other reasons why we may have missed information of ongoing R&D of primary remote passive and active gas imaging technologies are that we may have failed in our search process and routines. Also, we know that there is a hard competition for research resources among universities and research institutions, which restricts information exchange. However, with the knowledge of the market potential of remote gas detection technologies a plausible hypothesis is that technologies with technical maturity probably have been collected within the world wide survey, or otherwise will soon show up on the market.

New technologies, which are judged to be of interest for further evaluation, will continuously be added to the survey and presented in an updated version of this report.

3.4 Criteria for evaluation & ranking of remote gas detection technologies

According to the charter outline the project goal is ”the evaluation and prioritisation for future development of advanced remote sensing technologies for detection of natural gas emissions”.

In order to fulfil this goal the working group has to evaluate and rank state-of-the-art of potential technologies according to specific criteria, related to specified needs of the end users, and to practical scientific conditions necessary to develop cost-efficient operational technologies and methods.

The result from the world-wide survey presented in the technical reports (appendix 3), and in table (1) has given the basic information to start this evaluation procedure. However, the information from the survey also pointed out that in order to perform an adequate technology evaluation and selection it is necessary to sharpen up, and clarify the end users needs of remote sensing gas detection technologies & methods in terms of more specified operational criteria. Also, it is necessary to clarify the development potential of selected technical solutions/systems for specific applications.

Evaluation questions and criteria to consider:

1. **What gases do we finally include in ”natural gas emissions”?**
   In the charter outline methane gas is pointed out as the ”key gas”, but also that, ”the technologies and methods developed are expected to be useful for other gases as well”.

2. **Which applications are to be focused on?**
   The applications are related to the gas/es included in the project. Intentional application areas suggested by the reference and working group are:

   - Gas production and distribution systems (methane, LPG, biogas, etc.)
   - Landfill bodies (biogas)
   - Transportation of dangerous goods (natural gas, other gases as well)
   - Gas emissions within buildings, e.g. indoor industrial processing, etc.
   - General environmental Remote Sensing of atmospheric pollutants

Different end users applications require different technical solutions. This means that the end users have to specify their needs in terms of desired field operative features of the remote gas detection & imaging system, for the specific application.

As the international reference and working group consist of, and is backed up with organisations of end users and researchers with a unique educational and professional background it has been possible to perform a dialogue in order to specify the end users needs, and clarify the technical potential to develop cost-efficient technologies.

3. **What performance categories should be prioritised?**
   - Detect the leak sources (detection)
   - Visualise and map the gas plumes (mapping)
   - Map the dispersion of the gas plumes
   - Pinpointing

- Measuring (measure the gas concentration)
- Real time, sequential storage

4. **What weather & radiation conditions do we expect the system to work in?**
   - Day or night, or day and night registration
   - Clear-sky stable outdoor conditions
   - Min/max delta T-conditions
   - Special backscatter conditions
   - Wind-speed
   - Humidity-rate (etc.)
   - Others (indoor conditions, etc.)

5. **Technical features required (trade-off situations)?**
   - Gas detection sensitivity (in general)
   - Detectable levels (ppm-levels, l/min, for application 1....n)
   - Range (m)
   - Geometric resolution
   - Field-of-view (surface coverage at specific range)
   - Operational conditions (see item 4 above)
   - Safety issues
   - Advantages and limitations for specific applications

6. **What system & instrumental platforms and carriers are prioritised?**
   The choice of technology & instrumental platform & carrier is related to the specific gas, and application:

   - Airborne passive and/or active gas imaging systems (helicopter, fixed-winged aircraft)
   - Land-mobile, stationary or portable systems

Evaluation and ranking criteria's have been created as guidelines for priority selections of those technologies best satisfying the project goal of development of cost-efficient remote gas detection technologies (table 2a and 2b), on the basis of question 1 - 6 presented above.

3.5 Evaluation of the technical reports & technologies

The evaluation of the technical reports from the world-wide survey for natural gas applications has been performed in two steps. Step (1) includes a preliminary classification and evaluation of the 59 selected reports (61 technologies) in table (1), performed by KTH-BMG, and presented at a reference and working group meeting the 24 - 25 th of September, 1998, Malmoe Sweden. Step (2) includes a deepened classification and evaluation of that same 59 reports (61 technologies), performed by the international working group, based on the end users and researchers evaluation criteria's, developed by the working and reference group, September 1998 (table 2a).

A similar evaluation of the selected technologies for landfill applications was performed in May 1999 by Jan-Erik Meijer (JEM), based on criteria presented in table 2b. extracted from several world-wide evaluation studies of state-of-the-art of gas detection technologies for landfills. For example the Nordtest study: ”Methods for announcement of landfill gas generation and emission”, report 380, 1998, by Aage Heie, and Anders Lagerkvist, in which is stated the need for new cost-efficient technologies and methods for visual inspection in order to screen temporal and spatial variability in gas emissions. The authors propose an evaluation of infrared thermography and combined field measurement methods. JEM is the head of the R&D division of NSR, Sweden, and is international established within the field of landfills and biogas production.

Step (1) The information quality of the technical reports is in general good. However, due to absence of relevant information in some technical reports there have been difficulties to sort out whether some of the technologies presented are pure theoretical concepts, first stage of laboratory set up, or poorly tested operative systems. Also, for some of the technologies presented it is not quite clear whether the system described could be used for natural gas emission detection & application, a well as for the gas presented. Those rather few reports with inadequate information have been judged as none interesting in the final evaluation stage.

In general, most of the technologies presented in the technical reports are either laboratory systems, or systems with limited field operative tests performed. There are a few exceptions where the technologies presented are tested for field operation, and for commercial use.

Table (1), page 9, includes 22 reports that describe passive and active remote gas detection technologies for survey of natural gas emissions from manmade or natural sources. Some of the passive and active gas detection technologies presented are real time gas imaging technologies. Others are technologies with sequential storage imaging, processed for video or computer based presentation with frame grabber technology. 25 technologies presented in table (1) represent land-mobile or airborne Remote Sensing techniques & methods (DIAL, LIDAR, FTIR) for survey of gaseous pollutants in the atmosphere, measuring gas concentrations due to emissions from industrial processes (petrochemical plants, etc.), or warfare gases. The 12 remaining technologies, named ”Others”, include acoustic, photoacoustic, resistance meters, combined passive IR-Optical thermal contrast measurement technologies, etc. Most of the technologies of this group are not Remote Sensing technologies, but are judged as interesting for gas detection.

In order to perform a deepened evaluation according to the end users needs, and in order to select technologies of prime interest for further development according to specified criteria a second selection & evaluation of the technologies was performed in Step 2.

Step 2 includes a deepened classification and evaluation of the 61 selected technologies (59 reports) from the world wide survey executed according to criteria extracted from the end users needs of remote gas detection technologies & methods, expressed by the members of the international working and reference group, September 1998, Malmoe Sweden, and by the representatives of the landfill end users in May 1999.

It should be pointed out that the working group has not been able to fully evaluate the technical properties of existing technologies due to the incomplete and insubstantial nature

of the available technical information of the reports gathered within the international survey. However, the opinion of the working group is that the technical information of the 35 selected technologies is acceptable to judge and point out the direction of future technology development according to the end users requests.

The end users in the international working and reference group were represented by:
Gas Research Institute, GRI USA
Gas de France, GdF, France
VNIIGAZ, GAZPROM, Russia
Gasunie, the Netherlands
British Gas Technology, Great Britain
Japan Gas Association, Japan
Swedish Gas Center, SGC, Sweden

The researchers were represented by:
SANDIA National Laboratories, USA
The Royal Institute of Technology, Centre of Built Environment, KTH-BMG, Sweden
Tokyo Gas Ltd, Japan

The evaluation is concentrated on technologies for remote detection of **natural gas** emissions with methane gas as the key-gas. However, as pointed out in the ”Charter Outline”, and in section 1.2 in this report the technologies developed should be useful for other gases as well. Especially gases with a high methane content (40 - 70 % CH_4), for example biogas, LPG gas, etc. Biogas from degradation of organic material in landfills is also called landfill gas (LFG). The evaluation does not specifically include environment applications.

3.5.1 Natural gas applications (production and distribution)

Table (2a), page 29, gives the end users criteria as guidelines for evaluation and priorities of remote gas detection technologies of **natural gas** emissions for five high ranking applications including; Production, HP Transmission, LP Distribution, LNG Storage, and Indoor applications (industrial, etc.).

Detectability is set to signal/noise > 3 and false call rate < 20 % for all applications. Detectability is also related to operational range, specified for the different applications, detection technology and instrument carrier. As for example, for applications within a (1) **Production site** a handhold, mobile or airborne system could be used operating at a range of Û 10 m, Û 100 m respectively 100 - 500 m. For (2) **HP Transmission lines** one recommend an airborne system operating at a range of 50 - 500 m (table 2a).

Performance categories & criteria
Four (4) performance categories & criteria have been selected and prioritised, including; Detection (A), Mapping (B), Pinpointing (C) and Measuring (D). Levels for detectable size of a gas plum have been set for the 5 applications, ranging from 0.1 m for (5) **Indoor applications** to maximum Û 2 m for (2) **HP Transmission** lines. The performance criteria has been evaluated and prioritised by judgements of their usefulness for the different applications and

to the specific needs expressed by the different end users representatives within the working group.

Detection (A) was given the highest priority of the 4 performance criteria. The prioritised limits of delectability were set differently for the different applications, counted either in ppm-levels ranging from 1 - 500 ppm, percentage levels ranging from 0.1 - 2 %, or litre/hours ranging from 0.06 - 5 l/h.

A ranking of the criteria **Detection** (A) was performed through a simple method where each of the 7 delegates of the working group evaluated and gave priority points for the use of the category Detection for each of the five applications, ranging from ”Very interested” with maximum 4 points to ”Uninterested” with minimum 1 point, the sum divided by 7 which gave the final score. As for example **Detection** of gas emissions from **LP Distribution** lines was given the highest priority with altogether 25 points divided by 7 giving a total score of 3.6, while **Detection** of **Production** sites was given the lowest priority with 16 points divided by 7 = score 2.2 (table 2a).

The internal priority of the three (3) remaining performance criteria were likewise performed through a simple ranking model with 7 yes- or no-votes to express the judgement of the working group using **Mapping** (B), **Pinpointing** (C), and **Measuring** (D) for the different applications prioritised, (1) Production, (2) HP Transmissions, etc.

Mapping and **Pinpointing** gas emissions from Production sites, and **Mapping** gas emissions from HP Transmissions and LP Distribution lines were ranking the highest priority with score 5. **Pinpointing** sources of gas emissions from HP Transmission lines was also given high priority, with score 4 (table 2a). While the category **Measuring** was given the lowest priority for all applications, except for **(3) LP** Distribution which gained score 4 (table 2a). The general opinion of the end users of the working group is that pure measurement systems have low priority, because knowing that there is a gas leak one send out someone to repair it. However, it was pointed out that from an environmental point of view measurement systems may have high priority.

Each of the reports and technology from the world-wide survey of state-of-the-art of remote gas detection technology has been evaluated according to the different applications, the performance criteria, and the technical specifications presented in table (2a). The technologies that didn’t meet the requests stated in table 2a were withdrawn from the final evaluation.

3.5.2 **Biogas applications** (biogas production and distribution)

Table (2b), page 31, gives the end users criteria as guidelines for evaluation and priorities of remote gas detection technologies for three high ranking biogas landfill applications including; (1) Landfill sites, (2) LP Distribution, and (5) Indoor Applications.
The evaluation criteria are similar to those of natural gas production and distribution applications in table 2a. The detection is set to signal/noise >3, and the false call rate < 20 % for all applications. Detection limit is set to 10 - 500 ppm. Detectable size of plume is set to 0.1 - 1 m.

Like the case with natural gas applications the detection is also related to operational range for the different applications, detection technology and instrument carrier. A large surface coverage is required for (1) **Landfill site** applications, with 100 - 500 m for the (M) mobile systems, and 100 - 1000 m for (A) airborne systems, but 10 m for (H) handhold systems. (2) **LP Distribution**, and (5) **Indoor Applications** have the same performance criteria for biogas as for natural gas applications, presented in table 2a.

Performance categories & criteria
The same four (4) performance categories & criteria were selected for landfill **biogas** applications as for **natural gas** applications (table 2a, 2b), Detection (A), Mapping (B), Pinpointing (C), and Measuring (D).

Detection (A) is given the highest priority, Pinpointing (C) the second highest, Mapping (B) third, and Measuring (D) the lowest priority. Pinpointing (C) was given high priority because landfill sites often require systems that give large surfaces coverage combined with positioning of the specific gas leak sources.

The applications, performance categories & criteria, and the technologies selected are judged to be relevant for landfill applications world-wide according to Jan-Erik Meijer, NSR, Sweden. The draft report is going to be presented for eventual comments by other international representatives of landfill organisations and experts, if requested by the international working and reference group.

3.5.3 Evaluation of selected technologies for natural gas applications

The working group has selected 35 technologies out of the original 61 technologies (59 reports) from the world-wide survey for a final evaluation for **natural gas applications**. The 35 selected technologies are judged to be applicable for multi-purpose use including 83 different performance categories and applications (table 3 and 4). For example the technology in report US - 4 which is an active Laser-IR system is judged to be applicable for both Detection (A), Mapping (B), Pinpointing (C), and Measuring of gas emissions from (1) Production, (2) HP Transmission, (3) LP Distribution lines, and from (4) LNG Storage, and (5) Indoor Applications. Similar potentials of performances are valid for several other technologies evaluated and presented in table 3. However, there are also technologies that are judged to be applicable for only one performance category and application, as for example the technology in report R - 8 which is a Russian passive system applicable for Measuring (D) of gas emission from (2) HP Transmission lines (table 3).

Table 3 also shows that out of the 35 technologies selected and evaluated there are 10 Passive systems, 22 Active, and 3 combined Passive & Active systems. Notice that the application with the highest ranking of priority, Detection (A) of gas emissions from (3) LP Distribution with 3.6 points has only 6 selected technologies, table 5. While both application (1) Production, and (2) LNG Storage with the lowest priority points have the highest amount of technologies available according to the technical reports gathered from the world wide survey (table 4, and 5). In table 5 it should also be noticed that the technologies selected are rather evenly spread out within the recording categories and the applications (2) HP Transmission, (3) LP Distribution, (4) LNG Storage, and (5) Indoor applications.

When comparing the information in table 3 and 5 with each other one find that some technologies that apply to the highest ranked application and performance category, 3. LP Distribution, and Detection (A), also apply to many other applications and performance categories. This is even more obvious when looking at the priority listings presented in table 6 - 18, which confirm that the selected technologies could be used for multi-purpose applications and performance categories, and imply the importance for sharing costs of technology development and for future field applications.

3.5.4 Evaluation of selected technologies for biogas applications

The working group representative Jan-Erik Meijer, NSR, Sweden has selected eight (8) of the original 61 technologies (59 reports) from the international survey for a final evaluation for biogas applications, (6) Landfills, 05-06-99. The application (1) Production in natural gas applications (table 2a) is equivalent with (1) Landfill in biogas applications (table 2b). The eight technologies selected could be used for multi-purpose biogas applications, here including (1) Landfill (production), (3) LP Distribution and (5) Indoor applications. For information about evaluation and recommendation of the selected technologies, see item 4.2.

3.5.5 Evaluation questions to be considered

There are some questions to be considered in order to make adequate conclusions and relevant recommendations.

1. How do the technologies described in the technical reports meet the requests for accurate and cost-efficient remote gas detection technologies expressed by the end users?

2. Do the technologies presented in the technical reports evaluated represent the research frontier of remote gas detection technologies?

3. Is the information of the technical reports evaluated of such a quality that it is possible to perform an adequate evaluation, and ranking according to the end users needs?

4. What time frame is relevant to work within to prognosis and evaluate the end users future needs in order to propose relevant technical solutions?

5. What's the technical maturity of the technologies evaluated? Taken into consideration that Remote Sensing technology for remote gas emission detection is a young technology, costly to develop, but in general accurate and cost-efficient to operate.

6. What R&D resources are required to develop selected technologies into accurate, cost-efficient, and well tested operative field technologies?

7. What testing facilities, criteria, and methods are required to perform an adequate and unbiased (competent?) test of the accuracy, stability, and operative performances during for the specific application adequate weather and radiation conditions?

8. What are the advantages and limitations for respectively technology selected and evaluated?

9. What rules for consensus for recommendations for further development of the selected and evaluated technologies should be valid?

10. What should be the status of the working and reference group recommendations?

Regarding technology evaluation (question 1) it is with available information not possible to judge whether the selected technologies fully meet the request for accuracy and cost-efficiency expressed by the end users. In order to perform such an evaluation it is necessary to have detailed and reliable information about detectable levels, and operational conditions of the systems required for the different application and performance categories, related to the end users criteria. This type of information can be achieved for instance by field laboratory tests performed during well-defined and controlled conditions for the specific application, performed at an adequately equipped field test facility.

The technologies evaluated are judged to represent the research frontier of remote gas detection technologies (question 2). However, there may be some missing technologies especially from the military research areas. Because of the market potential of remote gas detection technologies most of the technologies within the research frontier of civilian research are probably covered by the international survey.

The quality of the information of the technical reports selected varies depending on whether the technology presented is a system with high technical maturity, a laboratory system or a system concept (question 3). The evaluation performed by the working group is based on technical facts, and assumptions about the potential of development for the system concepts presented in the reports gathered.

To prognosticate the future needs of remote gas detection for the end users is a difficult task (question 4). Partly because the gas systems may improve in quality of construction and materials, and in safety performance. Also, because there is an ongoing and rapid development of new generations Remote Sensing technologies. A qualified guess & prognosis for short term planning of development of a remote gas detection system could be 3 - 5 years, which also is a ”normal” project time developing a system from scratch to final product.

Technical maturity of a remote gas detection system/technology (question 5) is a matter of definition. If technical maturity means that a system is developed, tested, and proven to satisfy the end users needs according to real world operative conditions for a specific application, and performance category, then none of the selected and evaluated technologies have reached that state of technical maturity. If the definition is broadened and also includes systems that have been tested and proven to give acceptable results (accuracy, stability, etc.) during a limited range of optimal weather and radiation conditions, like clear sky conditions, wind speed 3 - 5 m/s, etc. then a few of the technologies evaluated have reached that stage.

Most of the technologies evaluated are laboratory or system concepts. If the definition also includes the potential of laboratory and system concepts to be developed to accurate and cost-efficient systems, then most of the technology selected is judged to have the ”potential for technical maturity”.

The R&D resources required to develop the selected technologies into accurate and cost-efficient field operative systems probably vary a lot depending on if it is a an upgrading and testing of a technical mature system or starting from scratch with high cost for development from a system concept to a field system.

In order to evaluate the advantage and limitations of remote gas detection systems it is necessary to perform repeated gas leak simulations with testing of the accuracy, stability and operative performances during adequate real world conditions specified for the specific application. For this is required field laboratory testing facilities that allows the tests to be performed during well defined and controlled conditions (question 7). It is of most importance to develop international criteria for such test facilities and test performances, for the specific remote gas detection systems, for different applications, weather and radiation conditions.

With to date information it is not possible for the working group to make an adequate evaluation of the advantages and limitations of the technologies selected (question 8). This is a task that has to be performed after that the systems have been developed or upgraded, and adequately tested.

Rules for consensus of recommendations for further development of selected and evaluated technologies should be suggested by the working group, and executed by the reference group (question 9).

Finally the working group should decide the status of the recommendations of the future technology development (question 10).

4. Recommendations of technology development for natural gas applications

Based on the information from the survey we have found that some of the technologies evaluated could be used to point out the direction for future development of accurate and cost-efficient remote gas detection technologies requested by the end users. Notice that we don’t point out any specific technology, researcher or manufacturer as superior of others. But we select some of the technologies to illustrate what system or concept which we judge have the potential for further development according to project goal, and to end users request presented in for instance table 2a-b. This judgement of the working group is to be considered as qualified guidelines for selection of direction of technology development.

Priority 1. Detection (A) of gas emissions from (3) LP Distribution lines

According to the working group evaluation Detection (A) for gas emissions from (3) LP Distribution (table 2a) was given the highest priority by the end users (table 2a). Six of the technologies selected are judged to have the potential for further development to become accurate and cost-efficient tools for remote detection of methane gas emissions from LP

Distribution lines. The 6 technologies selected presented in alphabetic order are J-6 which is a theoretical concept, R-5, with two separately operated passive & active IR-Laser system, SW-1 and 2, which are **passive** IR systems, one IR-correlation spectrometry system, and one high resolution IR-system with band pass filters, US-1 and 4, an **active** truck mounted LIDAR system, respectively a truck mounted **active** pulsed Laser-IR-system.

Five of the six systems selected have been tested in field operation and are judged to have the potential for further development, upgrading and testing at reasonable cost and time. As **passive** remote gas detection technologies are temperature dependent, and **active** gas imaging systems are distant dependent the opinion of the working group is that those two technologies should be looked upon as complementary to each other in order to cover operations in many different real world range, weather, and radiation conditions. The technologies selected could be mounted and operated from land-mobile or airborne units, and could be used for other applications and recording categories as well (see table 3). The six selected systems are presented in table 6.

Priority 2. Detection (A) of gas emissions from (2) HP Transmission lines were also given high priority by the working group. 16 of the technologies selected are judged to have the potential for further development. The same stands for the recording categories **Mapping (B) and Pinpointing (C)** with 4 technologies selected. Some of the altogether 20 technologies selected have reached high technical maturity but are not tested for methane gas detection**,** as for example US-6 which is an airborne FTIR spectrometer, 8 - 15 μm for SF_6 detection. This system could eventually be upgraded with a suitable detector sensitive within the methane gas absorption peaks of 3.37 or 7.9 μm. Also notice that 6 of the 20 selected technologies are the same systems that have been selected as potential technologies for Detection (A) for (3) LP Distribution lines, table 7.

Priority 3. Detection (A) of gas emissions from (4) LNG Storage are represented by 26 technologies selected. Here illustrated by for example US-4 a truck-mounted or stationary pulsed laser & FPA-IR system, 3.1 - 3.6 μm, for methane gas detection. Most of the 26 technologies selected are none-imaging systems, type airborne or truck-mounted LIDAR systems (report A-1, etc.), stationary or airborne FTIR systems (T-1, respectively US-6, etc.), or a two-step IR-Laser system like the technologies described in the Russian reports R-1 respectively R-5, presented in table 8.

Priority 4. Detection (A) of gas emissions from (1) Production sites which has the lowest priority according to the working group criteria (table 2a) is represented by 26 technologies selected. Most of these technologies (14) are none-imaging systems, type LIDAR, DIAL and FTIR systems. Two are photo-acoustic respectively ultrasonic systems. Six of the remaining systems represent the same technologies as selected for the highest ranked application ”Detection (A) of LP Distribution lines”, R-5, SW-1,2, US-1,2, and J-3. But also US-9,10, see table 9.

Mapping (B) and Pinpointing (C) of gas emissions from (3) LP Distribution lines are also given high priority (table 2a), represented by 4 technologies selected, report R-5, SW-1,2, and report US-4, a pulsed Laser-IR system, table 10.

Mapping (B) and Pinpointing (C) of gas emissions from the second highest prioritised application **2. HP Transmission** is represented by six technologies, J-3, R-5, SW-1, SW-2, US-4 and US-5. Where the four (4) first technologies are the same as in Detection (A) of 3. LP Distribution. The two remaining US-4 is a pulsed laser system, and US-5 an airborne DIAL-system, see table 11.

For Mapping (B) and Pinpointing (C) of gas emissions from **4. LNG Storage**, priority 3, are selected 8 technologies presented in report F-4, J-3 and J-4, R-5, SW-1 and SW-2, US-4 and US 10. Where for example F-4 is a French passive system which could be used for real time mapping of SF_6, and CH_4 developed by the BERTIN, France, and where the GasVue-systems TG-5, TG-20 and MG-30 (US-10) are active Laser-IR imaging systems (BAGI technology) for detection of SF_6, with future plans to include detection of CH_4, as well, table 12.

Detection (A), Mapping (B), Pinpointing (C) of gas emissions for **(5) Indoor applications** are represented by same six technologies, J-2,5, SW-1,2, US-1,4, extended with US-8 and US-10, for Detection (A), see table 13 and 14.

Mapping (B) and Pinpointing (C) for **1. Production** have the lowest priority (4) of the application, and is represented by seven technologies, F-4, J-3, R-5, SW-1, SW-2, US-4, US-10, which except for F-4 are the same technologies that apply for most applications and performance categories presented, see table 15.

Measuring (D) for all applications have the lowest internal priority of the performance categories according to the end users criteria's (table 2a). Technologies selected are for example the systems presented in R-5,6,7,8,9, and SW-1 where the Russian technologies are none-imaging two-step IR-Laser systems, and the Swedish system is a passive gas imaging IR-correlation spectrometry system. **Measuring** for **(5) Indoor applications** is represented only by 1 system, presented in report SW-1, see table 16 and 17.

4.1 Recommendation of technology development for biogas applications

Like for natural gas applications the selected technologies for biogas applications are judged to have the potential for further development according to project goal and end users requests, presented in table 2b. The following nine technologies have been selected:

F-4 which is a French passive stationary system (TACIT by BERTIN) applicable for Detection (A), Mapping (B), and Pinpointing (C) for (1) Landfill (Production) applications. G-4 a German Compact Diodlaser (dDIM) system for detection of emissions from Landfills. J-5 which is a Japanese conceptual portable active system for (5) Indoor applications with same performance categories as for F-4. R-5, which is a combined Russian passive and active system which besides the performance categories A,B,C also is applicable for Measurement (D) performance, for application 1-4. SW-1 and SW-2 which is a Swedish IR-correlation spectrometry system respectively a high resolution IR system covering application 1-5, and the performance categories A,B,C. US-4 which is a truck-mounted pulsed active gas imager (SANDIA) likewise applicable for 1-5 applications, and for A,B,C performance categories. Finally, US-10 which represents three active gas imaging systems, GasVue TG-5, TG-20, MG-30, here applicable for Detection (A), Mapping (B), and Pinpointing (C) for Landfill (1), and Indoor (5) applications.

Seven of the nine technologies (9 systems) selected have been tested in field operation, and are judged to have potential for further development according to the end users requests. Three of these systems are introduced on the market. One of the technologies selected is a conceptual system. The seven selected technologies are presented in Table 18.

Notice that three of the eight technologies selected for Landfills are the same as selected for the highest ranked performance category Detection (A) from LP- Distribution for natural gas applications, see table 6.

4.2 Environment Applications

Technologies for **7.** Environment applications (table 4) are not selected and evaluated in this draft report. However, several of the none-imaging technologies selected, LIDAR, DIAL and FTIR, and eventually some of the passive and active gas imaging systems could probably be used for 7. Environment applications. According to the announcements from some of the delegates of the working and reference group the evaluation should encompasses environment applications as well, and the result should be presented in the final report. Performance and evaluation criteria for environment applications have been suggested by Dr. Gretta Akapova, VNIIGAZ, GAZPROM, presented as a supplement to table 2b.

4.3 The working group consensus

The evaluation of the technologies selected encompasses information of remote gas detection technologies with different technical maturity and development potential. In table 6 (A), page 36, is presented examples of technologies that are judged to have the potential for further development in order to become accurate, reliable, and cost-efficient tools for remote gas detection & applications, according to the end users needs.

The criteria used for the down-selection of the technologies presented in table 6 (A) are selected from the end users criteria presented in table 2a and 2b, including the performance categories & criteria ”range, detection priority limit, size of gas plum”, for the highest ranked application ”Detection (A)”, including also the criteria ”Technical maturity”, and ”Multi-applications”. **Technical maturity** is divided into four levels: 0 = Concept = not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria. **Multi-applications** here mean technologies that could be used for ”Detection (A)” for the highest ranked application LP Distribution, and for other applications, and performance categories with high development and market potential.

It should be noted that most of the technologies from the international survey have been developed in the US. Also, here one finds the most mature technologies. However, this doesn’t mean that new and better technologies can’t be developed. The information gained from the international survey form the base from which it should be possible to make a further down-selection in order to point out the direction for further development of remote gas detection technologies according to the end users needs.

The key-questions are:

- How do the existing technologies meet the requests from the end users, expressed by the end users criteria?
- What's the development potential of the existing technologies selected?

The consensus is:

1. None of the selected technologies fully met the end users requests of performance, and technical maturity, presented in for instance table 2a, and 2b.

2. Several of the selected technologies have the potential for further development in order to meet the end users needs, illustrated for example in table A.

3. Most of the technologies evaluated and selected have been tested under conditions that span only a subset of the operational conditions for the applications of the end users. Also the performance attributes described in the technical reports are often specified on the basis of a few "demonstration" measurements and may not reflect normal operating performance.

4. As a consequence of item (2) and (3) above, the system criteria presented in table (2a,b) should be updated with operational and test performance criteria by the end users, and be presented as requests to the researchers and manufacturers.

5. Thus, it should also be investigated whether it is possible to develop international criteria for test facilities and test performance.

6. The end users criteria should form the basis for future development of remote gas detection technologies.

7. The end users criteria's should be distributed to researchers and manufacturers of Remote Sensing technologies to be used as a guideline for future development of accurate and cost-efficient remote gas detection technologies according to the end users need.

8. The selected and evaluated technologies presented in this report should be used as a guideline to point out the direction of technology development appointed by the working and reference group.

   In order to use the selected technologies as guidelines for future technology development it is necessary to execute a second very strict and selective evaluation of the remaining technologies, leaving out "vague" systems and theoretical concepts in order to extract only those technologies best satisfying the project goal for development according to the end users criteria's. Here one should also consider **Environment applications**.

9. The development of remote gas detection technologies should be performed during free market competition, and the system developed should be tested according to criteria of system properties required, accuracy, stability, cost-efficiency, and field performances stated by the working group and the reference group, according to the end users needs. This performance requires international prioritised criteria to be developed.

5. Recommendations of system, weather & radiation, test facility, and test performance criteria

None of the technologies and systems selected and evaluated are sufficiently tested according to the end users needs expressed by for instance the criteria in table 2a,b. In order to compare and evaluate the accuracy, stability, and field operation performances of remote gas detection technologies for specific applications, it is necessary to develop adequate **system criteria**, **weather and radiation criteria, test facility criteria**, and test **performance criteria**. The system criteria should be used to point out the technical specifications requested for the different applications by the end user. The tests should be performed according to international criteria for field test facilities and test performances. The technologies developed and tested according to these criteria could then be compared to one another, and the potential end user could rely on that the results from the tests meet the requests for the specific application, and fulfil the technical specification of the specific system.

The international working group has to suggest system, weather and radiation, test facility and test performance criteria which meet the operational requests of the end users, for different applications. **The criteria presented in table 2a,b are examples of system criteria**, suggested by the international working group. Remains to work out similar evaluation criteria for weather and radiation conditions test facility and test performance factors suggested below.

System Factors - Criteria:

The system factors below are given values representing the end users request of **system criteria** used to evaluate and compare the selected systems according to end users needs, presented in table 2 a-b.

Each technology selected from the technical reports of the international survey tells what system criteria they can work at to date. The system factors are listed as follows:

- Gas detection sensitivity (plume - ppm-m, leak rate - scf/hr or l/m)
- Confidence level at detection
- False alarm rate
- Range
- Detection rate, including analysis (area per unit time; measurement points per unit time)
- Field-of-view, spatial resolution (for imaging or mapping systems)
- Size, weight, power requirements
- Method of deployment (vehicle, man-portable, airborne, etc.)
- Safety issues

- Number of operators
- Cost of operation
- Cost of instrument
- Frequency of calibration needed
- Platform-associated effects (e.g. helicopter downdraft)

Weather and Radiation Parameters - Criteria:
In addition to the system criteria the following weather and radiation factors are suggested to be set values and represent the end users request for **weather and radiation criteria**:

- Surface-to-air temperature difference (ΔT, for passive gas detection)
- Wind speed at ground level
- Sensitivity to humidity/precipitation
- Sensitivity to background illumination (night vs. day)
- Dependence on ground radiometric properties (reflectivity, albedo, etc.)
- Effect of general meteorological conditions (cloud cover, ground temperature, etc.)

Test facility factors - criteria:
The test facilities should permit simulation of gas leak emissions at low ppm-levels (>3 ppm) from gas pipe lines above and buried in ground, for gas pump stations, gas transport vehicles, indoor industrial systems, landfill bodies, and for environmental applications, etc. It should be possible to perform the tests during controlled flow, pressure, weather and radiation conditions, etc. The test facility should also include continuos measurement of sun and sky radiation, ground surface temperature, and ambient temperature (for passive gas detection), relative humidity, wind speed & direction, etc. (for passive and active gas detection), executed before and during the gas test simulation & detection.

Below is suggested test facility factors to be set values and represent the end users request for **test facility criteria**.
Capability to measure the following parameters must be available:
- Temperature
- Wind-speed
- Gas concentration at a point
- Surface reflectivity and/or emissivity

Capability to control the following attributes of the gas release must be available:
- Depth of release (for below-ground leaks)
- Leak rate
- Plume geometry and concentration (for above-ground releases)
- Surface composition (soil, grass, etc.)

Physical features of a test facility
- Above-ground plume conditions to be controlled / measured
- Gas concentration
- Plume thickness
- Exit plume velocity
- Distance from nozzle

- Above-ground point-source leak conditions to be controlled / measured
- Leak rate
- Pipe internal pressure
- Below-ground leak conditions to be controlled / measured
- Leak rate
- Pipe internal pressure
- Measurements of surface concentrations as a function of surface position and height
- Conditions of soil environment
- Depth
- Soil type
- Moisture
- Packing density and methodology
- Area extent
- Nature of soil boundary (e.g., plastic wall)
- Temperature

Test Performance Factors - Criteria:
Testing of remote gas detection technologies should be performed according to the following international factors & criteria and procedures (see Table 2 a-b for end users needs):

Two types of tests are envisioned:
Tests against specified performance conditions
2. Side-by-side tests against existing technology (operated by neutral end-user)

(1) **Tests against specified performance conditions**
- Definition of detection (confidence level, signal-to-noise)
- Detection threshold (plume - ppm-m, leak rate - scf/hr or l/m) under a range of system and weather / radiation criteria specified above
- Known / unknown leak source searching capability

(2) **Side-by-side tests against existing technology (operated by neutral end-user)**
To be discussed and developed.

The advantages and limitations of the two types of tests envisioned should be carefully examined and evaluated by the working group before any decision is made about field test performance criteria & guidelines.

6. Conclusions

On the basis of the evaluation described above, the working group believes that some of the technologies selected and evaluated have the potential to become accurate, reliable, and cost-effective tools for remote detection of natural gas emission. However, none of the selected technologies have reached a level of performance desired by the end user. Some are technically mature, though not sufficiently tested for field operation; others are laboratory or system concepts with low technical maturity.

It is the opinion of the working group that the technologies selected in for example Table A, respectively table 6,7, and 10 show the highest potential for satisfying the applications of the end users, and should be supported for further development.

The working group recommend the establishment of uniformly-accepted test criteria. These will be used as a basis for objectively comparing the performance of candidate remote detection technologies and provide test results to the end-users to enable them to evaluate systems against their needs.

The working group also recommend the establishment of an international R&D-group to execute research of mutual interest of the end users.

7. Priority listing of selected technologies - table 6 - 18

Table 6 - 18 represent the result from a primary priority of 35 technologies selected from originally 59 technologies from the international survey. Each of the 35 technologies has been evaluated according to applications prioritised, and system performance criteria, established by the international working group (table 2a,b). Many of the technologies selected could be used for multi-purpose applications (table 3), and the same technology appears in different tables.

Table A, page 35, represent preliminary results from a second priority ranking of the technologies selected in order to point out technologies that are judged to have the potential for further development according to the end users needs.

Natural gas Applications **- End users priority of applications and performance criteria.**

Priority	**→**				**1**		**3**		**2**		**4**	
↓	**Performance categories & criteria:**	**Range**			**Detection (A) (priority/ limit)**	**Size of plume (m)**	**Mapping (B) priorities**		**Pinpointing (C) priorities**		**Measuring (D) priorities**	
	Applications:	**H**	**M**	**A**			**B**	**NB**	**B**	**NB**	**B**	**NB**
4	**1. Production**	**10 m**	**100 m**	**100-500 m**	**2,2 points 0,1 - 2 %**	**1**	**-**	**5**	**-**	**5**	**-**	**0**
2	**2. HP Transmission**	**-**	**-**	**50-500 m**	**3,4 points 10 - 500 ppm**	**0,5 - 2**	**5**	**-**	**4**	**-**	**-2**	**-**
1	**3. LP Distribution**	**30 m**	**5-30 m**	**-**	**3,6 points 1 - 10 ppm**	**0,1 - 1**	**5**	**-**	**3**	**-**	**4**	**-**
3	**4. LNG Storage**	**10 m**	**100 m**	**100-500 m**	**2,6 points 0.1 - 2 %**	**1**	**-**	**3**	**-**	**3**	**-**	**0**
3	**5 Indoor applications**	**5 m**	**--**	**-**	**2,6 points 0,06 - 5 l/h**	**0,1**	**-**	**-1**	**-**	**1**	**-**	**-5**

Table 2a. End users criteria's for evaluation and priorities of remote gas detection technologies for application 1 - 5, according to the judgements of the delegates of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998.

Definition of applications and performance categories:

Detection (A) = Detect the presence of a gas leak.
Mapping (B) = Area surveying of diffuse gas leaks and point sources.
Pinpointing (C) = Positioning of a gas leak source.
Measuring (D) = Measurement of gas leak concentration.

For all applications the following data shall apply:

- Detectability (signal/noise > 3)
- False call rate < 20 %

Abbreviations:
HP Transmission = High Pressure Transmission lines, **LP Distribution** = Low Pressure Distribution lines LNG Storage = Liquefied Natural Gas Storage.
Range: H = hand held, M = mobile, A = airborne
Priority levels: Very interested, 4 points, Interested, 3 points, Not really interested, 2 points, Uninterested, 1 point. The sum for each application is divided by 7, which is the number of the participants of the working group.

B = Buried pipe lines, **NB =** non buried pipe lines

The priorities within the categories: **Mapping** (B), **Pinpointing** (C), and **Measuring** (D) are internal priorities within these three categories and should not be compared with **Detection** (A) that has the highest priority. The priority levels of the three categories (B,C,D) are made from **yes** or **no-votes** including a total maximum of (7) points expressing the judgement of the seven delegates of the working group. For example a -1 vote for Mapping (B), Not Buried (NB) pipe lines means that 3 delegates gave 3-yes votes, while 4 delegates gave 4-no votes 3 - 4 = -1 points, etc
.

Biogas and Environment Applications **- End users priority of applications and performance criteria.**

Priority	**→**				**1**		**3**		**2**		**4**	
↓	**Performance categories & criteria:**	**Range**			**Detection (A) (priority/ limit)**	**Size of plume (m)**	**Mapping (B) priorities**		**Pinpointing (C) priorities**		**Measuring (D) priorities**	
	Applications:	**H**	**M**	**A**			**B**	**NB**	**B**	**NB**	**B**	**NB**
1	**1. Landfill**	**10 m**	**100-500 m**	**100-1000 m**	**10-500 ppm**	**0,1-1**	**High**	**-**	**High**	**-**	**Low**	**-**
3	**3. LP Distribution**	**30 m**	**5-30 m**	**-**	**10-500 ppm**	**0.1 , 1**	**5**	**-**	**3**	**-**	**4**	**-**
2	**5 Indoor applications**	**5 m**	**--**	**-**	**2,6 points 0,06 - 5 l/h**	**0,1**	**-**	**-1**	**-**	**1**	**-**	**-5**
	Applications:											
1-2	**7. Environment**	**5-30 m**	**5-100 m**	**100-1500 m**	**10-400* ppm**	**0.1-0.5**		**High**		**High**	**High**	**High**

**

Table 2b. End users criteria for evaluation and priorities of remote gas detection technologies for **landfill** application 1,3,5, according to the judgement by Jan-Erik Meijer NSR, Sweden, 05-06-1999. Respectively for **Environment** application, according to the judgement by Gretta Akopova, VNIIGAZ, GAZPROM. Both delegates of the international reference and working group. For definition of applications and performance categories, etc., see table 2a.

* Maximal permissible concentration CH_4 for residential area (in Russia).
Maximal permissible concentration CH_4 for industrial area (in Russia).

Report	System = S Tool = T Concept= C (Th)	Passive or Active P or A	Applicable to
A – 1	C	A	1, 4 - A
D – 1	S	P	1,2,4 -A
F – 4	S	P	1,4 - A,B,C
G – 4	S	A	1,4 - A
UK – 3	S	A	1, (4?) - A
J – 1	S	A	1,4 - A
J – 2	C (T)	A	5 -A,B,(C?)
J – 3	C (Th)	P	1,2,4 - A,(B?)
J – 4	C (T)	A	4 - A,B,C
J – 5	C (Th)	A	5 - A,B,C
J – 6	C (Th)	A	3 - A (costly to develop)
J – 7	C (T)	P & A	1,4 - A
J – 8	S	A	1,2 - A
R – 1	C (Th)	A	1,4 - A
R – 5	S	P & A	1,2,3,4 - A,B,C,D
R – 6	C (Th)	P	2.4 - D
R – 7	S	P & A	2, (3?) - D
R – 8	S	P	2 - D
R – 9	S	A	2 - D
SW – 1	S	P	1 to 5 -A to C (D?)
SW – 2	S	P	Same as SW - 1
T – 1	S	A	1,4 - A
US – 1	S	A	1 to 5 - A
US – 2	S	P	1,2,4 - A
US – 4	S	A	1 to 5 - A to C
US – 5	S	A	2 - A,B
US – 6	S	P	1,2,4 - A
US – 8	S	A	1,4,5 - A
US – 9	S	A	1,2,4 - A
US – 10	S	A	1,4,5 - A,B,C
US – 11	S	A	1,4 - A
US – 12	S	A	1,2,4 - A
US – 14	S	A	1,2,4 - A
US – 16	S	A	1,(4?) - A
US – 17	S	P	1,2,4 -A
Total 35 technologies	Passive = 10 Active = 22 Passive & Active = 3		

Table 3. Technologies selected and evaluated from the international survey, 1998. Notice! Additional technologies from Russia in a complementary table 3[1], below.

Report	System = S Tool = T Concept= C (Th)	Passive or Active P or A	Applicable to
R - 10	**S Multifunctional long-path laser gas analyser**	**A**	**1-4,6,7 - A,B,C,D**
R - 11	**S Coherent IR DIAL**	**A**	**1-4,6,7 - A,B,C,D**
R - 12	**S (T-?)**	**A**	**1-4,6,7 - A,B,C,D**
R - 13	**S Laser Methane Detector**	**P & A**	**1-4,6,7 - A,B,C,D**
R - 14	**S IAP Gas-Detection Spectral Instrument for System of Tomographic Absorption of Air Pollution in Industrial Area**	**P**	**1-4,6,7 - A,B,C,D**
R - 15	**S RIDIM - GAS**	**A**	**1-4,6,7 - A,B,C,D**

Table 3[1]. Additional reports/technologies submitted and evaluated by Gretta Akopova, VNIIGAZ, and GAZPROM. The technologies R-10 --R-15 have not yet been evaluated by the working group and is therefore not commented in the evaluation chapter in the report.

Application	Technologies - Applications	Priority points
1.Production	**27**	**2.2**
2.HP Transmission	**16**	**3.4**
3.LP Distribution	**6**	**3.6**
4.LNG storage	**26**	**2.5**
5.Indoor applications	**8**	**2.6**
6.Landfill bodies	**8****	**-**
7.Environment	**31****	**-**
Total:	**35 technologies => 83 applications**	

Table 4. The original 35 selected & evaluated technologies could be used for 83 different applications & performance categories.

Notice that the highest ranking performance category & application Detection (A) of gas emissions from (3) LP Distribution with 3.6 score has only 6 selected technologies. While both Detection (A) for (1) Production, and (2) LNG Storage with the lowest priority score have the highest amount of technologies selected.

* 8 technologies which apply to **6. Landfill bodies** applications.

** 31 technologies which apply to **7. Environment** applications (including 5 additional Russian technologies (R-10 - R14), not yet evaluated.

System = S System Tool = ST Concept Tool = C T Concept System = C S Concept Theoretical = C Th	**A = Detection**	**B = Mapping**	**C = Pinpointing**	**D = Measuring**
P = Passive, A = Active, P&A = Passive & Active				
1. Production	**S = 8 P S = 15 A S = 2 P&A CT = 1 P&A C Th = 1 P C Th = 1 A**	**C Th = 1 (?) S = 6 A**		**S = 1 P&A S = 1 P (?)**
2. HP Transmission	**S = 6 P S = 8 A S = 1 P&A C Th =1 P (?)**	**S = 2 P S = 2 A S = 1 P&A C Th = 1 P**	**S = 2 P S = 1 A S = 1 P&A**	**S = 1 P (?) S = 1 P&A**
3. LP Distribution	**S = 3 P S = 1 A S = 1 P&A C Th = 1 A**	**S = 2 P S = 1 A S = 1 P&A**	**S = 2 P S = 1 A S = 1 P&A**	**S = 1 P (?) S = 1 P&A**
4. LNG Storage	**S = 6 P S = 15 A (3?) S = 1 P&A C T = 1 A C T = 1 P&A C Th = 1 A C Th = 1 P**	**S = 3 P S = 2 A S = 1 P&A CT = 1 A Cth = 1 P (?)**	**S = 1 P S = 1 A S = 1 P&A C T = 1 A**	**S = 1 P (?) S = 1 P&A**
5. Indoor applications	**S = 2 P S = 4 A C Th = 1 A CT = 1 A**	**S = 2 P S = 2 A C T = 1 A C Th = 1 A**	**S = 2 P S = 2 A C T = 1 A (?) C Th = 1 A**	**S = 1 P (?)**
6. Landfill bodies				
7. Environment				

Table 5. Technologies classified & prioritised according to applications, and recording categories

Natural and *biogas applications* - a selection of technologies for further development, Table A (selection criteria, see table 2a).

Multi-applications (See Table 3)	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3			
		H	M	A			Concept (Th)	System laboratory	System	Commercial system
1,4-A,B,C	France 4 (F-4) Passive - IR+filters	Stationary	-	-	<0.5 % m	-			2	
1,4-A	Germany 4 (G-4) dDIM=Compact diode-laser	100 m Portable	-	-	not specified	-			2	
5-A,B (C?)	Japan 2 (J2) Frequency-modulated diode-laser	5 m	-	-	10 ppm-m				2 ?	
1,2,4-A (B?)	Japan 3 (J-3) Passive - IR	-	-	500 m	0,1 %-m	1	0			
4-A,B,C	Japan 4 (J-4) 3-D photo-acoustic technique	Stationary 10 m	-	-	1 %	1 cm	0 ?			
5-A,B,C	Japan 5 (J-5) Active OPO	Portable 5 m	-	-	10 ppm-m	10 cm	0			
1,2,3,4-A, B,C,D	Russia 5 (R-5) Laser + IR	-	≤1000 m	≤1000 m	1 ppm	-			2	
1,2,3,4,5-A, B,C (D?)	Sweden 1 (SW-1) IR-spectrometry	depending	on telescope	adoption	to be evaluated	-			2	
1,2,3,4,5-A, B,C (D?)	Sweden 2 (SW-2) Passive - IR	5-100 m	5-100 m	30-100 m	to be evaluated	≤1 m			2	2
1,2,3,4,5-A	USA 1 (US-1) JPL continuos-wave laser scanner	-	15-1000 m	-	3 ppm-m	-			(2)	
1,2,3,4,5-A,B,C	USA 4 (US-4) Pulsed Laser-IR 3 -3,5 μm	-	70-80 m (40-50 m)	-	16-22 ppm-m for dual-wavelength	-			2	2
2-A,B	USA 5 (US-5) Airborne DIAL (ELM-LIDAR)	-	-	500-700 m	methane ?	-			2	
1,4,5-A	USA 8 (US-8) LIDAR	500 m	-	-	5 ppm in 30m long range resolution element	-			2 (military)	
1,2,4-A	USA 9 (US-9) LIDAR II-airborne	-	-	2,5 km	1 ppm-m in a 5-m gas plume width	-			2 (military)	
1,4,5-A,B,C	USA 10 (US-10) Active - Laser-IR (TG-5, TG-20, MG-30)	1-30 m	1-30 m	-	1 - 5000 kgm/yr; gas dependent	-			2	2

Table A.Natural gas applications. Examples of technologies evaluated and prioritised for further development for remote gas detection for the high ranked applications, and performance categories, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998**., see also table 6 - 18. Technical maturity levels: 0 = Concept = not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria**

Natural gas applications - Priority 1 for Application 3. LP Distribution and Detection (A), Table 6.

Application:	**Report/System**	**Range**			**Detection (A) (priority/ limit)**	**Size of plume (m)**	**Technical maturity = 0 - 3**				**Multi-applications (See Table 3)**
		H	**M**	**A**			**Concept (Th)**	**System laboratory**	**System**	**Commercial system**	
3. LP Distribution	**Japan 6 (J-6)**	**-**	**30 m**		**10 ppm-m**	**0.5 m**	**0**				**3-A**
	Russia 5 (R-5) Laser + IR	**-**	**≤1000 m**	**≤1000 m**	**1 ppm**	**-**			**2**		**1,2,3,4-A, B,C,D**
	Sweden 1 (SW-1) IR- spectrometry	**depending**	**on telescope**	**adoption**	**to be evaluated**	**-**			**2**		**1,2,3,4,5-A, B,C (D?)**
	Sweden 2 (SW-2) Passive - IR	**5-100 m**	**5-100 m**	**30-100 m**	**to be evaluated**	**≤1 m**			**2**	**2**	**1,2,3,4,5-A, B,C (D?)**
	USA 1 (US-1) LIDAR		**15-1000 m**		**3 ppm-m**	**-**		**1**	**(2)**		**1,4-A**
	USA 4 (US-4) Pulsed Laser-IR 3 -3,5 μm	**-**	**70-80 m (40-50 m)**	**-**	**16-22 ppm-m for dual-wavelength**	**-**			**2**	**2**	**1,2,3,4,5-A,B,C**

Table 6. Natural gas applications. Technologies evaluated and prioritised for further development for remote gas **Detection (A)** for the highest ranked application **3. LP Distribution**, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998**.**

Technical maturity levels: 0 = Concept = not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Natural gas applications - Priority 2 for Application 2. HP Transmission & Detection (A), Table 7.

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
		H	M	A			Concept (Th)	System laboratory	System	Commercial system	
2. HP Transmission	Japan 3 (J-3) IR - Helicopter mounted	-	-	500 m	0,1 %-m	1 m	0				1,2,4-A (B?)
	Japan 8 (J-8) LIDAR- gas correlation	Stationary 50 m	-	-	0,1 ppm-m	-		1			1,2-A
	Russia 5 (R-5) Laser + IR	-	≤1000 m	≤1000 m	1 ppm	-			2		1,2,3,4-A, B,C,D
	Sweden 1 (SW-1) IR- spectrometry	depending	on telescope	adoption	to be evaluated	-			2		1,2,3,4,5-A, B,C (D?)
	Sweden 2 (SW-2) Passive - IR	5-100 m	5-100 m	30-100 m	to be evaluated	≤1 m			2	2	1,2,3,4,5-A, B,C (D?)
	USA 1 (US-1) JPL continuos-wave laser scanner	-	1000 m	-	3 ppm-m	-			(2)		1,2,3,4,5-A
	USA 2 (US-2) FTIR-spectrometer	Stationary 5000 m	5000 m		10s-100s mg/m^2	-		1	(2)		1,2,4 - A
	USA 4 (US-4) Pulsed Laser-IR 3 -3,5 μm	-	70-80 m (40-50 m)	-	16-22 ppm-m for dual-wavelength	-			2	2	1,2,3,4,5-A,B,C
	USA 5 (US-5) Airborne DIAL (ELM-LIDAR)	-	-	500-700 m	methane ?	-			2		2-A,B
	USA 6 (US-6) FTIR spectrometer	-	-	>300 m ?	not established	-			2		1,2,4-A
	USA (US-8) LIDAR	500 m	-	-	5 ppm in 30m long range resolution element	-			2 (military)		1,4,5-A
	USA 9 (US-9) LIDAR II-airborne	-	-	2,5 km	1 ppm-m in a 5-m gas plume width	-			2 (military)		1,2,4-A

Natural gas applications - Priority 2 for Application 2. HP Transmission & Detection (A), Table 7, cont.

Application:	**Report/System**	**Range**			**Detection (A) (priority/ limit)**	**Size of plume (m)**	**Technical maturity = 0 - 3**				**Multi-applications (See Table 3)**
	USA 12 (US-12) DIAL-airborne	**-**	**-**	**3,0 km**	**100 ppm-m (0,1 ppm-km)**	**-**			**2 (military)**		**1,2,4-A**
	USA 14 (US-14) DIAL	**-**	**50 m**	**-**	**13 ppm-m**	**-**			**2**		**1,2,4-A**
	USA 17 (US-17) FTIR	**5-25 km stationary**	**5-25 km**	**5-25 km**	**0,5 ppm-m (for SF_6)**	**-**			**2**		**1,2,4-A**

Table 7. **Natural gas applications.** Technologies evaluated and prioritised for further development for remote gas **Detection (A)** for the second highest ranked application **2. HP Transmission**, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998**.**

Technical maturity levels: 0 = Concept = not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Natural gas applications - Priority 3* for Application 4. LNG Storage & Detection (A), Table 8.

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
		H	M	A			Concept (Th)	System laboratory	System	Commercial system	
3. LNG Storage	Australia 1 (A-1) LIDAR	Stationary? 20 - 100 m	-	-	0,2%-m estimated	-		1			1,4-A
	Denmark 1 (D-1) Acoustic detector	Stationary > 20 m	-	-	leaks > 1 mm	-			2		1,2,4-A
	France 4 (F-4) Passive - IR+filters	Stationary	-	-	<0.5 % m	-			2		1,4-A,B,C
	Germany 4 (G-4) dDIM=Compact Diode-laser	100 m Portable	-	-	not specified	-			2		1,4-A
	United Kingdom 3 (UK-3) LIDAR (DIAL)	-	1000 m	-	not specified	-			2		1, (4?)-A
	Japan 1 (J-1) DIAL	Stationary	-	-	300 m	30 m	0				1,4-A
	Japan 3 (J-3) IR - Helicopter mounted	-	500 m	-	0,1 %-m	1 m	0				1,2,4-A (B?)
	Japan 4 (J-4) 3-D photo-acoustic technique	Stationary 10 m	-	-	1 %	1 cm	0 ?				4-A,B,C
	Japan 7 (J-7) Active+passive	Portable ? -	-	-	not specified	-		1 ?			1,4-A
	Russia 5 (R-5) Laser + IR	-	≤1000 m	≤1000 m	1 ppm	-			2		1,2,3,4-A, B,C,D
	Sweden 1 (SW-1) IR-spectrometry	depending	on telescope	adoption	to be evaluated	-			2		1,2,3,4,5-A, B,C (D?)
	Sweden 2 (SW-2) Passive - IR	5-100 m	5-100 m	30-100 m	to be evaluated	≤1 m			2	2	1,2,3,4,5-A, B,C (D?)
	Taiwan 1 (T-1) FTIR	Stationary 160 - 800 m	-	-	?pbb?	-			2		1,4-A
	USA 1 (US-1) JPL continuos-wave laser scanner	-	1000 m	-	3 ppm-m	-			(2)		1,2,3,4,5-A
	USA 2 (US-2) FTIR-spectrometer	Stationary 5000 m	5000 m		10s-100s mg/m^2	-		1	(2)		1,2,4 - A

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
	USA 4 (US-4) **Pulsed Laser-IR** **3 -3,5 μm**	-	70-80 m (40-50 m)	-	16-22 ppm-m for dual-wavelength	-			2	2	1,2,3,4,5-A,B,C
	USA 5 (US-5) **Airborne DIAL (ELM-LIDAR)**	-	-	500-700 m	methane ?	-			2		2-A,B
	USA 6 (US-6) **FTIR spectrometer**	-	-	>300 m?	not established	-			2		1,2,4-A
	USA (US-8) **LIDAR**	500 m	-	-	5 ppm in 30m long range resolution element	-			2 (military)		1,4,5-A
	USA 9 (US-9) **LIDAR II-airborne**	-	-	2,5 km	1 ppm-m in a 5-m gas plume width	-			2 (military)		1,2,4-A
	USA 10 (US-10) **Active - Laser-IR** **(TG-5, TG-20, MG-30)**	1-30 m	1-30 m	-	1 - 5000 kgm/yr; gas dependent	-			2	2	1,4,5-A,B,C
	USA 11 (US-11) **Laser-near-IR**	1 - 1000 m Stationary	1 - 1000 m	-	2,0 ppm-m	-				2	1,4-A
	USA 12 (US-12) **DIAL-airborne**	-	-	3,0 km	100 ppm-m (0,1 ppm-km)	-			2 (military)		1,2,4-A
	USA 14 (US-14) **DIAL**	-	50 m	-	13 ppm-m	-			2		1,2,4-A
	USA 16 (US-16) **Raman Lidar**	100 - 1000 m	-	-	2 - 20 % in air	-			2		1, (4?)-A
	USA 17 (US-17) **FTIR**	5-25 km stationary	5-25 km	5-25 km	0,5 ppm-m (for SF_6)	-			2		1,2,4-A

Table 8. Natural gas applications. Technologies evaluated and prioritised for further development for remote gas **Detection (A)** for the third* ranked application **4. LNG Storage**, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998**.** **(* same ranking as for 5. Indoor applications)**

Technical maturity levels: 0 = Concept - not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Notice! **Detection (A)** of natural gas emissions for the lowest ranked application, **1. Production** has almost the same technologies & performance criteria selected as for Priority 3 **= 3. LNG Storage & Detection (A),** excluding the technologies Japan 5 and 6, presented in table 9.

Natural gas applications - Priority 4 for Application 1. Production & Detection (A), Table 9.

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
		H	M	A			Concept (Th)	System laboratory	System	Commercial system	
1. Production	Australia 1 (A-1) LIDAR	Stationary? 20 - 100 m	-	-	0,2%-m estimated	-		1			1,4-A
	Denmark 1 (D-1) Acoustic detector	Stationary > 20 m	-	-	leaks > 1 mm	-			2		1,2,4-A
	France 4 (F-4) Passive - IR+filters	Stationary	-	-	<0.5 % m	-			2		1,4-A,B,C
	Germany 4 (G-4) dDIM=Compact Diode-laser	100 m Portable	-	-	not specified	-			2		1,4-A
	United Kingdom 3 (UK-3) LIDAR (DIAL)	-	1000 m	-	not specified	-			2		1, (4?)-A
	Japan 1 (J-1) DIAL	Stationary	-	-	300 m	30 m	0				1,4-A
	Japan 2 (J2) Frequency-modulated diode-laser	5 m	-	-	10 ppm-m				2 ?		5-A,B (C?)
	Japan 3 (J-3) IR - Helicopter mounted	-	500 m	-	0,1 %-m	1 m	0				1,2,4-A (B?)
	Japan 7 (J-7) Active+passive	Portable? -	-	-	not specified	-		1 ?			1,4-A
	Japan 8 (J-8) LIDAR- gas correlation	Stationary 50 m	-	-	0,1 ppm-m	-		1			1,2-A
	Russia 1 (R-1) IR-tunable opt. parametric oscillator	-	1000 m	1000 m	1 ppm-m	-			2		1,4-A
	Russia 5 (R-5) Laser + IR	-	≤1000 m	≤1000 m	1 ppm	-			2		1,2,3,4-A, B,C,D
	Sweden 1 (SW-1) IR-spectrometry	depending	on telescope	adoption	to be evaluated	-			2		1,2,3,4,5-A, B,C (D?)
	Sweden 2 (SW-2) Passive - IR	5-100 m	5-100 m	30-100 m	to be evaluated	≤1 m			2		1,2,3,4,5-A, B,C (D?)

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
	Taiwan 1 (T-1) **FTIR**	**Stationary 160 - 800 m**	**-**	**-**	**?pbb?**	**-**			**2**		**1,4-A**
	USA 1 (US-1) **JPL continuos-wave laser scanner**	**-**	**1000 m**	**-**	**3 ppm-m**	**-**			**(2)**		**1,2,3,4,5-A**
	USA 2 (US-2) FTIR-spectrometer	**Stationary 5000 m**	**5000 m**		**10s-100s mg/m²**	**-**		**1**	**(2)**		**1,2,4 - A**
	USA 4 (US-4) **Pulsed Laser-IR** **3 -3,5 μm**	**-**	**70-80 m (40-50 m)**	**-**	**16-22 ppm-m for dual-wavelength**	**-**			**2**	**2**	**1,2,3,4,5-A,B,C**
	USA 6 (US-6) **FTIR spectrometer**	**-**	**-**	**>300 m ?**	**not established**	**-**			**2**		**1,2,4-A**
	USA 8 (US-8) **LIDAR**	**500 m**	**-**	**-**	**5 ppm in 30m long range reso-lution element**	**-**			**2 (military)**		**1,4,5-A**
	USA 9 (US-9) **LIDAR II-airborne**	**-**	**-**	**2,5 km**	**1 ppm-m in a 5-m gas plume width**	**-**			**2 (military)**		**1,2,4-A**
	USA 10 (US-10) **Active - Laser-IR** **(TG-5, TG-20, MG-30)**	**1-30 m**	**1-30 m**	**-**	**1 - 5000 kgm/yr; gas dependent**	**-**			**2**	**2**	**1,4,5-A,B,C**
	USA 11 (US-11) **Laser-near-IR**	**1 - 1000 m Stationary**	**1 - 1000 m**	**-**	**2,0 ppm-m**	**-**				**2**	**1,4-A**
	USA 12 (US-12) **DIAL-airborne**	**-**	**-**	**3,0 km**	**100 ppm-m (0,1 ppm-km)**	**-**			**2 (military)**		**1,2,4-A**
	USA 14 (US-14) **DIAL**	**-**	**50 m**	**-**	**13 ppm-m**	**-**			**2**		**1,2,4-A**
	USA 16 (US-16) **Raman Lidar**	**100 - 1000 m**	**-**	**-**	**2 - 20 % in air**	**-**			**2**		**1, (4?)-A**
	USA 17 (US-17) **FTIR**	**5-25 km stationary**	**5-25 km**	**5-25 km**	**0,5 ppm-m (for SF_6)**	**-**			**2**		**1,2,4-A**

Table 9. Natural gas applications. Technologies evaluated and prioritised for further development for remote gas **Detection (A)** for the lowest ranked (4) application **1. Production**, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998**.**

Technical maturity levels: 0 = Concept - not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Natural gas applications - Priority 1 for Application 3. LP Distribution & Mapping (B), and Pinpointing (C). Table 10.

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
		H	M	A			Concept (Th)	System laboratory	System	Commercial system	
3. LP Distribution	Russia 5 (R-5) Laser + IR	-	≤1000 m	≤1000 m	1 ppm	-			2		1,2,3,4-A, B,C,D
	Sweden 1 (SW-1) IR- spectrometry	depending	on telescope	adoption	to be evaluated	-			2		1,2,3,4,5-A, B,C (D?)
	Sweden 2 (SW-2) Passive - IR	5-100 m	5-100 m	30-100 m	to be evaluated	≤1 m			2	2	1,2,3,4,5-A, B,C (D?)
	USA 4 (US-4) Pulsed Laser-IR 3 -3,5 μm	-	70-80 m (40-50 m)	-	16-22 ppm-m for dual-wavelength	-			2	2	1,2,3,4,5-A,B,C

Table 10. **Natural gas applications.** Technologies evaluated and prioritised for further development for remote gas **Mapping (B), and Pinpointing (C)** for the highest ranked application.
3. LP Distribution, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998**.**

Technical maturity levels: 0 = Concept = not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Natural gas applications - Priority 2 for Application 2. HP Transmission & Mapping (B) and Pinpointing (C), Table 11.

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
		H	M	A			Concept (Th)	System laboratory	System	Commercial system	
2. HP Transmission	Japan 3 (J-3) Passive - IR	-	-	500 m	0,1 %-m	1	0				1,2,4-A (B?)
	Russia 5 (R-5) Laser + IR	-	≤1000 m	≤1000 m	1 ppm	-			2		1,2,3,4-A, B,C,D
	Sweden 1 (SW-1) IR- spectrometry	depending	on telescope	adoption	to be evaluated	-			2		1,2,3,4,5-A, B,C (D?)
	Sweden 2 (SW-2) Passive - IR	5-100 m	5-100 m	30-100 m	to be evaluated	≤1 m			2	2	1,2,3,4,5-A, B,C (D?)
	USA 4 (US-4) Pulsed Laser-IR 3 -3,5 μm	-	70-80 m (40-50 m)	-	16-22 ppm-m for dual-wavelength	-			2	2	1,2,3,4,5-A,B,C
	USA 5 (US-5) Airborne DIAL (ELM-LIDAR)	-	-	500-700 m	methane ?	-			2		2-A,B

Table 11.Natural gas applications. Technologies evaluated and prioritised for further development for remote gas **Mapping (B),** and **Pinpointing (C)** for the second ranked application **2. HP Transmission**, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998**.**

Technical maturity levels: 0 = Concept = not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Natural gas applications - Priority 3 for Application 4. LNG Storage & Mapping (B) and Pinpointing (C), Table 12.

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
		H	M	A			Concept (Th)	System laboratory	System	Commercial system	
4. LNG Storage	France 4 (F-4) Passive - IR+filters	Stationary	-	-	<0.5 % m	-			2		1,4-A,B,C
	Japan 3 (J-3) Passive - IR	-	-	500 m	0,1 %-m	1	0				1,2,4-A (B?)
	Japan 4 (J-4) 3-D photo-acoustic technique	Stationary 10 m	-	-	1 %	1 cm	0 ?				4-A,B,C
	Russia 5 (R-5) Laser + IR	-	≤1000 m	≤1000 m	1 ppm	-			2		1,2,3,4-A, B,C,D
	Sweden 1 (SW-1) IR-spectrometry	depending	on telescope	adoption	to be evaluated	-			2		1,2,3,4,5-A, B,C (D?)
	Sweden 2 (SW-2) Passive - IR	5-100 m	5-100 m	30-100 m	to be evaluated	≤1 m			2	2	1,2,3,4,5-A, B,C (D?)
	USA 4 (US-4) Pulsed Laser-IR 3 -3,5 μm	-	70-80 m (40-50 m)	-	16-22 ppm-m for dual-wavelength	-			2	2	1,2,3,4,5-A,B,C
	USA 10 (US-10) Active - Laser-IR (TG-5, TG-20, MG-30)	1-30 m	1-30 m	-	1 - 5000 kgm/yr; gas dependent	-			2	2	1,4,5-A,B,C

Table 12.Natural gas applications. Technologies evaluated and prioritised for further development for remote gas **Mapping (B),** and **Pinpointing (C)** for the third ranked application **4. LNG Storage**, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998**.**

Technical maturity levels: 0 = Concept = not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Natural gas applications - Priority 3* for 5. Indoor applications & Detection (A), Table 13.

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
		H	M	A			Concept (Th)	System laboratory	System	Commercial system	
5. Indoor applications	Japan 2 (J2) Frequency-modulated diode-laser	5 m	-	-	10 ppm-m	-			2 ?		5-A,B (C?)
	Japan 5 (J-5) Active OPO	Portable 5 m	-	-	10 ppm-m	10 cm	0				5-A,B,C
	Sweden 1 (SW-1) IR-spectrometry	depending	on telescope	adoption	to be evaluated	-			2		1,2,3,4,5-A, B,C (D?)
	Sweden 2 (SW-2) Passive - IR	5-100 m	5-100 m	30-100 m	to be evaluated	≤1 m			2	2	1,2,3,4,5-A, B,C (D?)
	USA 1 (US-1) JPL continuos-wave laser scanner	-	1000 m	-	3 ppm-m	-			(2)		1,2,3,4,5-A
	USA 4 (US-4) Pulsed Laser-IR 3 -3,5 μm	-	70-80 m (40-50 m)	-	16-22 ppm-m for dual-wavelength	-			2	2	1,2,3,4,5-A,B,C
	USA 8 (US-8) LIDAR	500 m	-	-	5 ppm in 30m long range resolution element	-			2 (military)		1,4,5-A
	USA 10 (US-10) Active - Laser-IR (TG-5, TG-20, MG-30)	1-30 m	1-30 m	-	1 - 5000 kgm/yr; gas dependent	-			2	2	1,4,5-A,B,C

Table 13.Natural gas applications. Technologies evaluated and prioritised for further development for remote gas **Detection (A)** for the third* highest ranked application **5. Indoor applications**, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998 **(*same ranking as for 4. LNG Storage).**

Technical maturity levels: 0 = Concept = not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Natural gas applications - Priority 3 for 5. Indoor applications & Mapping (B) and Pinpointing (C), Table 14.

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
		H	M	A			Concept (Th)	System laboratory	System	Commercial system	
5. Indoor applications	Japan 2 (J2) Frequency-modulated diode-laser	5 m	-	-	10 ppm-m	-			2 ?		5-A,B (C?)
	Japan 5 (J-5) Active OPO	Portable 5 m	-	-	10 ppm-m	10 cm	0				5-A,B,C
	Sweden 1 (SW-1) IR-spectrometry	depending	on telescope	adoption	to be evaluated	-			2		1,2,3,4,5-A, B,C (D?)
	Sweden 2 (SW-2) Passive - IR	5-100 m	5-100 m	30-100 m	to be evaluated	≤1 m			2	2	1,2,3,4,5-A, B,C (D?)
	USA 4 (US-4) Pulsed Laser-IR 3 -3,5 μm	-	70-80 m (40-50 m)	-	16-22 ppm-m for dual-wavelength	-			2	2	1,2,3,4,5-A,B,C
	USA 10 (US-10) Active - Laser-IR (TG-5, TG-20, MG-30)	1-30 m	1-30 m	-	1 - 5000 kgm/yr; gas dependent	-			2	2	1,4,5-A,B,C

Table 14.Natural gas applications. Technologies evaluated and prioritised for further development for remote gas **Mapping (B)** and **Pinpointing (C)** for the third ranked application **5. Indoor applications**, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998**.**

Technical maturity levels: 0 = Concept = not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Natural gas applications - Priority 4 for Application 1. Production & Mapping (B) and Pinpointing (C), Table 15.

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
		H	M	A			Concept (Th)	System laboratory	System	Commercial system	
1. Production	France 4 (F-4) Passive - IR+filters	Stationary	-	-	<0.5 % m	-			2		1,4-A,B,C
	Japan 3 (J-3) Passive - IR	-	-	500 m	0,1 %-m	1	0				1,2,4-A (B?)
	Russia 5 (R-5) Laser + IR	-	≤1000 m	≤1000 m	1 ppm	-			2		1,2,3,4-A, B,C,D
	Sweden 1 (SW-1) IR-spectrometry	dependin g	on telescope	adoption	to be evaluated	-			2		1,2,3,4,5-A, B,C (D?)
	Sweden 2 (SW-2) Passive - IR	5-100 m	5-100 m	30-100 m	to be evaluated	≤1 m			2	2	1,2,3,4,5-A, B,C (D?)
	USA 4 (US-4) Pulsed Laser-IR 3 -3,5 μm	-	70-80 m (40-50 m)	-	16-22 ppm-m for dual-wavelength	-			2	2	1,2,3,4,5-A,B,C
	USA 10 (US-10) Active - Laser-IR (TG-5, TG-20, MG-30)	1-30 m	1-30 m	-	1 - 5000 kgm/yr; gas dependent	-			2	2	1,4,5-A,B,C

Table 15.Natural gas applications. Technologies evaluated and prioritised for further development for remote gas **Mapping (B),** and **Pinpointing (C)** for the lowest ranked (4) application **1. Production**, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998**.**

Technical maturity levels: 0 = Concept - not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

***Natural gas applications* - Priority:** **1 for Application 3. LP Distribution & Measuring (D), Table 16.**
2 -”- 2. HP Transmission -”-
3 -”- 4. LNG Storage -”-
3* -”- 5. Indoor Applications -”- *** Application 4 - 5. have the same ranking.**

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
		H	M	A			Concept (Th)	System laboratory	System	Commercial system	
3. LP Distribution	Russia 5 (R-5) Laser + IR	-	≤1000 m	≤1000 m	1 ppm	-			2		1,2,3,4-A, B,C,D
	Sweden 1 (SW-1) IR- spectrometry	depending	on telescope	adoption	to be evaluated	-			2		1,2,3,4,5-A, B,C (D?)

Table 16. **Natural gas applications.** Technologies evaluated and prioritised for further development for remote gas **Measuring (D)** for the highest ranked application **3. LP Distribution**, the second, third, and fourth ranking, **2. HP Transmission**, **4. LNG Storage**, and **5. Indoor Applications**, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998**.** Notice, for **5. Indoor applications** is selected only technology SW-1.

Technical maturity levels: 0 = Concept = not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Natural gas applications - Priority 4 for Application 1. Production & Measuring (D), Table 17.

Application:	**Report/System**	**Range**			**Detection (A) (priority/ limit)**	**Size of plume (m)**	**Technical maturity = 0 - 3**				**Multi-applications (See Table 3)**
		H	**M**	**A**			**Concept (Th)**	**System laboratory**	**System**	**Commercial system**	
1. Production	**Russia 5 (R-5)** **Laser + IR**	**-**	**≤1000 m**	**≤1000 m**	**1 ppm**	**-**			**2**		**1,2,3,4-A, B,C,D**
	Sweden 1 (SW-1) IR-spectrometry	**depending**	**on telescope**	**adoption**	**to be evaluated**	**-**			**2**		**1,2,3,4,5-A, B,C (D?)**
	Sweden 2 (SW-2) **Passive - IR**	**5-100 m**	**5-100 m**	**30-100 m**	**to be evaluated**	**≤1 m**			**2**	**2**	**1,2,3,4,5-A, B,C (D?)**
	USA 4 (US-4) **Pulsed Laser-IR** **3 -3,5 μm**	**-**	**70-80 m (40-50 m)**	**-**	**16-22 ppm-m for dual-wavelength**	**-**			**2**	**2**	**1,2,3,4,5-A,B,C**
	USA 10 (US-10) **Active - Laser-IR** **(TG-5, TG-20, MG-30)**	**1-30 m**	**1-30 m**	**-**	**1 - 5000 kgm/yr; gas dependent**	**-**			**2**	**2**	**1,4,5-A,B,C**

Table 17.Natural gas applications. Technologies evaluated and prioritised for further development for remote gas **Measuring (D)** for the lowest ranked (4) application **1. Production**, according to the judgements of the international reference and working group, Malmoe, Sweden 14 - 26th of September 1998.

Technical maturity levels: 0 = Concept - not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Biogas applications - Priorities for Detection (1), Mapping (B), Pinpointing (C), Measuring (D), Table 18.

Application:	Report/System	Range			Detection (A) (priority/ limit)	Size of plume (m)	Technical maturity = 0 - 3				Multi-applications (See Table 3)
		H	M	A			Concept (Th)	System laboratory	System	Commercial system	
1. Landfill	France 4 (F-4) Passive - IR+filters	Stationary	-	-	<0.5 % m	-			2		1,4-A,B,C
	Germany 4 (G-4) dDIM=Compact Diode-laser	100 m Portable	-	-	not specified	-			2		1,4-A
	Japan 5 (J-5) Active - OPO	5 m	-	-	10 ppm-m	1 cm	0				5-A,B,C
	Russia 5 (R-5) Laser + IR	-	≤1000 m	≤1000 m	1 ppm-m	-			2		1,2,3,4-A, B,C,D
	Sweden 1 (SW-1) IR-spectrometry	depending	on telescope	adoption	to be evaluated	-			2		1,2,3,4,5-A, B,C (D?)
	Sweden 2 (SW-2) Passive - IR	5-100 m	5-100 m	30-100 m	to be evaluated	≤1 m			2	2	1,2,3,4,5-A, B,C (D?)
	USA 4 (US-4) Pulsed Laser-IR 3 -3,5 μm	-	70-80 m (40-50 m)	-	16-22 ppm-m for dual-wavelength	-			2	2	1,2,3,4,5-A,B,C
	USA 1 (US-1) JPL continuos-wave laser scanner	-	1000 m	-	3 ppm-m	-			(2)		1,2,3,4,5-A
	USA 10 (US-10) Active - Laser-IR (TG-5, TG-20, MG-30)	1-30 m	1-30 m	-	1 - 5000 kgm/yr; gas dependent	-			2	2	1,4,5-A,B,C

Table 18. **Biogas applications.** Technologies evaluated and prioritised for further development for remote gas **Detection (A)**, **Mapping (B), Pinpointing (C),** and **Measuring (D) of 1. Landfills, 3. LP Distribution,** and **5. Indoor applications.**, according to the judgements by the Landfill representative of the international reference and working group, Jan-Erik Meijer, NSR, Helsingborg, Sweden 05-06-1999.

Definition of "Technical maturity" levels: 0 = Concept = not tested, 1 = Laboratory tests performed, 2 = Field tests performed, 3 = Meet the requests according to end users criteria.

Charter Outline: **Appendix 1.**

(charterl1)

The International Gas Detection Project

Define Problem:

Detection of natural gas emissions with traditional technologies provides inadequate coverage and is not cost-efficient.

Projects Goals:

The evaluation and prioritisation for future development of advanced remote sensing for detection of natural gas.

Remote sensing is taken to mean systems capable of detecting gaseous emissions at a distance from 5 m (15 feet) to 500 m (1500 feet).

Although the study will initially concentrate on methane gas, the technologies and methods developed are expected to be useful for other gases as well.

Furthermore the technologies developed, as a result of this project shall provide the tools necessary for accurate and cost-efficient gas detection for the end user.

The project goals will be achieved according to the following steps:

Step I Survey of the state-of-the-art of natural gas and methane detection technologies and methods.

A working group will be established to gather and evaluate current gas detection technologies. The working group shall consist of specialists in the various gas detection fields and the potential end users of these technologies.

When obtaining technology information working group members should keep the project goals in mind. Some simple guidelines are:

1. Purely theoretical concepts should receive less consideration.

2. Technologies of prime interest are:
   - Passive and active gas imaging
   - DIAL and LIDAR technologies
   - FTIR or DOAS technologies
   - Active and passive Line-Scan technologies

But other interesting technologies should also be considered. All relevant information should be copied and distributed to the working group members.

Step II Technology evaluation and selection

a) The working group shall establish evaluation criteria for the technologies of step 1.

Some examples of evaluation criteria might be:

- Gas detection sensitivity (concentration, leak rate.)
- Range
- Detection speed
- Field-of-view and resolution
- Size and weight (stationary or mobile platforms)
- Historical uses/applications
- Safety issues
- Reliability issues (accuracy, stability, repeatability, service life, etc.)
- Quantitative or Qualitative measurement capability

Note: There may be different criteria for the different end user applications

b) Based on these evaluation criteria the working group shall select those technologies best satisfying the project goal for development. The working group should be open to new technical approaches as well as to further development of current technologies; however, technology maturity and cost will be given high priority.

Recommendations of who is to be responsible for development of the selected technologies should be made by the working group. Special consideration shall be given to organisations in which state-of-the-art for each of the selected technologies resides.

A report summarising the evaluation criteria and technology development recommendations will be written by and distributed among the working group.

Step III Development of selected technologies and methods

Support of the development efforts will depend t he resources available. The results of the development efforts should be operational and cost-efficient technologies for the applications selected.

Step IV Testing of advantages and limitations of selected technologies and methods

The criteria's for the design of the test facilities and methods should be determined by the working group. These test criteria will be provided to the technology developers to be used as design goals.

The participants of the international projects should be informed of testing times and location, and invited to attend.

Step V Final results, evaluation and report

The working group will be responsible for the writing of a final report describing the development and test results for each technology application.

The final results should be documented in written report, video formats or as electronic storage. The final report will be distributed to all participants of the international project.

Time and Cost Schedule

Year	1997 1998 1999 2000 2001 ==>	$ Cost
Step 1.	---------	
Step 2	----	
Step 3	-------------	
Step 4	------------------	
Step 5.	---------------	

The time and cost schedule will be determined by the working group.

The share of the budget between the different potential end users organisations (GRI, SGC, etc.) must be determined. Possibilities to gain additional financial support should be investigated and discussed. Special attention should be paid to national and international sponsors.

Tasks and organisation for the International Gas Detection Research Group

Appendix 2. (gasiv984)

International Gas Detection Research Group

Chairman: Albert Teitsma, GRI

Working group elected:

- Gretta Akopova, GASPROM, Russia
- Sven-Åke Ljungberg, KTH-BMG, Sweden
- Tom Kulp, SNL, USA
- Hideo Tai, Tokyo Gas Ltd. Japan
- Albert Teitsma, GRI, USA

Working group tasks, according to ”Charter Outline”:

Step 1. Survey of the state-of-the-art of gas detection technology = the inventory project
Step 2. Technology evaluation and selection
Step 3. Development of selected technologies
Step 4. Testing of advantages and limitations of selected technologies and methods
Step 5. Final results, evaluation and report
Step 6. Time and cost schedule to be developed by the working group

The Inventory project, tasks and procedures

Responsible for the researching and gathering of information:

- **Sven-Åke Ljungberg:** Australia, New Zealand, China, Europe and the Baltic States Russia, the former Sovjetunion states, and the East European states
- **Gretta Akopova:** Russia, the former Sovjetunion states, the East European states, and the Arab States;
- **Hideo Tai:** Asia; except China
- **Tom Kulp:** North America and South America
- **Albert Teitsma:** GRI, Israel and Africa including South Africa.

Performance of gathering of information

Petra Andersson, Sven-Åke Ljungbergexcept for:

xxx
xxx
xxx
xxx

Responsible for classification and preliminary analysis of gathered information:
Petra Andersson, KTH-BMG

Co-ordinator and supervisor of the inventory project: Sven-Åke Ljungberg, KTH-BMG

Responsible for development of evaluation criteria's, evaluation of information gathered, and for selection of technologies of prime interest: The representatives of the working group - according to step 1 and 2 in "Charter Outline"

The continuation according to "Charter Outline ", step 3 - 6 will be planned and performed after the investigation, evaluation and selection in step 1 and 2.

CONTENTS	
1	AUSTRALIA
2	DENMARK
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11	RUSSIA
12	SPAIN
13	SWEDEN
14	SWITZERLAND
15	TAIWAN
16	THE NETHERLANDS
17	USA
18	OTHER RELEVANT ARTICLES IN ALPHABETIC ORDER

Australia

Scott, J.C., Maddever, R.A.M. and Paton, A.T., "Spectroscopy of methane using a Nd:YAG laser at 1.34μm" Applied Optics, vol. 31, no.6, feb 1992. **Australia1**

Lancaster, D.G. and Dawes, J.M. "A pulsed laser source using stimulated Raman scattering and difference frequency mixing: remote sensing of methane in air" Optics Communications 120 (1995) 307-310. **Australia2**

Methane detection with a narrow-band source at 3.4μm based on a Nd:YAG pump laser and a combination of stimulated Raman scattering and difference frequency mixing" Applied Optics Vol.35, No.21, juli 1996. **Australia2**

Denmark

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Denmark 1

Overview
"The MM0100 uses the airborne ultrasonic acoustic technique for detecting leaks. The transducer provides a trip output, which is used to raise the alarm. The MM0100 reliably detects gas leaks within a distance of up to 25 meters from the leak source, even in locations which may be subject to extreme weather conditions."

1. System identification
MM0100, An acoustic leak detector

2. Informant
Martin T. Olesen
Innova AirTech Instruments A/S
Energivej 30
2750 Ballerup
Denmark
Tel +45 44200100
Fax +45 44200101
E-mail mtolesen@innova.dk

3. Gases detected
All kinds of gases

4. Detection techniques
Ultrasound

5. Instrumental platform
Stationary

6. Gas detection sensitivity
Leaks > 1mm and pressure 10-200 bar

7. Range
"20 m or more" depending on the size of the leak.

8. Geometric resolution
Not applicable

9. Field of view
Not applicable

10. Detectionspeed
Not applicable

11. Size and weight
120*122*80 mm

12. Subsequent treatment of data needed
No

13. Intentional applications

Danish:"Detektoren er designet specielt til offshore industrien hvor man normalt arbejder med meget høje gastryk, og hvor installationerene of er uddendørs, og ofte mere eller mindre ubemanede. MM0100 "lytter" efter alle lyde i det ultrasoniske område og der skal helst være uhindret adgang i det område den installeres i. Ved praktiske tests på Nordsøen har det vist sig at MM0100 kan detektere en lækage fra en 3 mm huld i et system med omkring 80 bar, op til 20 meter væk!, hvor ingen af de eksisterende detektore på platforms komplekset reagerede!!. MM0100 er primært beregnet til højere gastryk da meget lave gastryk kun generere lidt ultralyd, og dette kan så vil interferere med eventuel baggrundsstøj. MM0100 er beregnet til stationær fast montage og ikke mobilt brug."
Free Translation: The detector is designed for the offshore industry where high gas pressures normally are used and the installations normally are outdoors and unmanned. MM0100 listen for all sounds in the ultrasonic area and it is preferred that there are no obstacles between the detector and the leak. At tests in the Northsea the MM0100 detected a leakage from a 3mm hole at 80 bar of pressure 20 meters away, no other detector reacted. MM0100 is primarily intended for high gas pressures since low pressures only result in a low level of ultrasound, which is difficult to distinguish from the background.

14. Application tested and evaluated

See above

15. Safety issues

No safety problems

16. Reliability issues

"No maintenance and reliable operation in hash outdoor installations"

17. Operational advantages and limitations

See above

18. Number of operators needed

"Virtually no maintenance"

19. Cost of operation

"Virtually no maintenance"   low cost

20. Cost of instrument

Not specified, but probably not to expensive

France

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France 4

Over view:

1. System identification name
TACIT

2. Informant name, postal address, phone, fax, e-mail, homepage
BERTIN:
Mailing address:
155, rue Louis Armand
Pôle d'activité d'Aix en Provence
BP 22000
13791 Aix en Provence CEDEX 3
FRANCE
Tél: +33 4 42 60 46 00
Fax: +33 4 42 60 00 13
Contact:
Laurence JUEN-GRENIER, ingénieur
Tél: +33 4 42 60 45 90

3. Gases detected
This system has been tested for propane, SF_6 and certainly toxic gases.
It should detect all hydrocarbons gases.

4. Detection techniques
It's a passive imaging system using an IR caméra and two filters.

5. Instrumental platform: stationary

6. Gas detection sensitivity
Propane: minimum concentration: 0.2%.m
SF6: 7 ppm.m

7. Range
?

8. Geometric resolution
? mrad

9. Field of view
?

10. Detectionspeed
Stationary system

11. Size and weight of instrument (mm and kg)
The system contains an IR camera Inframetrics 760BB and a computer PC 486.

12. Subsequent treatment of data needed
Treatment of three images
Response time: 30 s for a measurement

13. Intentional applications
Pollutants detection
Plants survey: security and maintenance

14. Application tested and evaluated
Tests has been realised:

- detection of SF6 in a city (see attached sheet, already sent)
- detection of propane in a refinery (SHELL, in France)

15. Safety issues for public, operator and environment
None (passive imaging)

16. Reliability issues
?

17. Operational advantages and limitations
Weather conditions: all the tests have been realised by a fine weather.
Response time: 30 s for a measurement

18. Number of operators needed
?

19. Cost of operation
?

20. Cost of instrument
(80 000 USD)

Germany

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Greece

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Ireland

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Italy

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Japan

For Japan we have seven reports, Japan 1-7 and one e-mail, Japan8

The literature search gave three papers

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Japan 1

Overview

1. System identification
Dial methane detection system

2. Informant
Dr. Kouyou Ikuta
ISEE, Kyushu University
E-mail: ikuta@laser.ed.kyushu-u.ac.jp

3. Gases detected
Methane

4. Detection techniques
DIAL
(Light source: Ti:Sapphire laser with Raman shifter (1.6 µm), or 1.6 µm OPO)

5. Instrumental platform
Stationary

6. Gas detection sensitivity
Sensitivity: 6000 ppm-m

7. Range
300 m

8. Geometric resolution
30 m

9. Field of view

10. Detectionspeed
1 sec

11. Size and weight

12. Subsequent treatment of data needed
Nothing

13. Intentional applications

14. Application tested and evaluated

15. Safety issues

16. Reliability issues

17. Operational advantages and limitations.

18. Number of operators needed

19. Cost of operation

20. Cost of instrument

Japan 2

Overview

1. System identification
Handy remote methane detector

2. Informant
Dr. Hideo Tai
Fundamental Technology Research Laboratory
Tokyo Gas Co., Ltd.
16-25, Shibaura 1-chome, Minato-ku
Tokyo 105-0023, Japan
Tel: +81-3-5484-4808
Fax: +81-3-3453-7583
E-mail: htai@tokyo-gas.co.jp

3. Gases detected
Methane

4. Detection techniques
Active remote methane detector
(Light source: frequency-modulated diode laser)

5. Instrumental platform
Portable

6. Gas detection sensitivity
Sensitivity: 10 ppm-m

7. Range
5 m

8. Geometric resolution

9. Field of view

10. Detectionspeed
0.1 sec

11. Size and weight
10cm*10cm*15cm, 2kg

12. Subsequent treatment of data needed
Nothing

13. Intentional applications
Discovery of a leakage point

14. Application tested and evaluated

No data

15. Safety issues

16. Reliability issues
No trouble in 5 years continuous operation

17. Operational advantages and limitations.

18. Number of operators needed
One operator needed

19. Cost of operation

20. Cost of instrument
5,000 USD?

Japan 3

Overview

1.System identification
Helicopter mounted methane-imagining system

2. Informant
Dr. Hideo Tai
The Japan Gas Association
15-21, Toranomon 1-chome, Minato-ku
Tokyo 105-0001, Japan
Tel: +81-3-3502-0113
Fax: +81-3-3502-0370
E-mail: htai@tokyo-gas.co.jp

3. Gases detected
Methane

4. Detection techniques
Passive methane imaging

5. Instrumental platform
Helicopter

6. Gas detection sensitivity
Sensitivity: 0.1 %-m

7. Range
500 m

8. Geometric resolution
1 m

9. Field of view
100 m* 100 m from 500m height

10. Detectionspeed
20 frames/s

11. Size and weight
50cm*50cm*50cm

12. Subsequent treatment of data needed
Nothing

13. Intentional applications
Discovery of a leakage point after big earthquake

14. Application tested and evaluated
No data

15. Safety issues

16. Reliability issues
No data

17. Operational advantages and limitations

18. Number of operators needed
One operator needed

19. Cost of operation

20. Cost of instrument
200,000 USD?

Japan 4

Overview

1. System identification
3-D measurement system by means of photo-acoustic technique

2. Informant
Dr. Makoto Ochiai
Toshiba Corporation, Nuclear Engineering Laboratory
8 Shinsugita-cho, Isogo-ku, Yokohama 235, Japan
Phone:+81-45-770-2373, Fax:+81-45-770-2308
E-mail: mak.ochiai@toshiba.co.jp

3. Gases detected
Methane

4. Detection techniques
3D measurement by photo-acoustic technique
(Light source: 1.3 µm OPO)

5. Instrumental platform
Stationary

6. Gas detection sensitivity
Sensitivity: 1 %

7. Range
10 m

8. Geometric resolution
1 cm

9. Field of view

10. Detectionspeed

11. Size and weight

12. Subsequent treatment of data needed

13. Intentional applications
Electric power plant

14. Application tested and evaluated

15. Safety issues

16. Reliability issues

17. Operational advantages and limitations.

18. Number of operators needed

19. Cost of operation

20. Cost of instrument

Japan 5

Overview

1. System identification
Portable methane imagining system

2. Informant
Dr. Hideo Tai
The Japan Gas Association
15-21, Toranomon 1-chome, Minato-ku
Tokyo 105-0001, Japan
Tel: +81-3-3502-0113
Fax: +81-3-3502-0370
E-mail: htai@tokyo-gas.co.jp

3. Gases detected
Methane

4. Detection techniques
Active methane imaging
(Light-source: Small size 3 μm OPO)

5. Instrumental platform
Portable

6. Gas detection sensitivity
sensitivity: 10 ppm-m

7. Range
5 m

8. Geometric resolution
1cm

9. Field of view

10. Detectionspeed
20 frames/s

11. Size and weight
20cm*20cm*5cm, less than 5kg

12. Subsequent treatment of data needed
Nothing

13. Intentional applications
Discovery of a leakage point

14. Application tested and evaluated

No data

15. Safety issues
Eye safety by scanning

16. Reliability issues
No data

17. Operational advantages and limitations

18. Number of operators needed
One operator needed

19. Cost of operation

20. Cost of instrument
30,000 USD?

Japan 6

Overview

1. System identification
Vehicle mounted remote methane detector

2. Informant
Dr. Hideo Tai
The Japan Gas Association
15-21, Toranomon 1-chome, Minato-ku
Tokyo 105-0001, Japan
Tel: +81-3-3502-0113
Fax: +81-3-3502-0370
E-mail: htai@tokyo-gas.co.jp

3. Gases detected
Methane

4. Detection techniques
DIAL with topographic targets
(Light-source: Narrow band 3 µm OPO)

5. Instrumental platform
Mounted on a small sized car

6. Gas detection sensitivity
Sensitivity: 10 ppm-m

7. Range
30 m

8. Geometric resolution
0.5 m along the pipeline

9. Field of view

10. Detectionspeed
40 km/h

11. Size and weight
1m*1m*1m, 100kg

12. Subsequent treatment of data needed
Display leakage point on the electrical map
Real time

13. Intentional applications
Leakage detection of buried pipelines

14. Application tested and evaluated
No data

15. Safety issues
Eye safety by scanning 20 Hz, 4 m

16. Reliability issues
No data

17. Operational advantages and limitations
Weather conditions, etc.

18. Number of operators needed
One operator needed

19. Cost of operation
3 cents/m

20. Cost of instrument
100,000 USD?

Japan 7

Overview:
Passive method using a commercially available infrared camera and an Active method using a HE-NE-laser or a white light source (SiC glowbar lamp). Different characteristics of the bandpass filter for the active and passive method.

1. System identification
Passive method using a commercially available infrared camera and an Active method using a HE-NE-laser or a white light source (SiC glowbar lamp).

2. Informant
Toshihide kanagawa, Hirofumi Ueda, Kohichi Sumida and Takeshi Nishio
Osaka Gas Co., Ltd, Japan
Paper: "Flammable Gas Imaging System Using Infrared Absorption", 1995 International Gas Research Conference, 99 539-548

3. Gases detected
Methane, Butane, Propane

4. Detection techniques
Active

5. Instrumental platform
Portable?

6. Gas detection sensitivity
Not specified

7. Range
not specified

8. Geometric resolution
Not specified

9. Field of view
Not specified

10. Detectionspeed
Not applicable

11. Size and weight
Not specified

12. Subsequent treatment of data needed
Real-time

13. Intentional applications
Not discussed

14. Application tested and evaluated
Simulated gas leakages up to 3 litters/minute were detected by the active methods, performance for the passive method depended on amount of background light. Monitor screen concentration variations due to gas concentration variations and background conditions could be distinguished.

15. Safety issues
Not discussed

16. Reliability issues
Not discussed

17. Operational advantages and limitations
Passive depend on background radiation

18. Number of operators needed
Not specified

19. Cost of operation
Not specified

20. Cost of instrument
Not specified

Japan 8

Owerview
Active, gas correlation long-path absorption LIDAR, for measurement of atmospheric methane as a greenhouse gas

1. System identification
Laser long-path absorption experimental system using a 3-micron all-solid-state optical parametric oscillator

2. Informant
Nobuo Sugimoto
National Institute for Environmental Studies
16-2 Onogawa, Tsukuba, Ibaraki 305-0053
Phone: +81-298-50-2459
Fax: +81-298-51-4732
E-mail: nsugimot@nies.go.jp

3. Gases detected
Methane

4. Detection techniques
Active, gas correlation long-path absorption LIDAR using a hard target (or a retroreflector)

5. Instrumental plattform
Stationary (experimental system)

6. Gas detection sensitivity
0.1 ppm

7. Range
50 m with a hard target

8. Geometric resolution
1 mrad

9. Field of view
1 mrad without a scanner

10. Detectionspeed
10s for 0.1 ppm sensitivity

11. Size and weight
2000 mm x 1000 mm x 1000 mm,100 kg (experimental system)

12. Subsequent treatment of data needed

13. Intentional applications
Measurement of atmospheric methane as a greenhouse gas

14. Application tested and evaluated
Sensitivity was tested in a laboratory experiment
Open pass experiment is being carried out

15. Safety issues
Eye-safe

16. Reliability issues

17. Operational advantages and limitations

18. Number of operators needed
One

19. Cost of operation

20. Cost of instrument
200,000 USD (experimental system)

Latvia

Arnolds Ubelis, Andris Leitass and Mãris Vitols, "Monitoring and analysis of air quality in Riga", SPIE 2506 pp319-329.

Russia

Nine faxes resulted in five reports, Russia 1-5 (four answers).
We got three-mail, Russia 6-8
Supplementary information is presented in Russia 9 - 15

Russia 1

Overview

1. System identification
Powerful Infrared tuneable optical parametric oscillator for hydrocarbons low concentration determination.

2. Informant
Prof.Yuri A. Bykovski,115409, Moscow, Kashirskoye sh.31,dept 25,
tel./fax (095) 323 90 66, mavr@pico.mephi.ru
Dr.Vadim B. Oshurko, 121357,Moscow,Initsiativnaya 7-2-4, tel/fax (095) 426 64 75, avb@phsearch.msk.ru
Andrew B.Karpiouk, 142717, Moscow region, Leninski district, Razvilka 26 - 44, tel. (095) 548 35 36

3. Gases detected
Demonstrated methane, water, benzene and other aromatic and aliphatic hydrocarbons; capable of detecting about 30 lines in infrared region of stretching (valence) vibration (and therefore these lines might be much easier and reliably identified and interpreted than in region about 10- 12 microns).

4. Detection techniques
This powerful tuneable source of infrared radiation (wavelengths 2-4 μm) with small divergency (10^{-3} rad) (energy per pulse is up to 100 mJ (single pulse mode) or 10 mJ 10 Hz, pulse duration 1 nsec) is used for active topographic backscatter lidar or long-path absorptional spectroscopic detection.

5. Instrumental platform
This equipment is proposed to be used in helicopter or aircraft lidar-systems.

6. Gas detection sensitivity
The detection sensitivity limits of low concentrations of hydrocarbons may be improved with increasing of the optical path throughout the sample. Infrared tuneable optical parametric oscillator has a small enough divergence (as mentioned above) and high intensity simultaneously. It gives the possibility to increase the optical path sufficiently, if compared with usual other laser sources. But the main advantage of this system is the possibility of wavelength tuning in the region stretching vibrations of the hydrocarbons. (The wavelength region can be easily scanned by simple rotation of crystal in cavity.) Therefore most of the aromatic as well as aliphatic hydrocarbons may be detected selectively. The sensitivity about 1 ppm was achieved in lab experiments.

7. Range
About 1000 m.

8. Geometric resolution
about 10 mrad.

9. Field-of-view
Same as geometrical resolution - there is a line-of-sight system.

10. Detection speed
Not stated.

11. Size and weight
Parametric oscillator unit - for 10 mJ at 10 Hz (without pump unit and detection unit) : Sizes - 400*350*250 mm, weight - 10 kg. An appropriate pump YAG:Nd source must give about 200 mJ/pulse of 1 ns.

12. Subsequent treatment of data needed
Two-channel digitizer mounted in computer. All necessary software is now in design.

13. Intentional applications
Methane leak detection in pipelines or other gas systems, other gases leakage, chemical analysis of unknown gas content, as powerful pump source for a series of fibre-optical sensors.

14. Application tested and evaluated
Helicopter backscatter lidar-system with this optical parametric oscillator was successfully tested in RAO “Gazprom”. As laboratory equipment this oscillator is continuously in use for the purposes of gas analysis with about 1 ppm sensitivity.

15. Safety issues for public, operator and environment
Optical parametric infrared oscillator radiation is likely eyesafe at lower intensities.

16. Reliability issues
The accuracy of correspondence of declared characteristics is near 90%, reliability is not yet tested.

17. Operation advantages and limitations -
Advantages - High sensitivity for selective hydrocarbons detection of both aromatic and aliphatic compounds, chemical content determination of gaseous products, simple construction (technically).
Limitations - Special pump system required.

18. Number of operators needed
Not specified.

19. Cost of operation
Not specified.

20. Cost of instrument
Not specified.

Russia 2

Overview

1. System identification
Interferometric system for gas deposits search and mapping by gravitation field characteristics.

2. Informant
Yuri A. Bykovski, 115409, Moscow, Kashirskoye sh.31, dept 25, tel./fax (095) 323 90 66, mavr@pico.mephi.ru
Vadim B. Oshurko, 121357,Moscow, Initsiativnaya 7-2-4, tel/fax (095) 426 64 75, avb@phsearch.msk.ru
Andrew B.Karpiouk, 142717, Moscow region, Leninski district, Razvilka 26 - 44, tel. (095) 548 35 36

3. Gases detected
System can detect only the average density of deposits content. Gas is not specified.

4. Detection techniques
Operation principles: external gravitation force or micro-acceleration causes the axial stretching or pressing of waveguides in three perpendicular fibre-optical Mach-Zander interferometers. These interferometers constitute three-dimensional Decart's system of co-ordinates in space. The direction and magnitude of external force may be calculated using a measured phase-shifts value.

5. Instrumental platform
Truck mounted ground experiment.

6. Gas detection sensitivity
This device was created for purposes of determination of gravitational forces vector direction in three-dimensional space as well as its magnitude in the range 10^{-6} - 1.5 G (where G = 9.8 m/sq.sec). Measurement accuracy: 10^{-6} G. Therefore the sensitivity depends of deposit size and depth (see table below). Ratio between densities of deposit's entire part and ground environment (~1500 kg/m^3) is about 0.1.

Deposit depth, m	500	1000	2000	5000	10 000
Deposit's volume, millions m^3	20	80	320	2000	8000
Deposit's size (diameter), m	70	100	130	210	300

7. Range
See table above

8. Geometric resolution
Not specified.

9. Field-of-view
Not specified.

10. Detection speed
Not specified.

11. Size and weight
Size (without computer unit): 800*800*800 mm, weight 20 kg.

12. Subsequent treatment of data needed
Not specified.

13. Intentional applications
Gas deposit search and mapping by gravitational field characteristics.

14. Application tested and evaluated
Not available.

15. Safety issues for public, operator and environment
Safe for all.

16. Reliability issues
Not available.

17. Operation advantages and limitations -
Advantages - Fast remote detection of new deposits and fast mapping of existing ones without drilling slits.
Limitations - Not selective for gas type. Depends on properties of ground.

18. Number of operations needed
1 or 2 operators assumed.

19. Cost of operation
Not specified

20. Cost of instrument
Not specified

Russia 3

Overview

1. System identification (name) - New MOS (metal-oxide-semiconductor) gas sensors for H_2, NO_2 and H_2S detection.

2. Informant (name, postal addresses, phone, fax, e-mail, homepage)
Yuri A. Bykovski, 115409, Moscow, Kashirskoye sh.31, dept 25, tel/fax (095) 323 90 66, mavr@pico.mephi.ru
Vadim B. Oshurko, 121357, Moscow, Initsiativnaya 7-2-4, tel/fax (095) 426 64 75, avb@phsearch.msk.ru
Andrew B.Karpiouk, 142717, Moscow region, Leninski district, Razvilka 26 - 44, tel (095) 548 35 36

3. Gases detected - Demonstrated hydrogen, nitrogen dioxide, sulphur dihydride. Some other gases might also be detected.

4. Detection techniques (passive, active, wavelength (μm), power (W), etc.)
Laser-based metal-oxide semiconductors (MOS) technology was especially developed for designing new gas sensors. These sensors are the passive system of continuous monitoring of listed gases. High sensitivity of sensors is provided by measurements of electrical capacity/transmittance of active element, which is sensitive to every listed gas separately. In this project a further development of sensors for detection of other gases is supposed.

5. Instrumental platform (stationary or mobile) - These gas sensors are the pocketsize units.

6. Gas detection sensitivity (concentration ppm and pathlength required)
Gas sensors based on MOS-structure have an excellent sensitivity and surprisingly high stability. Characteristic values of basic parameters of sensors are indicated below.
Basic performance:

- Limiting concentration (1 atm), %..........10^{-5} - 1,0 (for Í$_2$)
  10^{-6} - 10^{-4} (for H_2S)
  10^{-5} - 10^{-3} (for NO_2)
- Sensitivity, pf/ppm..................................2,0 (for H_2)
  40,0 (for H_2S)
  4,0 (for NO_2)
- Working temperatures, C^0.......................-50 ..+120 (for Í$_2$)
  -100 .. + 120 (for H_2S)
  -90 …+ 120 (for NO_2)
- Time of a measurement, s........................2 - 10
- Error of a measurement, less than (%)....... 10

All indicated performances (as well as technological processes) can be improved if necessary.

7. Range
An active element of sensor must be in contact with testing gas mixture.

8. Geometric resolution
Not available.

9. Field-of-view
Not available.

10. Detection speed
This sensor must be motionless during the time of a measurement indicated above.

11. Size and weight
Size of an active elements 10 mm õ 10 mm õ 5 mm, weight is less than one gram. The remote control unit - 100 mm õ 200 mm õ 50 mm.

12. Subsequent treatment of data needed
Not required.

13. Intentional application -
The main application is as a pocket detector for quantitative control of appropriate gas presence. These sensors can be also used as additional equipment in combination with any installation, which might be in contact with aggressive chemical medium (for example, H_2S).

14. Application tested and evaluated
All necessary tests have been successfully completed for each type of sensors. The characteristics indicated above were proved experimentally. During these tests the gas mixture with necessary concentrations was prepared and the temperature was varied. Error of the measurements was derived statistically.

15. Safety issues for public, operator and environment
No danger.

16. Reliability issues
Lifetime for each sensor is practically not limited. Stability in 5 % experimental error is guaranteed. No service required.

17. Operational advantages and limitations
- Advantages: always ready-to-work system, inexpensive, small size and weight; the combinations of sensors in one case is always possible; possibility of remote control. .
- Limitations: Each type of sensor's active element can detect only one type of gas.

18. Number of operators needed
Operators are not needed

19. Cost of operation (USD)
Not specified.

20. Cost of instrument (USD)
not specified.

Russia 4

Overview

1. System identification
Fibre-optical sensors for hydrocarbons detection.

2. Informant
Yuri A. Bykovski, 115409, Moscow, Kashirskoye sh.31, dept 25, tel./fax (095) 323 90 66, mavr@pico.mephi.ru
Vadim B. Oshurko, 121357,Moscow, Initsiativnaya 7-2-4, tel/fax (095) 426 64 75, avb@phsearch.msk.ru
Andrew B.Karpiouk, 142717, Moscow region, Leninski district, Razvilka 26 - 44, tel. (095) 548 35 36

3. Gases detected
The sensors are intended for a detection and localisation of gas leakage's in pipelines. Demonstrated methane sequence, aromatic and aliphatic substances due to source wavelength.

4. Detection techniques
Sensor device includes the system of coupled waveguides placed along pipeline, tunable infrared (or other) laser source (wavelength must be dependent on chosen gas). The coupling between two waveguides depends on absorption and refraction indices in media around the fibers. Hence the sensor can detect a chosen gas presence at fixed point along the pipeline by measuring of direct or inversed wave signal in coupled fibers.

5. Instrumental platform
Stationary: two fibres along pipeline (~ km) and single terminal (laser source+detector and computer monitor).

6. Gas detection sensitivity
Following performances may be realised: a threshold of sensitivity for methane - 0,01 % with pressure 1-10 atmospheres.

7. Range
Sensor keeps up gas presence when active element is in contact with gas. Max length of pipe is limited by the power of a laser source.

8. Geometric resolution
Not available

9. Field-of-view
Not available

10. Detection speed
Device is motionless.

11. Size and weight
Size depends on pipelength, weight is less than 0.01 kg by meter.

12. Subsequent treatment of data needed
The control equipment includes a source of laser pulse illumination with required wavelength, photodetector and signal processing unit for indication of a leakage.

13. Intentional applications
Specific applications mentioned include leakage detection of methane range, aromatic of aliphatic substances from natural gas leaks. Can be used generally for leakage detections on long pipelines

14. Application tested and evaluated
Not available.

15. Safety issues for public, operator and environment -
This system is likely not dangerous**.** Danger depends on laser source.

16. Reliability issues
Not applicable - experimental system.

17. Operation advantages and limitations -
Advantages - low cost (per kilometre), continuous monitoring for a long path of the pipeline from one terminal, fast response of a system, simplicity of installation and using, may be used in aggressive conditions: an aggressive chemical medium, force electromagnetic fields etc.
Limitations - losses in fiber waveguide is about 0.2 dB/km. A powerful illumination source is required.

18. Number of operations needed -
Not specified; assume 1 or 2

19. Cost of operation (USD)
Not specified.

20. Cost of instrument (USD)
Not specified.

Russia 5

Overview

1. System identification
Helicopter laser-thermovision complex

2. Informant
N_ Gaseconomika, Dr. P.G.Philippov: 107066, Moscow, St.Basmannaya., 20/8, tel. (095) -267-19-28, fax (095)-267-30-76, e-mail: pgfil@ch.ph.ras.ru

3. Gases detected
Methane, propane, butane and other light hydrocarbons, ammonia, else plus unit 10 volatile substances (HCl, H2CO and so on)

4. Detection techniques
Passive - active techniques

5. Instrumental platform
Mobile: helicopter or car

6. Gas detection sensitivity
For route 100 m:
methane - 1 ppm
propane - 2 ppm

7. Range
Operative range is from 200 m up to 1000 m depending of reflective target

8. Geometric resolution
Angle resolution
thermovision system - 10-3rad
laser system - 10-2rad

9. Field of view
Scanning angles, deg:
heading - +/-30
roll - +10 - -60

10. Detectionspeed
Up to 120 km/hour

11. Size and weight
1700*700*200 mm3 + 900*520*600 mm3, total weight - 170 kg

12. Subsequent treatment of data needed
Data processing is occur in real time with fixing information at PC and vidoerecorders

13. Intentional applications
Pre-industrial exploitation test

14. Application tested and evaluated
Laboratory, field and flight tests were made to determine mention above parameters

15. Safety issues
Full safety for operator and environment during exploitation

16. Reliability issues
The full time working period now is investigated

17. Operational advantages and limitations
Operator is used only PC for control of functional regime and getting of registered information

18. Number of operators needed
1

19. Cost of operation
10-15 $ US /km, including helicopter exploitation expenses

20. Cost of instrument
190 000 USD.

Russia 6

Overview
Passive permanent comparisons of inlet and outlet gas flow by computerised flowmeters and self-educated algorithms

1. System identification
System for gas leakage detection from gas pipeline on the basis of permanent comparison inlet and outlet gas flow.

2. Informant
127018, Russia Soviet Army 5, CNII AG, tel. (095) 9713033, 9712944,
Fax (095) 2819534, E-mail: karimov@microdin.ru

3. Gases detected
Anyone.

4. Detection techniques
Passive technology on the basis of permanent comparison of inlet and outlet gas flow by means of computerized gas flowmeters and self-educated algorithms.

5. Instrumental plattform
Stationary, mobile (aircraft, car, et cetera)

Stationary (posts for measuring gas flow, gas pressure and temperature, which are placed near compressors stations).

6. Gas detection sensitivity
Sensivity by determination of concentration (in *ppm*) and needed distance or velocity of leakage and demanded square
Not more then 0.1—1% of present gas flow (will be corrected by test results).

7. Range
Distance, area of function
They are determined by the pipeline's length (up to ~120 km). Typical allocation and distances are identical with compressor stations.

8. Geometric resolution
Instead of this parameter must be given accuracy of leakage coordinates determination by parameters of wave generated by leakage.

9. Field of view

10. Detectionspeed
Instead of this parameter may be given the time of reaction for leakage beginning (15–20 min).

11. Size and weight
Stationary devices for flow and pressure measurements and industrial computers equipments.

12. Subsequent treatment of data needed
Dates are delivered from computer output. Reports form may be arbitrary.

13. Intentional applications

14. Application tested and evaluated

15. Safety issues
Entirely safe.

16. Reliability issues

17. Operational advantages and limitations
Tests in the industry was not done.

18. Number of operators needed
Operator must interfere only by alarm signal, which system gives automatically.

19. Cost of operation
400,000 USD**?**

20. Cost of instrument

Approximately the cost of equipment for one part of gas pipeline with length 120km is 20,000—30,000 USD.

Russia 7

Overview
Airborne infrared and optical line-scan sensor integrated TV-camera (TVIRCam) for detection of thermal contrast, due to gas emissions from natural pipeline systems.

1. System identification
Passive technology:
Infrared and optical Line-Scan Sensor, GPS-GLONASS for geocoding imagery, PC for archivating GIS commpatible images.
After flight processing of IR Contrast and optical images by use GIS and archives of images

2. Informant
Non commercial organisation «Àssosiation of Converse enterprises «ÌIL-ECO»
President «Àssosiation of Converse enterprises «ÌIL-ECO» Ivan L. Mescheryakov
Information sours
8/1 Povarskaya str., 121069, Moscow
Contact telephones - (095) 290-0361
290-1029
290-4578, Doscotch Yaroslav,
Kovriznih Ludmila.

3. Gases detected
Transporting on a gas pipeline natural gas

4. Detection techniques
Passive, Integrated infrared and TV Camera (TVIRCam)
Active, Laser Fluorograph Sensor is in development to provide increasing of reliable of outflow identification Mobile, helicopter of a types Mi-8 or Mi-34

5. Instrumental plattform

6. Gas detection sensitivity

7. Range
Location of gas outflows only by detection of thermal contrasts.
Flight altitude H (req. Distanse) 50-1 000 m

Range is limited to range of carrier’s action - 300 km (along to the pipeline or across the monitoring area)

8. Geometric resolution
1 mrad (0,057°) or 0,001 H
Thermal resolution of TVIRCam; 0,3 K
Observation area of TVIRCam¸ 1 rad (or 1,2 H) in direction to a fly path 140-220 km/h

9. Field of view

10. Detectionspeed

11. Size and weight
Cylinder 180 mm, 1=380 mm (without installation equipment
3,5 kg (without installation equipment

12. Subsequent treatment of data needed
a) operative - during a flight time;
b) detailed analysis - at ground Unit with use image databases and updating image archives

13. Intentional applications
TVIRCam passes primary lab and field tests at that time (1998)

14. Application tested and evaluated
Environmental condition and mechanical tests, resolution tests

15. Safety issues
Safe

16. Reliability issues
Probability of non-failure work during 2 hours 0,97
Maintenance service - 1 time in a year

17. Operational advantages and limitations
The restrictions are not present

18. Number of operators needed
2 operators (the flight operators and the operator of ground Unit

19. Cost of operation
$ 800 000: (excluding cost of helicopter (carrier)).
Completion of developing activity have include:
- complete manufacturing of a system prototype;
- installation on a experimental carrier;
- execution a complex flight test over the gas pipeline
- adjusment of the technology and operating manuals.

20. Cost of instrument
56,000 USD
includes:
- TVIRCam – 20,000 USD
- On-board registration and software - 2,500 USD
- Equipment and software of ground Unit - 11,000 USD

Russia 8

Overview

1. System identification
(passive optical correlative spectrometer)

2. Informant
M.K.Shaykov, E.A. Chayanova, E.V. Ivanov. "New Technique and Correlation Spectrometer for remote Sensing of the NO_2 Content in the Atmosphere. "Institut atmospheric optical Sientifical Academium UdSSR "Atmospheric Optic" 1990. Vol.3, pp. 320-324 M.K.Shaykov. E-mail: evivanov.insk.ru. Tel: (095) 752-32-98.

3. Gases detected
SO_2, NO_2, CH_2O, CL_2, vapor J_2, in perspective CS_2, CH_4, Phenol. One instrument for each gas.

4. Detection techniques
Passive optical spectrometer for received an solar topographic or atmospheric scattered radiation at wavelengths 307-315 nm. For SO_2, 430-450 nm for NO_2, 330-360 nm for CH_2O, 300-400 nm for $CL_{2,}$ 1,7-2,7 mkm for CH_4,.

5. Instrumental platform: Any stationary or mobile platform

6. Gas detection sensitivity (concentration ppm and pathglength required)
Sensitivity for $NO_{2,}$ SO_2, - 1 ppm*m, for CH_2O - 10 ppm*m. For another gases not tested. Results of $NO_{2,}$ measurements by means the correlative spectrometers presented at the diamond ore quarry "Udachninsky" Sakha-Yakutia, when at 1995 year line-of-sight of spectrometer scanned from distant 1-2 km vertical distribution NO_2, Measurements of SO_2 and NO_2 was demonstrated at plumes of smoke-stock electric power stations and metallurgical factory.

7. Range.
The maximum distant of measurements is depended from meteorological condition and horizontal range sight and usually equivalent 3-5 km. For projected CH_4 spectrometer the distant measurements was estimated to 10-20 km.

8. Geometric resolution
Angle sight about 1-3 degree

9. Range
Range of sight is depended from a scanned device range

10. Detectionspeed
Time resolution about 1S

11. Size and weight
Size 300*150*60 mm. Weight 3 kg

12. Subsequent treatment of data needed
Application to rapid detection distribution and measurement average concentration air pollutant of gas

13. Intentional applications
Remote detection gas pollutant in the day-time

14. Application tested and evaluated
Sensitivity and measurements of spectrometer was checked at "Institute of Metrology name Mendeleeva" t.S.-Peterburg, with accuracy 20% by range 50-500 ppm* m.Certification Ò525 laboratory of "Investigation and certification clear gases"

15. Safety issues
Completely safety for public

16. Reliability issues
Stability sensitivity about 0,2 ppm* m/h. Guarantee life at laboratory condition 3 years, at field condition 1 year. Possible for automatic control.

17. Operational advantages and limitations
Small power - 5 Wall, lngh Sensitivity, small weight, rapid detection ans autonomous utilise for investigation ecological problem.

18. Number of operators needed
One operator

19. Cost of operation

20. Cost of instrument
5,500 USD

Russia 9

Overview

1. **System identification** – Multifunctional long-path laser gas analyser.

2. **Informant –** Zhitov Alexander N., Kholodnykh Alexandr I., Russian Academy of Science, Vernadski Institute of Geochemistry and Analytical Chemistry, Moscow 117975, Kosygin str. 19.
   Krasnikov V.V., Pshenichnikov M.S. Razumikhina T.B., Solomatin V.S., Kholodnykh A.I. " remote sounding of atmospherixc gases by means of laser IR spectrometer in spectral region near 3 μm with the resolution of 0.1 cm^{-1}". Optika Atmosfery (USSR), v.3, 436-443 (1990).
   Ivanov S.N., Novoderezhkin V.I., Panchenko V.Ya.,Solomatin V.S., Kholodnykh A.I. "Laser infrared spectrometer for atmosphere gas analysis and medicine", Optical Engineering, 33,N10 (1994).

3. **Gases detected –** CH_4, C_2H_6, C_3H_8 and others saturated and unsaturated hydrocarbons, nitrogen and carbon oxides, halogen halides, ammonia and other molecules with CH, OH, NH bands absorbing in 2.7 – 4.2 μm spectral region.

4. **Detection techniques –** The diagnostic is based on the long-path measurements of the IR transmittion spectra. The spectrum of pulsed IR radiation source is continiously tuned in the 2.7 – 4.2 μm spectral range with the spectral width of 0.1-0.2 cm^{-1} and pulse energy of 0.1 mJ. The optical path length is up to 1 km when the corner reflector is used.

5. **Instrumental platform –** The gas analyzer is mounted on the track "GAZ-66" and the measurement path is formed with corner retroreflector mounted outside.

6. **Gas detection sensitivity –** The signal to noise ratio is 10-20 for 1 km path length without average and this ratio is 100-200 for 1 min averaging time. Gas detection sensitivity depends on the signal to noise ratio and on the absorption sensitivity of the molecules on the analytical frequencies. For the path length of 1 km and absorption level of 10% the detection sensitivity is:

   CH_4 – $2*10^{-2}$ ppm (3086 cm^{-1})
   H_2CO - $4*10^{-2}$ ppm (2883 cm^{-1})
   HF - $2*10^{-2}$ ppm (4174 cm^{-1})
   N_2O - $50*10^{-2}$ ppm (2577 cm^{-1})
   C_2H_5OH - $5*10^{-2}$ ppm (2899 cm^{-1})
   $(CH_3)_2N_2H_2$ - $6*10^{-2}$ ppm (2775 cm^{-1})
   C_3H_8 - $90*10^{-2}$ ppm (2967 cm^{-1})
   HCl – $3*10^{-2}$ ppm (2799 cm^{-1})
   NH_3 - $7*10^{-2}$ ppm (3302 cm^{-1})
   CO - $7*10^{-2}$ ppm (2203 cm^{-1})
   N_2H_4 - $7*10^{-2}$ ppm (3332 cm^{-1})
   The analytical frequencies are chosen from the atmospheric transparency microwindows.

7. **Range (m) –** The measurements are done directing the laser beam to the corner retroreflector located at the distance up to 1 km from the truck.

8. **Geometric resolution (mrad) –** Geometric resolution is assumed to be equal to angle size of retroreflector, which is 0.2 mrad for 1 km distance.

9. **Field-of view –** Same as geometrical resolution. The gas analyzer is line of sight system.

10. **Detection speed –** Not explicitly stated. The minimum measurement time time is a few seconds for the one gas on the stationar path if it may be assumed, that that the absorption of other gases at the selected analytical frequency is absent.

11. **Size and weight (mm,kg) –**
    The laser spectrometer – 600*300*1500 mm, 30 kg
    Receiving telescope – 450*450*600mm, 15 kg
    Power block – 450*600*500 mm,30 kg
    Personal computer IBM PC

12. **Subsequent treatment of data needed –** Two- channel data are rationed and displayed in real-time with some electronic averaging, the gas concentration is calculated automatically.

13. **Intentional applications –** Specific applications mentioned include leak detection of methane and other gases from natural gas leaks and from landfills. Can be used generally for remote detection of the multycomponent gas leaks on the stationar pathes.

14. **Application tested and evaluated –** The gas analyzer is a experimental system now, but there are all reasons for the creation of upgraded system working with topographical reflectors instead of a corner reflector. This gas analyzer was used for long path monitoring of chemical composition of aircraft IL-86 exhaust in Moscow airport Vnukovo, chemical pollutants on the Voronezh chemical plant. It was also used for the measurements of the natural concentration of methane and water vapors in the atmosphere near the ship during the sea expedition on the Norway and North sea and during the expedition on Volga river. The pathlength used varied from 50 m up to 1 km and the sensitivity was as listed above.

15. **Safety issues for public, operator and environment –** Radiation of laser gas analyzer is eyesafe. The maximal energy density in the atmospheric part <1 mJ/cm^2.

16. **Reliability issues –** Laser gas analyzer is the automatic sytem and the operational mode is chosen by the operator from the PC keyboard. Data processing and results presentation is produced in real-time mode. The accuracy of concentration determination depends on gas concentration, path length, signal-noise ratio and other gases interference.
    When the background concentration of methane in atmosphere is studied the error doesn't exceed 10% level. The reliability of the system is determined by the reliability of solid state and dye lasers and the analyzer may be operated during several monthes without the change of the elements.

17. **Operational advantages and limitations –**
    Advantages – The possibility of remote analyses of multycomponent gas mixture with the high sensitivity, possibility of optimal choise of analytical frequencies for different conditions. Automatic mode of the measurements and data processing.
    Limitations – Necessity of use of corner reflector which doesn't allow to realize the angle scanning and vertical measurements.

18. **Number of operators needed –** 1.

19. **Cost of operation –** Determined by the operator salary, payment for the car and expenced for the expluatation of the laser.

20. **Cost of the instrument –** About 100,000 USD (without truck).

Russia 10

Overview

1. **System identification** – Coherent IR DIAL system.
2. **Informant –** Patent N2106658 on 29.12.1993
3. **Gases detected –** NH_3, hydrocarbons, freons and other gases absorbing in 9 – 11 μm spectral region. It is also possible to measure the speed of gas cloud in atmosphere.
4. **Detection techniques –** The diagnostic is based on the scattering of radiation of two single frequency cw CO_2 lasers by the atmospheric aerosol or topographic target. The signal detection is of heterodin type, the zero, first and second moments of Dopler spectrum are measured. The laser power is 6 W. When the aerosol scattering is used, the range resolution is realized by the radiation focusing.
5. **Instrumental platform –** Car, helicopter or airplane
6. **Gas detection sensitivity –** For the topographic target located at the distance of 100 m and receiving telescope aperture of 100 mm the signal to noise ratio is 10^6. For the aerosol scattering and the receiving telescope aperture of 400 mm the signal to noise ratio is 10^3.
7. **Range (km) –** The range depends on the atmosphere condition. It is 3-7 km for the topographic target and 1-3 km when the aerosol scattering is used.
8. **Geometric resolution (mrad)** – 1 mrad for 100 mm receiving telescope and 0.25 mrad for 400 mm telescope .
9. **Field-of view –** ± 30 degrees from the helicopter and the whole hemisphere for the ground based system.
10. **Detection speed –** The time of one measurement is 3 ms for topographic target and 30 ms for aerosol scattering.
11. **Size and weight (mm,kg) –**
    For topographic target – 600*250*250 mm, 30 kg
    For aerosol scattering – 800*600*500 mm, 120 kg
12. **Subsequent treatment of data needed –** Real-time data presentation.
13. **Intentional applications –** The system was developed for the Ministery of Extremal Situation, it is installed on a car and used for the wind measurements and ammonium detection. The system was also tested on helicopter for different altitudes and surface types.
14. **Application tested and evaluated –** The testing has demonstrated that the maximal distance of the sounding is at least 2 km for aerosol target and 4.5 km for helicopter based system.
15. **Safety issues for public, operator and environment –** Radiation of laser with 50 mm beam size is eyesafe.
16. **Reliability issues –** The may be operated without any parts replacement at least for 1000 hours.The error of wind velocity measurement – 0.5 m/c, wind direction – 10 grad, ammonium concentration – 20%.
17. **Operational advantages and limitations –**
    Advantages – Compactness, relatively low price, the possibility of remote analyses of multycomponent gas mixture with the high sensitivity, and gas flux measurement.
    Limitations – Low spatial resolution.
18. **Number of operators needed** – 1.
19. **Cost of operation –** not specified
20. **Cost of the instrument –** About 100.000$

Russia 11

Overview

1. **System identification** – Raman lidar.
2. **Informant –** Zhitov Alexandr N., Veselovskii Igor A.
   Physics Instrumentation Center of General Physics Institute, Troitsk, Moscow reg., 142092, Russia.
   I.Veselovskii, B.Barchunov "Excimer lasers based DIAL system for the tropospheric ozone studies", Appl.Phys.B, 1-7 (1999).
3. **Gases detected –** CH_4.
4. **Detection techniques –** Radiation sourse is XeCl excimer laser (308 nm) with output energy 30 mJ and repetition rate of 300 Hz. Raman signal from atmospheric methane is collected by 30 cm aperture telescope.
5. **Instrumental platform –** At a present the system is used in laboratory but it may be installed on a track.
6. **Gas detection sensitivity –** The system is capable to detect 1% of methane volume concentration in the atmosphere at the distance of 500 m from 50 m layer. Integration time is 2 seconds.
7. **Range (m) –** Up to 1 km.
8. **Geometric resolution (mrad) –** Geometric resolution is 0.5 mrad.
9. **Field-of view –** Same as geometrical resolution. The gas analyzer is line of sight system.
10. **Detection speed –** Not explicitly stated. The measurement time time is 2 seconds for 0.5 km distance and 1% methane concentration.
11. **Size and weight (m,kg) –** At a present 1*0.6*1 m, 100 kg.
12. **Subsequent treatment of data needed –** Data are rationed and displayed in real-time with some electronic averaging.
13. **Intentional applications –** Specific applications mentioned include leak detection of methane
14. **Application tested and evaluated –** The Raman lidar is a part of tropospheric ozone system where it is used for water vapor measurements. The system is in operation already during 2 years..
15. **Safety issues for public, operator and environment –** Radiation of laser is telescoped up to 200 mm and doesn't present danger for personal. But still it is danger for direct irradiation in the eye.
    Reliability issues – Not specified.
16. **Operational advantages and limitations –**
    Advantages – High spatial resolution, simple in operation, data are easy to process and no interference from other gases. No retroreflectors are needed.
    Limitations – Relatively low sensitivity.
17. **Number of operators needed –** 1.
18. **Cost of operation –** Determined by the operator salary, payment for the car and expenced for the expluatation of the laser.
19. **Cost of the instrument –** About 100.000$.

Russia 12

1. System Identification (name)

"IAP Gas-Detection Spectral Instrument for System of Tomographic Observations of Air Pollution in Industrial Area"

The proposed instrument is intended for using as an individual instrument or in a combination with other ones in an automated system for remote monitoring of polluted atmosphere over an industrial region. Its operation is based on a method of passive optical sounding. The spectral instruments scanning in the horizontal and vertical directions register the intensity of scattered solar radiation coming at different angles in the visible and UV spectral ranges. The radiation absorption within separate spectral bands gives information on the content of such impurities as nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), and aerosol.

These impurities can be measured simultaneously within a 5-km radius by one instrument. To determine the three-dimensional distribution of the impurities, several instruments are necessary. In connection with different extent of availability of the calculation algorithms and of the software of remote sounding, instruments of the system must be put into service one after another in turn. The first stage of the work is the creation of an automated system for tomographic monitoring of one of the key pollutants, namely, nitrogen dioxide. At the following stage, the instrumentation created will be used for O_3, SO_2, CO, and aerosol monitoring.

This monitoring system is based on techniques and software designed in the IAP RAS and used at the world network of atmospheric monitoring. The monitoring system is unique in the world.

2. Informant

Dr.Nikolai F.Elansky.
Institute of Atmospheric Physics of RAS. Russia

References:

Crutzen P.J., G.S.Golitsyn, N.F.Elansky, C.Brenninkmeijer, M.Hahn, D.Sharffe, A.M.Grisenko, V.V.Sevostyanov. Surface minor species concentration over Siberia. J.Atmos.Chemistry, 29, 179-194, 1998.

N.F.Elansky, I.V.Mitin, and O.V.Postylyakov. Maximum accuracy of Umkehr measurements of vertical ozone profiles. Izvestya Academii Nauk, Atmospheric and Oceanic Physics. Vol. 35, No 1, 1999, pp. 65-77.

N.F.Elansky, O.I. Smirnova. Concentration of ozone and nitrogendioxide in surface air of Moscow. Izvestya Academii Nauk, Atmospheric and Oceanic Physics, 1997, 33, _4, 1-15.

Elokhov A.S., Gruzdev A.N. Stratospheric and tropospheric NO2 at Zvenogorod scientific station: 6 years of observations. Proc.XVIII Quard.Ozone Symp., L'Aquaila, Italy, 12-21 Sept.1996.

Elokhov A.S., A.N. Gruzdev. Estimation of tropospheric and stratospheric NO_2 from spectrometric measurements of column NO_2 abundaces. SPIE, 1995, 2506, 444-453.

3. Gases detected

System tested for detection of NO2, O3, SO2 and aerosol concentration in the surface air. Could be applied for CH4, CO, traces of OClO and BrO.

4.Detection techniques

Passive measurement at visual and UV wavelength regions. Instrument measures scattered solar spectral radiance incoming from different direction of upper hemisphere. For retrieval three-dimensional distribution of pollution in the atmosphere the tomographic methods are used.

Nitrogen dioxide remote monitoring system

In the Institute of Atmospheric Physics RAS, a sensitive technique for the atmospheric NO_2 content monitoring is designed. This technique is based on atmospheric scattered solar radiation measurements. This technique is practically used by two IAP RAS scientific stations monitoring the NO_2 content in the stratosphere over Zvenigorod and Kislovodsk. These stations combined in a network together with several observation stations in the USA, Canada, France, and the New Zealand form the world network of atmospheric NO_2 monitoring.

On the basis of this technique, in the IAP RAS, concepts of a procedure and instrumentation for tomographic monitoring of the NO_2 content within the atmospheric boundary layer over cities, in industrial emissions, and in the vicinity of highways.

The concept of such a monitoring site includes measurements of the intensity of scattered radiation from different sky segments. The attenuation of radiation within the NO_2 absorption bands determines the NO_2 content on the beam path. An angular resolution of 1^o and quick space scanning characterizing the instrument give a possibility for a short-time registration of the NO_2 distribution within a 5-7 km radius over the observation site. The radius of sounding can be increased up to 10 km by using a system of the space-apart angle reflectors.

The instrument should be installed on an elevation to have a possibility for measuring the NO_2 content in the ambient air by the azimuth scanning from 0^o to 360^o with a step of 1^o and by the zenith scanning from 60^o to 90^o with a step of 5^o. The use of a diode rule as a sensor allows performance of a cycle of NO_2 measurements in all possible directions of sounding for a period from 4 to 15 minutes depending on the desired measurement accuracy.

Under conditions of moderate or good visibility, one instrument measures the azimuth and zenith NO_2 distributions over a rather large-scale industrial region. However, under conditions of dense haze, a distance of sounding can reduce to 2 km. Measurements from one point give no possibility for determination of the distance along the beam up to a source of NO_2 emission or up to some local area of its enhanced content.

A detailed three-dimensional design of the NO_2 distribution over an industrial region with a coordinate relation of all NO_2 sources can be obtained with several instruments by methods of the tomographic analysis. Such methods are developed in the IAP and are currently used for remote atmospheric sounding from space. These instruments transmit observational data to the center of processing and analysis. At this center, a design of distributions of key impurities over an industrial region under control is being constructed at the actual time-scale.

Instrumentation

The instrumentation is based on an optical spectrophotometer operating in the spectral range 300-480 nm. Space scanning is performed with a original computer-controlled unit. For programming the spectrophotometric measurements and for data processing, a computer is used. The instrument underwent repeatedly international calibrations. Its sensitivity is 3.0×10^{14} molecules of NO_2 along a direction of sounding at a storage time of 10 s. The computational algorithm takes into consideration all possible errors at the measurements of radiation, absorption of radiation by water vapor and oxygen compounds, and other side effects. Each individual measurement with no storage of a signal lasts for 0.1 s. To measure, with a standard error of 50%, the NO_2 concentration of 0.07 mg/m^3 that is the average one over the city of Moscow, a sounding length of 20 m is sufficient. If the NO_2 concentration exceeds the average one or the signal is measured with storage, the sounding length can be reduced or the accuracy of the measurements can be increased by an order of magnitude at a storage time of 10 s.

The above characteristics of the instrument and measuring procedure give a possibility for monitoring the NO_2 space field irregularities caused by local sources, such as gascompressor units, gas producing objects, smokestacks of industrial enterprises, highways, filter beds, etc. The instrumentation can be installed either at stationary or mobile observation points, for example, at cars, helicopters, etc. The stationary instrumentation operates in automatic regime.

5. Instrumental platform (specify carrier)

Tested as stationary ground and mobile instrument. It could be mounted at car, train or helicopter.

6. Gas detection sensitivity

NO2 - 0.01 ppm*km
O3 - 20 ppb*km
SO2 - 5ppb*km
CH4 - 0.2 ppm*km
CO - 0.02 ppm*km

7. Range (km)

Up to 5-7 km from instrument location.

8. Geometric resolution (mrad)

Angle resolution 0.5^{O}=9 mrad or more. Resolution of tomographic system depends on number of used instruments.

9. Field-of-view (degree)

0.5^{O}=9 mrad or more.

10. Detection speed (km/h)

Not specified, depend on necessary resolution, sensitivity and gas species. The single measurement for one direction <2s.

11. Size and weight

25 kg, 0.6m*0.6m*0.4m

12. Subsequent treatment of data needed

PC is used for instrument automatic control and data processing.

13. Intentional applications

The instrument and the tomographic system can be used together for monitoring of leakage and transfer of impurities within industrial areas, in the vicinity of gascompressor units, gas producing and gas using objects.

14. **Applications tested and evaluated**

Prototype of instrument was tested for observation of surface NO2 in Moscow. Prototype of instrument is used for regular measurements of vertical distribution of NO2, O3 and SO2 in troposphere and stratosphere from stationary ground-based station and in train expeditions. Data of measurements and instruments took part in international intercomparisons in Zvenigorod in September 1997, were successfully validated using space-based instruments. Prototype for stratospheric NO2 observations has the international certificate.

15. **Safety issues for public, operational and environment**

Instrument and used technology are purely safe for human and environment.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)

Accuracy - 5% of measured value, repeatability - 3%, life of instrument-more than 10 years.

17. Operational advantages and limitations

Advantages: System of instruments or one mobile instrument can present 3D tomographic map of pollution. Instrument could be modified for measurement of additional gas species.

Limitations: The instrumentation is valid for use in daylight time; for use during nighttime, additional light sources are necessary.

18. Number of operator need

1 hour*person/day

19. Cost of operation

1,000 USD/year

20. Cost of instrument

Estimated costs: 15,000 USD for instrument based on Russian spectrophotomere,
20,000 USD for instrument based Jobin-Ivan and etc. spectrophotomere.

Russia 13

1. System identification (name)

"Laser Methane Detector (LMD)"

LMD is based on using tunable diode laser as a source of infrared radiation absorbed by the detected gas. Instrument is capable to operate in nonstop mode under full computer control for several months. The LMD contains analytical and reference channels. Reference cell filled with nitrogen maintaining 1000 ppm of methane Analytical multi-pass cell filled with gas sample under investigation. Signals from both channels are recorded simultaneously. Signals from reference channel used as reference one in auto-correlation procedure to determine methane concentration in the optical sell.

2. Informant
Vyacheslav Khattatov, Central Aerological Observatory, Russia

Publications (source of information)

1. S. Sugawara, T. Nakazawa, G.Inoue, T.Machida, H.Mukai, N.Vinnichenko, V.Khattatov,

"Aircraft measurements of the stable carbon isotopic ratio of atmospheric methane over Siberia"

Global Biogeochemical Cycles, vol.10, No2, pp.223-231, 1996.

2. Y.tohijima, H.wakita, S. Maksutov, T.Machida, G.Inoue, N.Vinnichenko, V.Khattatov

"Distribution of tropospheric methane over Siberia in July 1993.

Journal of Geophysical Research, vol.102, NoD21,pp.25371-25382, 1997.

3. Gases detected -

Methane (CH4) in the atmosphere.

4. Detection Techniques (passive, active, wavelength ((m), power (W), etc.) -

In - situ measurements by high resolution TDL-spectroscopy technique at near infrared band.

(1.64 micron for methane detection).

5. Instrumental platform, stationary or mobile (specify carrier)

Several options are possible:
stationary (ground based)
mobile
helicopter or propeller plane

6. Gas detection sensitivity (concentration ppm and pathlength required)

The detection sensitivity for methane is 0.2 ppm, for 3 m optical length in analytical multi-path cell.

7. Range (m)

Not applicable parameter - in situ measurements

8.Geometrical resolution (mrad)

Not applicable parameter- in situ measurements

9. Field of view

Not applicable parameter - in situ measurements

10. Detection speed (km/h)

The same as carrier speed with 1 sec time resolution

11. Size and weight (mm, kg) -

250 x 1000 - optical unit
350 x 250 x 400 - signal processing unit
Total weight is approximately 30 kg

12. Subsequent treatment of data needed

Ttwo-channel output data in ppm and reference data processed and displayed by the portable computer using developed software

13.Intentional applications

Gas leaks detection from the gas pipeline systems and distribution of methane concentration in the atmosphere.

14. Applications tested and evaluated (brief description of tests performed and results)

Experimental mock-up of LMD was used to measure methane and carbon monoxide in urban atmosphere on stationary and aircraft platforms. The detection sensitivity was found to be that specified above.

15. Safety issues for public, operator and environment

Instrumet can be sertified as safe for applications

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)

Life time of instrument is not less than 5 years. Regular service of instrument can be provided by the CAO personnal.

17. Operational advantages and limitations -

Advantages - safe, stable and low-cost near infrared optics
It is possible significant rising of the sensitivity by tuning multi-pass sell up to hundreds meters of optical length. It is possible to use the same instrument for carbon monoxide and carbon dioxide measurements in the atmosphere.
Limitations - sensitivity limited by 10-5 Hz -1/2 noise-equivalent absorption mainly associated with quasireproducible laser power variations due to laser itself as well as optical feedback and interference.

18. Number of operators needed

One operator.

19. Coast of working out.
Instrument s are available for ground based applications. It takes about 6 month to prepare aircraft or helicopter modification of LMD. The cost of integration is about 45000 USD.

20. Cost of instrument (USD)

50,000 (single instrument)

Russia 14

1. System Identification (name)
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These impurities can be measured simultaneously within a 5-km radius by one instrument. To determine the three-dimensional distribution of the impurities, several instruments are necessary. In connection with different extent of availability of the calculation algorithms and of the software of remote sounding, instruments of the system must be put into service one after another in turn. The first stage of the work is the creation of an automated system for tomographic monitoring of one of the key pollutants, namely, nitrogen dioxide. At the following stage, the instrumentation created will be used for O_3, SO_2, CO, and aerosol monitoring.

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3. Gases detected

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The concept of such a monitoring site includes measurements of the intensity of scattered radiation from different sky segments. The attenuation of radiation within the NO_2 absorption bands determines the NO_2 content on the beam path. An angular resolution of 1^o and quick space scanning characterizing the instrument give a possibility for a short-time registration of the NO_2 distribution within a 5-7 km radius over the observation site. The radius of sounding can be increased up to 10 km by using a system of the space-apart angle reflectors.

The instrument should be installed on an elevation to have a possibility for measuring the NO_2 content in the ambient air by the azimuth scanning from 0^o to 360^o with a step of 1^o and by the zenith scanning from 60^o to 90^o with a step of 5^o. The use of a diode rule as a sensor allows performance of a cycle of NO_2 measurements in all possible directions of sounding for a period from 4 to 15 minutes depending on the desired measurement accuracy.

Under conditions of moderate or good visibility, one instrument measures the azimuth and zenith NO_2 distributions over a rather large-scale industrial region. However, under conditions of dense haze, a distance of sounding can reduce to 2 km. Measurements from one point give no possibility for determination of the distance along the beam up to a source of NO_2 emission or up to some local area of its enhanced content.

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At this center, a design of distributions of key impurities over an industrial region under control is being constructed at the actual time-scale.

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The above characteristics of the instrument and measuring procedure give a possibility for monitoring the NO_2 space field irregularities caused by local sources, such as gascompressor units, gas producing objects, smokestacks of industrial enterprises, highways, filter beds, etc. The instrumentation can be installed either at stationary or mobile observation points, for example, at cars, helicopters, etc. The stationary instrumentation operates in automatic regime.

5. Instrumental platform (specify carrier)

Tested as stationary ground and mobile instrument. It could be mounted at car, train or helicopter.

6. Gas detection sensitivity

NO2 - 0.01 ppm*km
O3 - 20 ppb*km
SO2 - 5ppb*km
CH4 - 0.2 ppm*km
CO - 0.02 ppm*km

7. Range (km)

Up to 5-7 km from instrument location.

8. Geometric resolution (mrad)

Angle resolution 0.5^{O}=9 mrad or more. Resolution of tomographic system depends on number of used instruments.

9. Field-of-view (degree)

0.5^{O}=9 mrad or more.

10. Detection speed (km/h)

Not specified, depend on necessary resolution, sensitivity and gas species. The single measurement for one direction <2s.

11. Size and weight

25 kg, 0.6m*0.6m*0.4m

12. Subsequent treatment of data needed

PC is used for instrument automatic control and data processing.

13. Intentional applications

The instrument and the tomographic system can be used together for monitoring of leakage and transfer of impurities within industrial areas, in the vicinity of gascompressor units, gas producing and gas using objects.

14. **Applications tested and evaluated**

Prototype of instrument was tested for observation of surface NO2 in Moscow. Prototype of instrument is used for regular measurements of vertical distribution of NO2, O3 and SO2 in troposphere and stratosphere from stationary ground-based station and in train expeditions. Data of measurements and instruments took part in international intercomparisons in Zvenigorod in September 1997, were successfully validated using space-based instruments. Prototype for stratospheric NO2 observations has the international certificate.

15. **Safety issues for public, operational and environment**

Instrument and used technology are purely safe for human and environment.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)

Accuracy - 5% of measured value, repeatability - 3%, life of instrument-more than 10 years.

17. Operational advantages and limitations

Advantages: System of instruments or one mobile instrument can present 3D tomographic map of pollution. Instrument could be modified for measurement of additional gas species.

Limitations: The instrumentation is valid for use in daylight time; for use during nighttime, additional light sources are necessary.

18. Number of operator need

1 hour*person/day

19. Cost of operation

1,000 USD/year

20. Cost of instrument

Estimated costs:
15,000 USD for instrument based on Russian spectrophotomere, 20,000 USD for instrument based Jobin-Ivan and etc. spectrophotomere.

Russia 15

1. System identification (name) - RIDIM-GAS.

2. Informant (name, postal addresses, phone, fax, e-mail, homepage)

Private Stock Company "Komplex" (S. - Peterburg)

3. Gases detected - The system is intended for a detection and localization of gas leakages in pipelines. Demonstrated methane.

4. Detection techniques (passive, active, wavelenght (μm), power (W), etc)

Radiolocation system for remote sensing natural gas emissions on gas pipelines.

5. Instrumental platform (stationary or mobile) - mobile. The system is mounted on cross country chasses.

6. Gas detection sensitivity (concentration ppm and pathlength required) - 1 - 100 m^3/min

7. Range (m) - 0,6 - 15 km

8. Geometric resolution (mrad) - Not available

9. Field-of-view (degrees) - Not available

10. Detection speed (km/h) - The detection time of gas cloud 3- 10 min.

11. Size and weight (mm, kg) - On-board helicopter radiolocation system. Topographical system of locality follow. PC is used for data processing.

12. Subsequent treatment of data needed - Data are displayed in real time. Gas concentration is calculated automatically.

13. Intentional applications - Sensing of natural gas leaks.

14. Application tested and evaluated (brief description of tests performed and results) - Working system.

15. Safety issues for public, operator and environment - Instrument is sertified as safe for applications**.**

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.) -

17. Operation advantages and limitations -

Advantages - weather proof. Large range.

18. Number of operations needed - 2

19. Cost of operation (USD) - Determinated by the operator salary, payment for the car and expenced for the exploitation of the laser.

20. Cost of instrument (USD) -

Spain

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M. Pujadas, A. Oche', J.M. Barcala and J. Teres, "Continous Emission Monitoring System based on a PbSe detector array", SPIE 2506, pp 738-747. **Spain1**

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R. San Jose', J. Moreno and A. San Feliu, "A field study on O_3, SO_2 and NH_3 deposition over a suburban area: Madrid case study" SPIE 2506, pp. 274-285.

Sweden

Yushkov Vladimir, Lukjanov Alexander, Merkulov Serafim, Khaplanov Mikhail, Shyshatzkaya Ludmila and Gumbel Jorg, "Optical Flourescent hygrometer for water vapor low concentration measurements", SPIE 2506, pp 783-794. **Sweden 1**

Sweden 2

Overview
A passive gas imaging system using an AGEMA Thermovision 1000 with a Stirling cooled MCT SPRITE detector, LW, 8 - 12 µm.

1. System identification
AGEMA Thermovision 1000 and a Stirling cooled MCT SPRITE detector, LW, 8 - 12µm

2. Informant
Sven-Åke Ljungberg, KTH-BMG, Box 88, 80102 Gävle, Sweden, +4626147800, fax +4626147801, e-mail Ljungberg@bmg.kth.se,
Homepage http://pcsib7.bmg.kth.se/Inftec/default.htm

3. Gases detected
Methane, LPG

4. Detection techniques
Passive

5. Instrumental platform
Two-wheel carrier, car, helicopter or fixed-winged aircraft. Stabilized Gimbal for airborne survey (ARGUS 350).

6. Gas detection sensitivity
Not specified

7. Range
5-100 m

8. Geometric resolution
Active pixels, 800 (horizontal) x 445 (vertical)

9. Field of view
Wide 20° x 13°, Narrow 5° - 3.3°.

10. Detectionspeed
Real time, NSC.

11. Size and weight
IR-camera unit 3.90 x 3.50 cm, 8 kg.
IR-system with complementary equipment (monitor, tape recorder, etc.), about 30 kg.
Gimbal including IR-camera unit 27 kg.

12. Subsequent treatment of data needed
No

13. Intentional applications
Landmobile and airborne survey of gas emissions from gas pipe systems located under and above ground, landfill bodies, and at accidents related to transportation of dangerous gods. Condition monitoring respectively surveillance applications.

1**4. Application tested and evaluated**
Preliminary field tests performed at Malmö Firebrigade exercise area (BARBARA)indicate detectability of simulated gas leaks at overpressures of 10, 15, 30, 50 millibars up to 8 bars

15. Safety issues
None

16. Reliability issues
None

17. Operational advantages and limitations
Results from preliminary field tests performed during different weather and radiation conditions confirm that passive gas imaging is temperature dependent, and need a certain Delta T between gas and ambient air. A critical level of Delta T is not yet established. Detector sensitivity is another critical parameter.

18. Number of operators needed
One

19. Cost of operation
Depend on the application.

20. Cost of instrument

THV 1000 system with complementary image analysis system,	98,000 USD.
Instrument platform for airborne carrier, Gimbal ARGUS 350,	60,000 USD.

Switzerland

H. Alause, J.P. Malzac, F. Grasdepot, V. Nouaze, J. Hermann and W. Knap, "Micromachined optical tunable filter for long term stability gas sensors" IEE Proceedings - Optoelectronics vol.144, no.05, October 1997, p.350-354.

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A. Mannoni, C. Flesia, P. Bruscaglioni and A. Ismaelli, "Simulated Multiply-Scattered Lidar Returns From Nonsperical Particles" SPIE 2506 666-675.

Andras Miklos and Miklos Feher, "Optoacoustic detection with near-infrared diode lasers: trace gases and short-lived molecules" Infrared Physics and Technology 37 (1996) 21-27.

Taiwan

Rong Tai Wu, Shih-Yi Chang, Y. W. Chung, H. C. Tzou and Tai-Ly Tso, "FTIR REMOTE SENSOR MEASUREMENTS OF AIR POLLUTANTS IN THE PETROCHEMICAL INDUSTRIAL PARK" SPIE 2552, pp 719-727, 1995

The Netherlands

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Richard A.H. Engeln, Rienk T. Jongma, Maarten G.H. Boogarts, Iwan Holleman and Gerard Meijer, "Trace gas detection via cavity ring down spectroscopy" SPIE 2506 pp727-736.
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Gerard J. Kunz, "Time resolved multiple-scattering" SPIE 2506 pp.608-620.
Andre' van Lammeren, Arnout Feijt and Andre' Hulshof, "Cloud detection system in the Netherlands" SPIE 2506 pp.524-534.

USA

From USA we have 15 reports, USA1-15 and 5 e-mails, USA16-20.

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Overview

1. System identification (name)
"JPL continuous-wave laser scanner"

2. Informant
William B. Grant "He-Ne and cw CO_2 laser long-path systems for gas detection", *Applied Optics* **25** pp. 709 - 719 (1986).

3. Gases detected
Demonstrated methane (HeNe system) and methanol (CO_2 system); capable of detecting gases absorbing at IR HeNe (3.3913 and 3.3903 µm) and CO_2 laser (~ 50 lines between 9 and 11 µm) wavelengths.

4. Detection techniques
Active topographic backscatter lidar (column integrated measurement) at wavelengths indicated above. HeNe power used was 2 mW (data extrapolated to other levels); CO_2 laser power used was up to 8W (data extrapolated to other levels).

5. Instrumental platform
Truck-mounted ground experiment tested stationary and mobile.

6. Gas detection sensitivity
<u>HeNe system</u> - 0.5% noise-equivalent absorption (3 ppm-m for methane) demonstrated when the beam was pointed at a single spot on an asphalt road at a distance of 15 m. It may be expected that this sensitivity would be reduced when detecting from a moving platform or in a mode where the laser is scanned. Results were presented in which the system was driven over a landfill; however, there was no indication of minimum detectable concentration for that result. <u>CO_2 system</u> - Results presented demonstrating detection of an undulating plume of methanol; however no quantitative data presented. The backscatter surface was flame-sprayed aluminium at a range of 80 m. Observation of the baseline of the return signal (as a function of time) indicates a single-channel fluctuation less than 1% can be detected, depending on the time constant. No plots of rationed (wavelength 1 over wavelength 2) data are provided. No data are presented in which the laser is scanned or operated from a moving platform. Sensitivity estimates for some other gases are provided, assuming a 1% absorption sensitivity. They are: hydrazine - 17 ppm-m; monomethyl hydrazing (MMH) - 19 ppm-m; unsymmetrical dimethyl hydrazine (UDMH) - 13 ppm-m; ammonia 0.3 ppm-m; methanol - 2.4 ppm-m.

7. Range
<u>HeNe system</u> - All measurements were made aiming the laser at a spot 15 m from the vehicle. Extrapolations to longer ranges (up to 1 km) are described. A "state-of-the-art" system (5 mW laser) having a range of 90 m is mentioned. <u>CO_2 system</u> - Gas measurements were made at 80-m; extrapolations to longer ranges (100-1000 m) are described.

8. Geometric resolution (mrad) -
<u>HeNe system</u> - 5 mrad;
<u>CO_2 system</u> - 1.6 mrad (both assumed to be equal to the laser divergence.

9. Field-of-view
Same as geometrical resolution - these are line-of-sight systems.

10. Detection speed
Not explicitly stated. Single-point measurement times of 100's of ms to a few seconds were indicated.

11. Size and weight
Not available.

12. Subsequent treatment of data needed
Two-channel data must be ratioed and displayed, presumably in real-time (with some electronic averaging). The system was not developed to the extent that it did automated scans or areal surveying.

13. Intentional applications
Specific applications mentioned include leak detection of methane from natural gas leaks and from landfills (HeNe system), and hydrazine leaks (CO_2 system). Can be used generally for leak detection and fugitive emission detection.

14. Applications tested and evaluated
Both are experimental systems; demonstrations are of that nature and do not represent comprehensive evaluations of a hardened device.
<u>HeNe system</u>
Test 1. As indicated above, the system was tested in a mode where it was directed at a single point on an asphalt surface at a range of 15-m. The signal-to-noise ratio was evaluated and the system was demonstrated to be able to detect a methane plume as it blew across the laser line-of-sight. The detection sensitivity was found to be that specified above.
Test 2. The system was driven at a landfill as the sensor was aimed at a point 15-m behind the truck. Methane leaks were detected. A minimum sensitivity was not specified.
<u>CO_2 system</u>
The system was demonstrated to detect a plume from a jar of methanol as it blew across the fixed laser line-of-sight. No other gas detection data were provided. A significant amount of data was provided to quantify the effects of speckle noise.

15. Safety issues for public, operator and environment
Not discussed. HeNe system likely eyesafe; CO_2 potentially not eyesafe.

16. Reliability issues
Not applicable - experimental system.

17. Operational advantages and limitations -
<u>Advantages</u> - standoff capability, low-cost rugged lasers, and potentially high sensitivity due to low detector bandwidth.
<u>Limitations</u> - Sensitivity needs to be determined more completely in a scanning mode where albedo and speckle variations are present. This could reduce sensitivity below that specified. Because measurement is column integrated, the HeNe system could be susceptible to fluctuations in naturally abundant methane.

18. Number of operators needed -
Not specified; assume 1 or 2.

19. Cost of operation (USD) -
Not specified.

20. Cost of instrument (USD) -
Not applicable - experimental system.

Overview
The M21 is a U.S. Military passive Fourier-transform infrared (FTIR) spectrometer. A passive FTIR is a single-ended sensor that measures the spectrum of passively emitted infrared radiation collected by its receiver aperture. Gases can modulate the spectrum by absorption or emission of radiation. The M21 is designed for chemical and biological warfare agent detection, but can detect other gases as well. The resolution of the M21 is 4 cm^{-1}. Its detection sensitivity is a few 10s to a few 100s mg/m^2 of the agents to be detected, depending upon the temperature difference between the gas and the background. Its standoff range is 5 km or more.

1. System identification (name) -
M21 Remote Sensing Chemical Agent Alarm (RSCAAL)

2. Informant (name, postal address, phone, fax, e-mail, homepage)
Dennis Flanigan, 2418 Briarwood Rd, Baltimore, MD 21209, 410-367-2338 (v), 410-367-1438 (fx), dfflanig@worldnet.att.net

3. Gases detected - The sensor is intended for chemical warfare agent detection. Gases detected are GA, GB, GD, VX (all are nerveagents) if there is enough vapour and HD (mustard). The FTIR can detect many other species absorbing in the operating wavelength range, however.

4. Detection techniques (passive, active, wavelength (µm), power (W), etc.) - broadband passive remote Fourier transform infrared (FTIR) spectrometry (detecting in the range from 8 to 12 µm at a resolution of 4 cm^{-1} resolution using a cooled Hg:Cd:Te detector

5. Instrumental platform (stationary or mobile ==> specify carrier)
Stand alone operation on a tripod or stationary operation from an armored vehicle.

6. Gas detection sensitivity (concentration ppm and pathlength required)
The M21 requirements are stated in CL units (concentration in $mg\text{-}m^{-3}$ time's pathlength in m). The requirements call for an automatic alarm for nerve agents at about 90 mg/m^2 and about 2500 mg/m^2 for mustard. The actual sensitivity probably ranges from a few 10s to a few 100s mg/m^2, depending upon the temperature difference between the gas and the background.

7. Range (m) - The range depends upon cloud size and meteorological conditions; however army specifications are 5 km.

8. Geometric resolution (mrad) - 1.5 by 1.5 degrees for the single detector.

9. Field-of-view (degrees) - The M21 is a single detector sensor that sequentially scans 7 positions each 10 degrees apart. The result is a discontinuous line 60 degrees by 1.5 degrees with open spaces of 9.25 degrees (between measurement points).

10. Detection speed (km/h) - Officially, the M21 is a stationary sensor although it has been operated from a helicopter for research measurements. Information regarding platform speed and detection success are not available.

11. Size and weight (mm, kg) - Size in inches is 19(L) X 17 (W) X 12 (H). Weight is 50.5 lbs. for the instrument and 50 lbs. for the transit case. There are much smaller (but not as well ruggedized) FTIRs available now.

12. Subsequent treatment of data needed - The M21 is supposed to be fully automatic; consequently, the standard military model does not have a data output (but rather an indication of recognition for specific species). However, all of the research systems have been modified with a nonstandardized data output.

13. Intentional applications - Chemical defence and research on fugitive gas detection.

14. Applications tested and evaluated (brief description of tests performed and results) - The M21 has been extensively tested over the last 15 years both formally and informally. The formal tests include DT/OT (developmental testing/ operational testing). OT involves the soldier. The results are quite extensive but not briefly summarised anywhere to my knowledge. Suffice to say that the hardware has proven to be relatively reliable, but its interaction with the environment is not well understood.

15. Safety issues for public, operator and environment - There are no operational safety problems that I am aware of. The sensor contains a low power HeNe laser that may require a little care on the part of the service technician. There may be some materials that require disposal care when the system is decommissioned.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
A few years ago the M21 was, by far, the most reliable FTIR available for field operation, hence its popularity as a research device. The lifetimes of its critical components is measured in thousands of hours; however, specific numbers are not available.

17. Operational advantages and limitations -
Advantages: Wide optical band for detection versatility, generation of a spectral signature, relatively small size and weight, high safety, no need for laser source, longer range than laser-based sensors.
Limitations: Need for a temperature differential, very little convincing work regarding the *quantitative* passive measurement of fugitive gas concentrations.

18. Number of operators needed - Several people are general required for setting up the tripod version because of weight. However, the set-up is simple and supposed to operate unattended for 12 hours. It is safe to say that objective has not been consistently met and it does help to have at least a part time operator.

19. Cost of operation (USD) - Information not available.

20. Cost of instrument (USD) - For a government agency the cost is dependent on the size of the production run. (Probably less than 500 systems totals have been built.) Reports indicate estimates ranging from $60K to $120K per copy.

Overview
The Sandia long-range BAGI imager is an active imager that uses the raster-scanned approach in conjunction with a 20W CO_2 laser source. The imager was developed to allow long-range (~300 m) gas imaging in the 9-11 µm range. It accomplishes this by incorporating telescopic optics in the transmit and return beam paths, thus increasing the collection aperture at the expense of field-of-view. The system was demonstrated to image a few ppm of sulphur hexafluoride at ranges of up to 360 m.

1. System identification (name) - “Sandia long-range BAGI imager”

2. Informant (name, postal address, phone, fax, e-mail, homepage)
Thomas J. Kulp, PO Box 969, MS 9051, Livermore, CA 94551-0969
(925) 294-3676 (ph), (925) 294-2276 (fx), tjkulp@sandia.gov

3. Gases detected - Any gases absorbing at CO_2 laser wavelengths (~50 lines in the 9- to 11-_m wavelength range).

4. Detection techniques (passive, active, wavelength (µm), power (W), etc.) - Backscatter absorption gas imaging (BAGI) using a raster-scanned, 20-W, 9-11 _m tunable wavelength CO2 laser. The system differs from the Laser Imaging Systems GasVue system in being optimized for long-range operation. This is accomplished using refractive telescopes for the transmit and receiver paths that serve to increase the collection aperture (while reducing the imager field-of-view). To accommodate these optics, the scanner was redesigned to allow separated transmit and return paths. Gases are imaged via the spatial contrasts that they cause in the video image.

5. Instrumental platform (stationary or mobile ==> specify carrier)
Truck-mounted, tested in a stationary mode. Could operate in a mobile mode.

6. Gas detection sensitivity (concentration ppm and pathlength required)
Single-wavelength detection sensitivity when viewing against uniformly reflecting (e.g., a wall) surfaces is that causing an absorption of about 8-16%. Against complex surfaces this may increase to about 25-50%. The detection sensitivity was shown to be about 2 ppm-m for detection of sulphur hexafluoride (SF_6).

7. Range (m) - The system was demonstrated to operate at ranges as high as 360 m.

8. Geometric resolution (mrad) - 0.6 mrad

9. Field-of-view (degrees) - 3.6 degrees

10. Detection speed (km/h) - Currently operated solely from a stationary platform; could be operated from a moving platform. The frame rate is 30 Hz. Maximum speed is determined by operator’s ability to identify plume in moving video image.

11. Size and weight (mm, kg) - 107 x 36 x 51 cm, weight approximately 150 lb.

12. Subsequent treatment of data needed - No subsequent data processing needed.

13. Intentional applications - Detection of fugitive emissions of various gaseous species absorbing in the 9-11 m range.

14. Applications tested and evaluated (brief description of tests performed and results) - The system was tested against controlled releases generated by calibrated gas source having an exit plume diameter of 2-m. SF_6 was imaged at plume concentrations between 1 and 150 ppm. A target consisting of silicon-carbide sandpaper covered panels served as the imaging backdrop. Images were made at ranges between 40 and 360 m. The sensitivities determined are described above. No "real-world" image tests were conducted with this system.

15. Safety issues for public, operator and environment - Eyesafe. No other safety issues.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
Not applicable - experimental system.

17. Operational advantages and limitations -
Advantages - Stand-off capability, wide-area coverage, easy plume recognition and easy identification of the plume source, longer range (than original scanned BAGI) attainable because of large collection aperture (which reduces laser power requirement)
Limitations - Sensitivity and standoff range potentially not as high as line-of-sight techniques, due to its multipoint nature.

18. Number of operators needed - 1

19. Cost of operation (USD) - Not specified.

20. Cost of instrument (USD) - Not applicable - experimental system.

Overview
The Sandia pulsed gas imager is an active gas imager. It differs from scanned active imagers in its use of a pulsed laser source and a focal-plane array camera rather than a scanner (as in the LIS GasVue system). It was originally intended for methane imaging, but is tunable in the 3-3.5 µm wavelength range to detect other hydrocarbons. It is capable of operating in a single-wavelength or differential mode. Differential-mode allows elimination of background clutter and enhances gas plume imagery. The pulsed imager is currently a developmental system.

1. System identification (name) - "Sandia pulsed gas imager"

2. Informant (name, postal address, phone, fax, e-mail, homepage)
Thomas J. Kulp, PO Box 969, MS 9051, Livermore, CA 94551-0969
(925) 294-3676 (ph), (925) 294-2276 (fx), tjkulp@sandia.gov

3. Gases detected - Demonstrated to detect methane. Can detect any gas absorbing in the 3.1-3.6 _m range; camera capable of operating in the 1-5 _m range. Extension to those wavelengths is dependent upon availability of laser source.

4. Detection techniques (passive, active, wavelength (µm), power (W), etc.) - Active imager operating by flood illuminating a scene with pulses of laser radiation that are emitted at a rate of 30 Hz to coincide with the framing of a gated indium antimonide (InSb) focal-plane array (FPA) detector. Gases are detected via active backscatter absorption gas imaging (BAGI) carried out in a pulsed mode. The system operates in two modes: single-wavelength imaging and dual-wavelength imaging. The single-wavelength mode is ordinary BAGI, in which gases are imaged via the spatial contrasts that they cause in the video image. In the dual-wavelength mode, the laser is rapidly (on a 33 ms timescale) switched between an absorbing and non-absorbing wavelength. Frames are collected at each wavelength and subsequently ratioed and logarithmed to generate an absorbance movie of the scene. This serves to highlight gas plumes in the presence of scene clutter. The average power of the laser source used is 150 mW. Other, more powerful, lasers are available that are compatible with this system.

5. Instrumental platform (stationary or mobile ==> specify carrier)
Truck-mounted, tested in a stationary mode.

6. Gas detection sensitivity (concentration ppm and pathlength required)
Single-wavelength detection sensitivity when viewing against uniformly reflecting (e.g., a wall) surfaces is that causing an absorption of about 8-16%. Against complex surfaces this may increase to about 25-50%. For dual-wavelength imaging, the sensitivity is retained at 8-16% for both uniform and complex surfaces. The system has been field tested against methane plumes of controlled thickness and concentration. The detection sensitivity was shown to be 16-32 ppm-m for dual-wavelength imaging and 16-100 ppm-m for single-wavelength imaging.

7. Range (m) Against moderately reflecting target materials (sandpaper, building walls) a range of about 70-80 m was attained. Against low-reflectivity surfaces (grass at grazing incidence) a range of about 40-50 m was demonstrated.

8. Geometric resolution (mrad) - 256X256 element array with 0.34 mrad geometric resolution

9. Field-of-view (degrees) - 5 degrees

10. Detection speed (km/h) - Currently operated solely from a stationary platform; single-wavelength mode could be operated from a moving platform, but dual-wavelength mode cannot operate from a moving platform in present format. The frame rate in each case is 30 Hz. Detection (platform) speed is determined by the operator's ability to identify plumes in this video mode**.**

11. Size and weight (mm, kg) - Not applicable - currently a developmental system. The system currently requires operation in a truck, due to the size of the laser. If the developmental laser were replaced by a more suitable compact source, the size would be approximately 0.4 m^3 and the weight approximately 40 kg.

12. Subsequent treatment of data needed - Single-wavelength imaging requires no subsequent data treatment. Dual-wavelength imaging requires a 2-3 minute processing period prior to viewing a video segment. This could be ultimately be replaced by a real-time implementation.

13. Intentional applications - Detection of fugitive emissions of methane and other hydrocarbons absorbing in the 3-3.5 _m range.

14. Applications tested and evaluated (brief description of tests performed and results)
The system was tested in a series of tests against uniform backgrounds of moderate reflectivity (panels covered with silicon-carbide sandpaper) and against grass at grazing-incidence angles. In all cases, methane was emitted in front of these backgrounds using a plume generator that produced methane plumes having known concentration and geometrical extent. Single and dual-wavelength tests were performed. Imaging was conducted at ranges up to 90 m with the uniform targets and 60 m using the grass background. The sensitivity results are described above.

15. Safety issues for public, operator and environment - Eyesafe. No other safety issues.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
Not applicable - experimental system.

17. Operational advantages and limitations -
Advantages - Stand-off capability, wide-area coverage, easy plume recognition and easy identification of the plume source, compatible with pulsed lasers (which increases the number of wavelengths available to BAGI), longer range (than scanned BAGI) attainable because of large collection aperture (which reduces laser power requirement)
Limitations - Sensitivity and stand-off range potentially not as high as line-of-sight techniques, due to its multipoint nature.

18. Number of operators needed - 1

19. Cost of operation (USD) - Not specified.

20. Cost of instrument (USD) - Not applicable - experimental system.

Overview

ELM is an airborne lidar capable of operating in a topographic backscatter mode. The range is 0.5-0.7 km. It operates in the 3.3-3.6 μm wavelength range using a KTA OPO pumped by a 1.06 μm Nd:YAG laser. It is projected to detect gases absorbing in the laser tuning range, with a stated ethane sensitivity of ≤3 ppm-m.

1. System identification (name) - "Environmental Laser Mapper (ELM)"

2. Informant (name, postal address, phone, fax, e-mail, homepage)

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PetroLaser/LaSen, Inc.
300 N. Telshor, Suite 600
Las Cruces, New Mexico 88011
(505) 522-5110 (ph)
(505) 522-6355 (fx)
lasen@ianct.com

3. Gases detected - The target gases for this system are ethane, propane, benzene, toluene, ethylmercaptan. It can, potentially, detect other industrial hydrocarbons absorbing in the 3.3-3.6 μm wavelength range.

4. Detection techniques (passive, active, wavelength (μm), power (W), etc.) - Active topographic differential absorption lidar (DIAL). Uses a KTA optical parametric oscillator (OPO) to achieve pulse energies of 1.7 mJ per channel per pulse at a repetition rate of 300 Hz. Thus, average power is 51 mW per channel. Emits 8 wavelengths at once. Total tuning range is 3.3-3.6 μm. Lidar employs new detection strategy (upconversion). Combines the lidar with 3-5 μm thermal imager and a low light-level video camera.

5. Instrumental platform (stationary or mobile ==> specify carrier)

Small fixed-wing aircraft.

6. Gas detection sensitivity (concentration ppm and pathlength required)

Ethane detection at ≤3 ppm-m. The sensitivity is determined via a combination of system modelling and demonstrations using a previously-developed lidar (for Phillips Petroleum). There is no claim for gas identification in this performance specification, although the system can be set up to generate a search sequence.

7. Range (m) - 0.5-0.7 km for pipeline survey.

8. Geometric resolution (mrad) - 30 mrad

9. Field-of-view (degrees) - 30 mrad

10. Detection speed (km/h) - Typical 250 kph with a 25-cm ground resolution and 96% shot-to-shot overlap. The sensitivity specifications listed in (6) are claimed to occur for single-shot detection.

11. Size and weight (mm, kg) -
• Lidar: 80 kgm; located in belly pod of Cessna 337
• Onboard electronics and operator: 150 kgm

12. Subsequent treatment of data needed -
• On board processing of real-time data for alert status
• Post processing and sensor fusion using archival and risk management software (see attached system flowchart)

13. Intentional applications -
• DoD - Military base remediation mapping and laser radar imagery
• Commercial - Pipeline and land surveys for risk management systems

14. Applications tested and evaluated (brief description of tests performed and results)
System under contract to USAF with flight tests to begin in 18 months. In ground-based simulations of airborne lidar using propane as target, chemical detection was 0.63 ppm.

15. Safety issues for public, operator and environment - Meets ANSI standards.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
On-board data capability of only 6 hrs.

17. Operational advantages and limitations -
Advantages - 8 laser lines in the 3.3-3.7 µm range transmitted simultaneously (system can be upgraded to operate out to 14.0 µm).
Limitations - For maximum positional accuracy local GPS transponder must be used.

18. Number of operators needed -
One plus pilot for field system.
Two in house data personnel for preparing final data.

19. Cost of operation (USD) -
Comparable to pipeline ground surveys.

20. Cost of instrument (USD) -
Development cost: 9,200,000 USD
Reproduction hard cost - approximately 700,000 USD

Overview
This is an airborne passive Fourier transform infrared (FTIR) spectrometer that has been integrated into an aircraft and flight tested for some specific applications. It detects gases in the 8-15 µm range. Specific operating capabilities (i.e., gas detection sensitivity and range) are not well developed at this time, although performance data for the tests that have been accomplished are available.

1. System identification (name) -
SRI Airborne Fourier Infrared Spectrometer

2. Informant (name, postal address, phone, fax, e-mail, homepage)
Edwared Uthe
SRI International
Menlo Park, CA 94025
(650) 859-4667 (v)
(650) 859-5036 (fx)
edward_uthe@sri.com
paper: R.D. Kaiser, E.E. Uthe, and J. van der Laan, "Airborne Fourier Infrared Spectrometer System", Proceedings Second International Airborne Remote Sensing Conference and Exhibition, San Francisco, California, 24-27 June 1996.

3. Gases detected - Gases with absorption spectra in the 8 - 15 µm wavelength range. Airborne tests were performed using SF_6.

4. Detection techniques (passive, active, wavelength (µm), power (W), etc.) - Passive Fourier transform infrared spectrometry measuring total gas column content.

5. Instrumental platform (stationary or mobile ==> specify carrier)
Airborne, tested on a Queen Air aircraft

6. Gas detection sensitivity (concentration ppm and pathlength required)
Not established, depends upon the thermal characteristics of the background and of the target gas.

7. Range (m) - Not established, tested on an aircraft at 1000 ft AGL.

8. Geometric resolution (mrad) - 10 mrad.

9. Field-of-view (degrees) - 10 mrad.

10. Detection speed (km/h) - Tested at aircraft speed of 300 km/hr.

11. Size and weight (mm, kg) - Sensor 81 cm x 122 cm x 460 cm and 218 lb weight. Data system 41 x 15 x 22 inch and 126 lb.

12. Subsequent treatment of data needed - Real-time plots of gas plume available.

13. Intentional applications - Military application.

14. Applications tested and evaluated (brief description of tests performed and results) - Tested with SF_6 releases from the ground — plume tracked to 45 km from source. Also used to map ozone over Los Angeles.

15. Safety issues for public, operator and environment - Airborne safety requirements for Federal Aviation Administration (FAA).

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
Not established.

17. Operational advantages and limitations -
Advantages: Continuous spectra over wide wavelength range

18. Number of operators needed - One and pilot.

19. Cost of operation (USD) - Aircraft $500/hr; operators $2000/day.

20. Cost of instrument (USD) - Commercial unit purchase, integrated with 14-inch telescope on aircraft optical bench, data system developed and system airborne tested for $350K.

Overview

The AIRIS-LW is a spectrally filtered imaging sensor that allows visualization of gas plumes. It is a passive device that operates in the long-wave infrared. It consists of an infrared focal-plane array camera whose incoming radiation is filtered by a tunable cryogenic Fabry-Perot interferometer (etalon). The tuning allows centering of a 7 cm^{-1}-wide bandpass at wavelengths in the 8.5-12 µm range. Images are collected and displayed after a short (seconds) amount of mathematical processing.

1. System Name:

AIRIS-LW - Adaptive Infrared Imaging Spectroradiometer - Long Wavelength

2. Informant Name:

Dr. William J. Marinelli, Area Manager of Applied Photonics, Physical Sciences, Inc., 20 New England Business Center, Andover, MA 01810; Ph. 978.689.0003; FAX. 978.689.3232; e-mail: marinelli@psicorp.com

3. Gases Detected:

SF_6, dimethyl methyphosphonate (chemical agent simulant), isopropyl alcohol. Generally can detect same set of compounds observable using FTIR, within the instrumental tuning range. When first constructed, the tuning range was 9-11 µm. Recently, a new mirror set was fabricated that allows tuning over the 8.5-12 µm wavelength range.

4. Detection Technique:

Passive infrared emission/absorption. Operates using a cooled tunable Fabry-Perot etalon filter that filters the field-of-view of an infrared focal-plane array camera.

5. Instrumental Platform:

Currently stationary with designs in process for mobile/airborne system.

6. Gas Detection Sensitivity:

The sensitivity for sulfur hexafluoride is 0.6 ppmv-m for a 6K temperature differential between the gas and the background. The sensitivity for DMMP is a factor of three times worse for the same conditions.

7. Range:

Current device optimized for short range (< 1 km) with modifications underway for 5-10 km range.

8. Geometric Resolution:

Current device is 15 mrad IFOV with modifications underway for 1 mrad IFOV.

9. Field of View:

Current device is 40 x 40 deg FOV with modifications underway for 64 x 64 mrad IFOV.

10. Detection Speed:

Currently, data processing is partially manual and takes a few seconds using the IDL/ENVI image processing package.

11. Size and Weight:

Current device ~ 4 cu. ft and 60 lbs.

12. Subsequent Data Treatment:
Absolute radiance calibration followed by image processing to extract spatial/spectral information.

13. Intentional Applications:
1) Monitoring of chemical releases during hazardous chemical waste remediation activities; 2) Standoff chemical and possibly biological agent detection.

14. Applications Tested:
Standoff chemical agent detection - field testing using SF_6 and flow tunnel testing using DMMP and IPA. SF_6 sensitivity cited above.

15. Safety Issues:
None identified.

16. Reliability Issues:
Interferometer long term stability. Radiance calibration stability.

17. Operational Advantages/Disadvantages:
Advantages: Passive and imaging with simplified data processing - no Fourier transform required. Disadvantages: Need gas plume temperature to make absolute column density measurements. Sensitivity decreases with background/chemical plume temperature differential.

18. Number of Operators Needed:
One.

19. Cost of Operation:
N/A

20. Cost of Instrument:
Approx. $200K for initial prototype.

Overview

Lidar I is an man-portable lidar capable of operating in an aerosol backscatter mode. The range is 0.5 km. It operates in the 3.3-3.6 µm wavelength range using a KTA OPO pumped by a 1.06 µm Nd:YAG laser. It is capable of detecting gases absorbing in the laser tuning range, with a methane sensitivity of 150 ppm-m.

1. System identification (name) - "Lidar I"

2. Informant (name, postal address, phone, fax, e-mail, homepage)

Al Geiger
PetroLaser/LaSen, Inc.
300 N. Telshor, Suite 600
Las Cruces, New Mexico 88011
(505) 522-5110 (ph)
(505) 522-6355 (fx)
lasen@ianct.com

3. Gases detected - The target gases for this system are methane, ethane, propane, benzene, and toluene. It can, potentially, detect other gases absorbing in the 3.3-3.6 µm wavelength range.

4. Detection techniques (passive, active, wavelength (µm), power (W), etc.) - Active aerosol backscatter differential absorption lidar (DIAL). Uses a KTA optical parametric oscillator (OPO) to achieve pulse energies of 1.7 mJ per channel per pulse at a repetition rate of 30 Hz. Thus, average power is 51 mW per channel. Operates in a burst mode, emitting 10 pulse pairs (on/off absorption wavelength) each time. Total tuning range is 3.3-3.6 µm.

5. Instrumental platform (stationary or mobile ==> specify carrier)

Man-portable.

6. Gas detection sensitivity (concentration ppm and pathlength required)

Active aerosol backscatter DIAL lidar 150 ppm-m; 5 ppm in 30 meter-long range resolution element. Sensitivities indicated are for methane. The sensitivities have been generated via a combination of system modeling and demonstrations using a previously-developed lidar (for Phillips Petroleum). There is no claim for gas identification in this performance specification, although the system can be set up to generate a search sequence.

7. Range (m) - 0.5 km.

8. Geometric resolution (mrad) - 2 mrad

9. Field-of-view (degrees) - 2 mrad

10. Detection speed (km/h) - Point and shoot; sensitivity stated for one firing (10 laser pulse pairs). Uses a tripod to stabilize system during the acquisition period.

11. Size and weight (mm, kg) - 75 cm x 86 cm x 30 cm; 30 kgm. Size is somewhat large because it is a developmental (brassboard) system and because it uses a fairly large telescope.

12. Subsequent treatment of data needed - Range-resolved real-time.

13. Intentional applications - Military base remediation mapping, test-bed for 2nd generation optics and software.

14. Applications tested and evaluated (brief description of tests performed and results)
Initial field tests begin August '98, calibration and characterization test at Oak Ridge National Laboratory October '98, U.S. Air Force delivery February '99.

15. Safety issues for public, operator and environment - Meets ANSI standards.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
Battery life before recharge 2 hours, nominal operating temperature 0˚C - 40˚C, scan time to new wavelength 10 seconds, lock-down time of tuner 5 msec.

17. Operational advantages and limitations -
Advantages - Ground-based system transported in padded case. Operates in the 3.3-3.6 µm region, so works in adverse weather fairly well.
Limitations - Not sealed from rain or snow. Test instrument.

18. Number of operators needed - 1

19. Cost of operation (USD) - Nominal, battery recharge and computer disks.

20. Cost of instrument (USD) -
Development cost: 740,000 USD
Reproduction hard cost - approximately 85,000 USD

Overview
Lidar II is an airborne lidar capable of operating in a topographic or aerosol backscatter mode. The range for topographic backscatter is 2.5 km. It operates in the 3.3-3.7 µm wavelength range using a KTA OPO pumped by a 1.3 µm Nd:YAG laser. It differs from Lidar I in its broader tuning range, its simultaneous broadcasting of both laser wavelengths, and its modified (using upconversion) detection strategy. As a result of these differences, PetroLaser claims higher performance.

1. System identification (name) - "Lidar II"

2. Informant (name, postal address, phone, fax, e-mail, homepage)
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300 N. Telshor, Suite 600
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(505) 522-5110 (ph)
(505) 522-6355 (fx)
lasen@ianct.com

3. Gases detected - Intended gases are ethane, propane, benzene, toluene, nerve agents. Can potentially detect other gases absorbing in the 3.3-3.7 µm range.

4. Detection techniques (passive, active, wavelength (µm), power (W), etc.) - Active topographic and aerosol backscatter differential absorption lidar (DIAL). Uses a KTA OPO simultaneously emitting on/off absorption pulse pairs at 30 Hz. Energy per pulse is 1.7 mJ; average power is 51 mW per channel. The detection methodology is improved (using upconversion) to achieve higher performance than Lidar 1

5. Instrumental platform (stationary or mobile ==> specify carrier)
Remotely piloted vehicle (RPV) or unmanned stand-alone.

6. Gas detection sensitivity (concentration ppm and pathlength required)
Using topographic backscatter, the system can detect 1 ppm in a 5-m gas plume width at 2.5 km range. Sensitivities indicated are for methane. The sensitivities have been generated via a combination of system modeling and demonstrations using a previously-developed lidar (for Phillips Petroleum). There is no claim for gas identification in this performance specification, although the system can be set up to generate a search sequence.

7. Range (m) - 2.5 km when operated in a topographic backscatter mode.

8. Geometric resolution (mrad) - 30 mrad

9. Field-of-view (degrees) - 30 mrad

10. Detection speed (km/h) - 30 Hz rep rate, RPV - 220 km/hr; staring mode 30 mph**.** Single laser-shot integration is required to achieve the detection sensitivities stated above.

11. Size and weight (mm, kg) - 15 cm x 25.5 cm x 38 cm; 15.5 kgm.

12. Subsequent treatment of data needed - Real-time to PC or satellite link to base station.

13. Intentional applications -
Department of Defense: RPV slant-path surveillance
Commercial: Railroad car inspection

14. Applications tested and evaluated (brief description of tests performed and results)
System being developed under U.S. Air Force contract for delivery in August ‘99. Railroad demonstration to take place late in ‘98.

15. Safety issues for public, operator and environment - Meets ANSI standards.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
There are potential problems with species interferences during multi-chemical analysis, given the limited time for spectral sorting scans.

17. Operational advantages and limitations -
<u>Advantages</u> -
- Semi-hardened for airborne operations
- Sealed for stand-alone operations along rail lines with remote control and data transfer available.
- Uses non-cryogenic detectors

<u>Limitations</u> -
- Single chemical analysis at one time

18. Number of operators needed - 1

19. Cost of operation (USD) - Comparable to thermal camera; periodically requires replacement of diode pumps (typically 5000-10,000 hr lifetimes).

20. Cost of instrument (USD) -
Development cost: 745,000 USD
Reproduction hard cost - approximately 95,000 USD

Overview
Laser Imaging Systems is a manufacturer of GasVue leak location products. All current GasVue products operate in the 9-11 µm region using BAGI detection technology with CO_2 lasers. GasVue models are available as either single-wavelength or tunable units, in either fixed or shoulder-mounted configurations. The systems are qualitative (no gas concentration information is provided) and are used for rapid location of fugitive emissions.
These systems provide real-time, gas-imaging capabilities for ranges up to 30 meters.

1. System identification (name) -
GasVue models TG-5, TG-20, MG-30

2. Informant (name, postal address, phone, fax, e-mail, homepage)
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204-A E. McKenzie St.
Punta Gorda, FL 33950
voice: (941) 639-3533
fax: (941) 639-6458
lis@sunline.net

3. Gases detected -
More than 70 different (see website @ www.sunline.net/lis). CO_2 laser systems do not work for methane.

LIS is developing 3.0 - 3.5 µm system for methane and other hydrocarbons that absorb in this spectral region.

4. Detection techniques (passive, active, wavelength (µm), power (W), etc.) - BAGI - continuous-wave lasers with synchro-scan technology

5. Instrumental platform (stationary or mobile ==> specify carrier - Stationary (fixed-mounted), shoulder-mounted or mobile

6. Gas detection sensitivity (concentration ppm and pathlength required)
1 - 5000 kgm / yr; gas dependent (see database at website)

7. Range (m) - 1- 30 m

8. Geometric resolution (mrad) -
2 mrad (TG-5), 3 mrad (TG-20, MG-30)
400 lines (200 repeated line pairs).

9. Field-of-view (degrees) - 18 degrees horizontal x 14 degrees vertical

10. Detection speed (km/h) - Real-time video display, 50 or 60 Hz interlaced

11. Size and weight (mm, kg)
TG-5

	Laser camera:	46 cm long 15.2 cm high 15.2 cm wide 33 kg
	Power / cooling unit:	75 cm high 56 cm deep 65 cm wide 350 kg
TG-20		
	Laser camera:	46 cm long 15.2 cm high 15.2 cm wide 35 kg
	Power / cooling unit:	75 cm high 56 cm deep 65 cm wide 350 kg
MG-30		
	Laser camera:	66 cm long 15.2 cm high 15.2 cm wide 41 kg
	Power / cooling unit:	75 cm high 56 cm deep 65 cm wide 350 kg

12. Subsequent treatment of data needed - Real-time video, no data post-processing required.

13. Intentional applications - Location of fugitive emissions from chemical plants and electrical substations. Leak testing of products on assembly lines using SF_6 tracer gas.

14. Applications tested and evaluated (brief description of tests performed and results) - Currently in use for location of fugitive emissions of ethylene, ammonia, and refrigerant leaks (Union Carbide, Lockheed Martin Energy Systems).

SF_6 leaks in electrical substations (Public Service Electric & Gas (New Jersey), Consolidated Edison of New York, ABB (Pennsylvania), National Grid (United Kingdom).

Leaks in aircraft fuel tanks and hydraulic systems (Boeing, Lockheed-Martin).

15. Safety issues for public, operator and environment - CO_2 laser and mid-IR laser operate in the "eyesafe" region, low laser powers (< 7 W) makes for minimal laser safety requirements.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
GasVue products have been used successfully in the field for many years.

17. Operational advantages and limitations -
Advantages: Simple device, easy to use

Limitations: Range limit (≤ 30 m) and poor sensitivity for some gases

18. Number of operators needed - one

19. Cost of operation (USD) -Maintenance costs less than $8000 per year; systems come with 2000 hour warrenty.

20. Cost of instrument (USD) -
TG-5 $84,900
TG-20 $99,900
MG-30 $119,900

Overview
The LasIR is a near-IR absorption sensor that uses diode lasers. It can operate as a point sensor or as a long-path absorption sensor. In the second mode, it uses a retroreflector. Thus, it cannot be operated as a single-ended remote sensor in either mode. Its detection sensitivity for methane is 2 ppm-m for long-path detection; for point-monitoring it is 0.2 ppb. It can detect many other gases with the caveat that multiple diode lasers may have to be used to do this.

1. System identification (name) -
LasIR Near Infrared Tunable Diode Laser

2. Informant (name, postal address, phone, fax, e-mail, homepage)
Dr. Harold Schiff
96 Bradwick Dr.
Concord, On. Canada L4K 1K8
(905) 669-3547 X 334 (v)
(905) 669-8652 (fx)
hschiff@yorku.ca

3. Gases detected -
Methane, ethane, ethylene, acetylene, NO_2, HF, HBr, H_2O, HI, NH_3, HCN, H_2S, CO, CO_2, chloroethylene, HCl, NO, propane, others

4. Detection techniques (passive, active, wavelength (µm), power (W), etc.) - Near-infrared tunable diode laser absorption spectroscopy. Operates in a point-sensor mode (using a multipass cell & gas sampling) and in a long-path absorption mode (using a retroreflector).

5. Instrumental platform (stationary or mobile ==> specify carrier)
Stationary and mobile

6. Gas detection sensitivity (concentration ppm and pathlength required)
Methane detection sensitivity is 2.0 ppm-m (10 ppb for 100-m path), 0.2 ppb for point sampling

7. Range (m) - 1-1000 m (however, retroreflector must be located at sample region).

8. Geometric resolution (mrad) - 0.5˚ FOV telescope, unspecified retroreflector size

9. Field-of-view (degrees) - 0.5˚ FOV telescope, unspecified retroreflector size

10. Detection speed (km/h) - 0.1 seconds

11. Size and weight (mm, kg) - 46 x 22 x 45 cm; 15 kgm

12. Subsequent treatment of data needed - Real-time output.

13. Intentional applications - Remote sensing and/or point monitoring

14. Applications tested and evaluated (brief description of tests performed and results) - Some 30 installations have been operating for periods from months to 2 years in a variety of environments and applications.

15. Safety issues for public, operator and environment - Meets all laser safety requirements.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
Precision - 1%; accuracy - 10%; stability - excellent; service life-indefinite except for occasional cleaning of exterior optical elements depending on environmental conditions. A very rugged and stable system.

17. Operational advantages and limitations -
Advantages: Rugged system, temperature range - 0 to 45˚C. All elements operate at ambient temperature, not affected by humidity or particles. Fiber optic cables can be used to separate the instrument from the sensor location. Multiplexing permits measurements at a number of locations simultaneously with the same instrument.

Limitations: Generally, a separate diode laser must be used for each of a multiple gas measurement although multiplexing can be used to more than one laser in the same instrument.

18. Number of operators needed - For stationary installation - none; for mobile applications - one

19. Cost of operation (USD) -Virtually nothing.

20. Cost of instrument (USD) - Approximately $50K (US)

Overview
This is an airborne topographic differential absorption lidar (DIAL) system that was constructed for military applications and tested in a field campaign. The laser used is a KTA OPO, which allows operation in the 3-5 µm range of the mid-infrared. The test not comprehensive, but indicated methane detection sensitivities of on the order of 100 ppm-m.

1. System identification (name) -
SRI Airborne DIAL Surveillance Sensor

2. Informant (name, postal address, phone, fax, e-mail, homepage)
Edwared Uthe
SRI International
Menlo Park, CA 94025
(650) 859-4667 (v)
(650) 859-5036 (fx)
edward_uthe@sri.com
Papers: “Compact Airborne Lidar System Measures Methane,” Laser Focus World, December, 1995.
“Compact Lidars Search for Air Pollution,” Aviation Week and Space Technology, September 23, 1996.
E.E. Uthe and N.B. Nielsen, “Small-Aircraft Lidar Techniques,” Proceedings Second International Airborne Remote Sensing Conference and Exhibition, San Francisco, California, 24-27 June 1996.

3. Gases detected - Can potentially detect a variety of gases with spectra in the 3-5 µm wavelength range — tested with methane.

4. Detection techniques (passive, active, wavelength (µm), power (W), etc.) - Active topographic reflection differential absorption lidar. Detects integrated column absorption using reflections off solid surfaces. Uses a KTA optical parametric oscillator.

5. Instrumental platform (stationary or mobile ==> specify carrier)
Airborne-tested on a Queen Air aircraft

6. Gas detection sensitivity (concentration ppm and pathlength required)
Not established/gas plume detection depends on background gas concentration. Sensitivity of 100 ppm-m (0.1 ppm-km) indicated.

7. Range (m) - Aircraft flown at 2000 ft. AGL, goal of 10,000 ft.

8. Geometric resolution (mrad) - <1 mrad.

9. Field-of-view (degrees) - 1 mrad.

10. Detection speed (km/h) - Tested at about 300 km/hr.

11. Size and weight (mm, kg) - ~400 lb., two components (52 x 24 x 18 in and 34 x 20 x 16 in.).

12. Subsequent treatment of data needed - Real-time gas concentration possible.

13. Intentional applications - Military application.

14. Applications tested and evaluated (brief description of tests performed and results) - Airborne tests/detection of methane plumes downwind of sources.

15. Safety issues for public, operator and environment - Laser is eye-safe/ aircraft safety meets FAA requirements.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
Not established.

17. Operational advantages and limitations -
Advantages: Wavelength tunability to adjust sensitivity and reduce background gas absorption.

18. Number of operators needed - One and pilot.

19. Cost of operation (USD) - Aircraft $500/hr; operators $2000/day.

20. Cost of instrument (USD) - Unit developed, constructed, and airborne tested for $750K.

Overview
This is a topographic absorption DIAL system that operates in the 9.19-10.78 µm portion of the long-wave infrared. Its intended use is chemical warfare agent detection. It uses four CO_2 lasers - 2 wavelengths to make the DIAL measurement and 2 to correct for target reflectivity. It appears to be much more well-packaged and engineered than comparable systems.

1. System identification (name) -
Remote Active Spectrometer (RAS)

2. Informant (name, postal address, phone, fax, e-mail, homepage)
J.V. Cernius, D.A. Elser, and J. Fox, "Remote Active Spectrometer", SPIE Vol. 1062 - Laser Applications in Meteorology and Earth and Atmospheric Remote Sensing, pp. 203 - 216 (1989).

3. Gases detected - Targeted at chemical warfare agents; detects gases absorbing in the range of 9.19 - 10.78 µm at the emission lines of the CO_2 laser.

4. Detection techniques (passive, active, wavelength (µm), power (W), etc.) - Active topographic reflection differential absorption lidar. Detects integrated column absorption using reflections off solid surfaces. The system contains four CO_2 laser transmitters: two are used for DIAL measurements and two are used to estimate target reflectivity variations. Laser output is 60-80 mJ per pulse.

5. Instrumental platform (stationary or mobile ==> specify carrier)
Tripod-mounted stationary ground unit.

6. Gas detection sensitivity (concentration ppm and pathlength required)
The minimum detectable transmission change is ~4.4-6.0%. This yields a detection sensitivity of 19.1 mg/m^2 for DMMP vapor for an 8-shot average.

7. Range (m) - 0.1 - 2.4 km.

8. Geometric resolution (mrad) - 1.12-1.66 mrad.

9. Field-of-view (degrees) - Can be scanned ±10 elevation, ±38 azimuth.

10. Detection speed (km/h) - Laser repetition rate = 10 Hz; time to generate 4 lines ≤ 1msec; sensitivity specified for 8-shot average - assume that measurement time is 0.8 s.

11. Size and weight (mm, kg) - Tripod mounted system appears to be ~4-5' tall. Requires associated personal computer and two racks of equipment (photo in article). Weight unspecified.

12. Subsequent treatment of data needed - Appears to provide real-time data reduction.

13. Intentional applications - Military application.

14. Applications tested and evaluated (brief description of tests performed and results) -
The system was tested at the Dugway Proving Ground to determine its sensitivity toward chemical warfare agent simulants.

15. Safety issues for public, operator and environment - Not discussed — application probably requires eyesafe operation.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
Not established.

17. Operational advantages and limitations -
Advantages: Rapid wavelength tunability, four lasers can provide additional compensation for reflectivity variations, operates in a range of strong absorption by many organic species.

Disadvantages: Long-wave operation is strongly affected by speckle, system is relatively insensitive.

18. Number of operators needed - Not specified; probably one (after it is set up).

19. Cost of operation (USD) - Not specified.

20. Cost of instrument (USD) - Not specified.

Overview
This is van-mounted DIAL system that was developed under GRI funding for detection of natural gas leaks. The approach taken was to use frequency addition of CO_2 lasers to generate near-3-µm light for detecting ethane (with the goal of reducing the false alarm rate).

1. System identification (name) -
SRI Triple CO_2 DIAL System

2. Informant (name, postal address, phone, fax, e-mail, homepage)
J. Leonelli, P.L. Holland, and J. E. van der Laan, “Multiwavelength and Triple CO_2 Lidars for Trace Gas Detection”, SPIE Vol. 1062 - Laser Applications in Meteorology and Earth and Atmospheric Remote Sensing, pp. 203 - 216 (1989).

3. Gases detected - Methane and ethane; potentially other hydrocarbons .

4. Detection techniques (passive, active, wavelength (µm), power (W), etc.) - Active topographic reflection differential absorption lidar. Detects integrated column absorption using reflections off solid surfaces. Uses a source based on three pulsed CO_2 lasers. One laser is frequency tripled to generate light at ~2931 cm^{-1}; the second is doubled and then summed with the output of a third laser to generate light at about 2996 cm^{-1}. These beams are then combined and transmitted to the target area for making the topographic DIAL measurement.

5. Instrumental platform (stationary or mobile ==> specify carrier)
Van mounted.

6. Gas detection sensitivity (concentration ppm and pathlength required)
The sensitivity is not specified explicitly, but can be inferred from their data. The data plot shows a shot-to-shot noise floor of ~35%. The indicated ethane absorption coefficient is 18 $(atm\ cm)^{-1}$. Equating this noise floor with a minimum detectable absorption and solving for two-pass concentration yields an ethane detection limit of ~13 ppm-m.

7. Range (m) -50

8. Geometric resolution (mrad) - Not specified; single line-of-sight.

9. Field-of-view (degrees) - Not specified; single line-of-sight.

10. Detection speed (km/h) - 50

11. Size and weight (mm, kg) - Not specified; exists as a console (dimensions appear to be ~18” wide x 24” high x 36” deep) and a top-mounted scan unit (dimensions appear to be 14” high x 20” deep x 12 “ wide). Weight unknown.

12. Subsequent treatment of data needed - Not specified — appears to produce real-time data output.

13. Intentional applications - Van-mounted natural gas leak surveying.

14. Applications tested and evaluated (brief description of tests performed and results) -
Article describes calibration; it is believed that the system is not currently operational.

15. Safety issues for public, operator and environment - Not specified.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
Not specified.

17. Operational advantages and limitations -
Advantages: Operation at an ethane absorbing wavelength would reduce false-alarm rates.

Disadvantages: The system sensitivity appears to be lower than what would be required. Topographic DIAL suffers from speckle noise, laser shot fluctuations, and albedo variability.

18. Number of operators needed - Not specified.

19. Cost of operation (USD) - Not specified.

20. Cost of instrument (USD) - Not specified.

Overview

1. System identification
Utra Konsult

2. Informant
Dr. Foster B. Stulen, Battelle, 505 King Ave., Columbus, OH, 43201-2693, USA, ph: 614 424 4856, fx: 614 424 3315, GRI-95/0504, "Airborne Pipeline Integrity Monitoring"

3. Gases detected
Ethane

4. Detection techniques
Passive IR: ground radiance

5. Instrumental platform
airborne: helicopter

6. Gas detection sensitivity
concentration in ppm and pathlength required or leakrate (kg/s) and area (m^2)

7. Range

8. Geometric resolution
mrad

9. Field of view

10. Detectionspeed
km/h

11. Size and weight
of instrument (mm and kg)

12. Subsequent treatment of data needed
if yes then specify type and time

13. Intentional applications
airborne leak detection of natural gas by detecting its ethane component.

14. Application tested and evaluated
the project was abandoned.

15. Safety issues
for public, operator and environment

16. Reliability issues
accuracy, stability, repeatability, service, life, etc.

17. Operational advantages and limitations
weather conditions, etc.

18. Number of operators needed

19. Cost of operation
USD

20. Cost of instrument
USD

Overview
This system is a Raman lidar that is intended to detect methane using Raman backscatter occuring on laser illumination of methane molecules in the atmosphere. The system is truck-mounted and was intended for measurement of methane plume dispersion in the atmosphere. It is capable of measuring methane at levels between 2 and 10% in air at ranges between 110 and 1000 m, with detection times of <1 to 130 seconds.

1. System identification (name) - Optech Raman Lidar

2. Informant (name, postal address, phone, fax, e-mail, homepage)
Optech Incorporated
701 Petrolia Road
Downsview Ontario MJ2 2N6

J.D. Houston, S. Sizgoric, A. Ulitsky, and J. Banic, "Raman lidar system for methane gas concentration measurements", Applied Optics, Vol. 25, pp. 2115-2121 (1986).

3. Gases detected - Methane

4. Detection techniques (passive, active, wavelength (μm), power (W), etc.) - Raman lidar detecting Raman backscatter from methane gas. The system uses an eximer laser excitation source that emits light at 308 nm at an energy per pulse of 30 mJ and a repetition rate of 100 Hz. The receiver collects Raman backscatter photons from the atmosphere at two wavelengths (methane backscatter at 338.4 nm and nitrogen backscatter at 331.8 nm). The nitrogen signal is used to calibrate the methane signal to allow methane concentration measurements to be made. The technique measures the concentration at various range increments along the beam path through the atmosphere, up to the maximum range point.

5. Instrumental platform (stationary or mobile ==> specify carrier)
Truck-mounted, tested in a stationary mode.

6. Gas detection sensitivity (concentration ppm and pathlength required)
Measurement under daylight conditions demonstrated detection of methane at concentrations between 2 and 20% in air at a range of 110 m, using a detection time of 1 second. The detection was made with a range-increment pathlength of ~3 m. From these data, the following integration times and ranges were inferred for detection of 10% methane in air (3-m pathlength): 3 seconds at 200-m range; 4.2 seconds at 500-m range; 46 seconds at an 800-m range; and 130 seconds at a 1 km range.

7. Range (m) 100 m to 1 km.

8. Geometric resolution (mrad) - 2 mrad

9. Field-of-view (degrees) - 2 mrad

10. Detection speed (km/h) - Speed in km/h not applicable. See entry 5 above for detection times required to achieve specified sensitivities and ranges.

11. Size and weight (mm, kg) - Not indicated - the system is a large, truck-mounted lidar.

12. Subsequent treatment of data needed - The data acquisition program collects the range-resolved data and converts it to methane concentration profiles. It is then plotted as a function of range on the monitor.

13. Intentional applications - Measurement of the dispersion of methane plumes in the atmosphere.

14. Applications tested and evaluated (brief description of tests performed and results)
The system was tested in field calibration trials in which the lidar was demonstrated to detect various amounts of methane in nitrogen at a range of 110 m. The results were extrapolated to infer sensitivity at other ranges.

15. Safety issues for public, operator and environment - Not discussed. The most likely issue is eye safety for the 30 mJ per pulse transmitted laser beam.

16. Reliability issues (accuracy, stability, repeatability, service, life, etc.)
Not applicable - experimental system.

17. Operational advantages and limitations -
Advantages - Only one laser required. Simple receiver.
Limitations - Sensitivity is rather low; the system is large; the transmitted laser energy is high causing concerns for eye safety.

18. Number of operators needed - Not indicated.

19. Cost of operation (USD) - Not specified.

20. Cost of instrument (USD) - Not specified.

Overview
This entry documents general capabilities of passive FTIR instruments at the Aerospace Corporation. They have several systems operating in the 8-12 and 3-5 micron infrared atmospheric windows. A typical sensitivity of 0.5 ppm-m for sulfur hexafluoride is stated. Detection at ranges of 5-25 km is indicated. Systems have been developed in ground-based, vehicle-mounted, and airborne formats.

1. System identification
Aerospace Corporation FTIR spectrometers

2. Informant
Tom Knudtson - Dirctor
Surveillance Technologies Department
The Aerospace Corporation
Space and Environment Technology Center
P.O. Box 92957 - M2/747
Los Angeles, CA 90008-2957
310-336-8705 (ph)
310-336-6524 (fx)
tom.j.knudtson@aero.org

3. Gases detected
All gases that absorb in the 8-12 or 3-5 micron atmospheric window.

4. Detection techniques
Passive infrared absorption/emission detected using an FTIR spectrometer.

5. Instrumental platform
Truck-mounted, ground-mounted, and airborne (twin-engine aircraft).

6. Gas detection sensitivity
Depends on many conditions. Typical example is SF_6 detection at a concentration of 0.5 ppm-meters.

7. Range
Depends upon conditions - 5-25 km.

8. Geometric resolution (mrad) - 0.5 degrees

9. Field-of-view
0.5 degrees

10. Detection speed
25 - 100 spectra per second.

11. Size and weight
1ft x 1ft x 1ft; 25-250 lb, depending upon configuration.

12. Subsequent treatment of data needed
Some data calibration required.

13. Intentional applications
Remote sensing of gases.

14. Applications tested and evaluated
FTIR systems have been used to detect a wide variety of industrial (SO_2) and military (chemical warfare agent simulants) gases. Has been used to locate, identify, and quantify airborne gas clouds for many customers and problems.

15. Safety issues for public, operator and environment
None.

16. Reliability issues
Very reliable.

17. Operational advantages and limitations
Advantages - Low cost, lightweight, low power.
Limitations -

18. Number of operators needed
Typically one; autonomous operation possible.

19. Cost of operation
Depends upon requirements.

20. Cost of instrument
~$200K.

Overview

1. System identification
Sensors for leak detection for natural gas vehicles

2. Informant
Clifford, Paul K., Dorman, Michael G.,Mosaic Industries, Inc., Newark, CA, BDM-Oklahoma, Inc., Bartlesville, OK,
"Research and Development of a Highly Reliable Leak detection System for Natural Gas Vehicles", GRI-98/0205, 1998.

3. Gases detected
Methane

4. Detection techniques
Multi-sensor incorporating both metal oxide semiconductor and catalytic bead sensors.

5. Instrumental platform
Natural gas vehicles, fire suppression systems, refueling centers, and transit companies.

6. Gas detection sensitivity

7. Range
N/A

8. Geometric resolution
N/A

9. Field-of-view (degrees)
N/A

10. Detection speed (km/h)
N/A

11. Size and weight

12. Subsequent treatment of data needed
No

13. Intentional applications
Natural gas vehicles and related infrastructure.

14. Applications tested and evaluated
A prototype was tested and a new leak detector made available for field testing.

15. Safety issues for public, operator and environment

16. Reliability issues (accuracy, stability, repeatability

17. Operational advantages and limitations

18. Number of operators needed
None

19. Cost of operation (USD)

20. Cost of instrument (USD)

Owerviev

1. System identification
Helium and hydrogen to pinpoint gas leaks.

2. Informant
Henningsen, T., Malingowski, J. S., and Supertzi, E. P., Westinghouse Science and Technology Center, Pittsburgh, PA,
"Use of Helium to Pinpoint Gas Leaks from Buried Pipes", GRI-96/0024, 1996

3. Gases detected
Helium and hydrogen

4. Detection techniques

5. Instrumental platform

6. Gas detection sensitivity

7. Range
Contact

8. Geometric resolution
N/A

9. Field-of-view
N/A

10. Detection speed
N/A

11. Size and weight

12. Subsequent treatment of data needed

13. Intentional applications
Leak pinpointing

14. Applications tested and evaluated
No advantage of using helium or hydrogen for more accurate leak location was demonstrated

15. Safety issues for public, operator and environment

16. Reliability issues

17. Operational advantages and limitations
Helium and hydrogen have a higher mobility in soil than methane and were postulated to reach the surface above a gas leak by a more direct route than methane.

18. Number of operators needed

19. Cost of operation

20. Cost of instrument

Overview
In situ measurements with flame ionisation detection, collecting samples during helicopter flight, by nuclear absorption spectrometry

1. System identification
Aerial detection of pipeline leakage fumes using a helicopter mounted flame ionization detector.

2. Informant
Sparks, Cecil R., and Morrow, Thomas B., Southwest Research Institute, San Antonio, TX
"Field Report on Aerial Detection of Pipeline Leakage Plumes", GRI-97/0409, 1997

3. Gases detected
Methane

4. Detection techniques
Flame ionization

5. Instrumental platform
Helicopter

6. Gas detection sensitivity
A few ppm or better.

7. Range
Contact

8. Geometric resolution
N/a

9. Field-of-view
N/A

10. Detection speed
100 km/h

11. Size and weight

12. Subsequent treatment of data needed

13. Intentional applications

14. Applications tested and evaluated
Release rates or 25 to 100 standard cubic feet did not produce plume sizes and concentrations that could be detected reliably. Dispersion modeling showed that a release rate of 100 SCFM will produce marginally detectable plumes.

15. Safety issues for public, operator and environment

16. Reliability issues
Found to be not reliable

17. Operational advantages and limitations
N/A

18. Number of operators needed
N/A

19. Cost of operation
N/A

20. Cost of instrument
N/A

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10. Geiger, Allen R.; Prasad, S.N., PetroLaser Inc., Las Cruces, NM, USA "Mid-infrared DIAL lidar for petroleum exploration and pipeline monitoring", Novel Applications of Lasers and Pulsed Power, Proceedings of SPIE - The International Society for Optical Engineering v 2374 1995. Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, USA. p 240-248.

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13. Holland, P. L. SRI International, Menlo Park, CA., "GMBU (Ground Mobile Breadboard Upgrade) Lidar and Bubbler Correlation Study at Dugway Proving Ground" (Technical rept. Aug-Dec 8) Army Dugway Proving Ground, UT. Report No.: DPG-FR-89-901 17 Mar 89 30p

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