be observed with reasonable efficiency only by using scintillation detectors. However, as can be seen by comparing the gamma-ray spectra of Fig. 1, germanium detectors increase by a large factor our ability to analyze complex samples and therefore have made a significant difference to all types of activation analysis. Recently, these methods have been applied to the analysis of pottery and other artifacts of interest to archeologists (*21*).

### Conclusion

The past decade has seen the rapid development and exploitation of one of the most significant tools of nuclear physics, the semiconductor radiation detector. Applications of the device to the analysis of materials promises to be one of the major contributions of nuclear research to technology, and may even assist in some aspects of our environmental problems. In parallel with the development of these applications, further developments in detectors for nuclear research are taking place: the use of very thin detectors for heavy-ion identification, position-sensitive detectors for nuclear-reaction studies, and very pure germanium for making more satisfactory detectors for many applications suggest major future contributions to physics.

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# Air Pollution Surveillance Systems

George B. Morgan, Guntis Ozolins, and Elbert C. Tabor

The activities of man, the intellectual species, must be in harmony with the natural environment. Such harmony, however, will be achieved only when precepts for managing the renewable resources are as firmly entrenched in our individual lore of survival as the tutored reflex to "look both ways before crossing the street." Until that day arrives, organized society will have to compensate collectively for indifferent, careless, or deliberately negligent individuals. Policing the potability of drinking water is representative of such community action on behalf of the individual. Likewise, management of our air resources is increasingly being recognized as a new community responsibility.

Surveillance of air pollution is an integral and very important part of the total effort to control air pollution. The data derived from atmospheric monitoring and emission measurements are required throughout the various stages of the abatement effort. Atmospheric surveillance efforts serve to identify the pollutants emitted to the air, to establish their concentrations, and to record their trends and patterns. Subsequently, after air quality and emission standards have been legislated, surveillance systems may be used to evaluate the progress being made in meeting standards, and to facilitate direct enforcement activities including the activation of emergency control procedures during episodes of high air pollution.

In the following discussion of surveillance we shall briefly summarize the types of pollutants and their sources, describe the current instrumentation and anticipated developments of more specific and sensitive sensors, and discuss the contrast between the air quality in our nation's urban environment and that of the rural environment or so-called background air quality.

## Nature and Origins of Pollutants

Air pollutants can occur in the form of gases, solid particles, or liquid aerosols. These forms can exist either separately or in combinations; for example, gases may be sorbed on particulates or in liquid droplets (*1*). Gaseous pollutants constitute about 90 percent of the total mass emitted to the atmosphere, and particulates and liquid aerosols make up the other 10 percent.

Gaseous pollutants are evolved primarily from combustion of fuels and refuse. In the case of sulfur oxides, the burning of high-sulfur fuels in stationary sources is the primary source.

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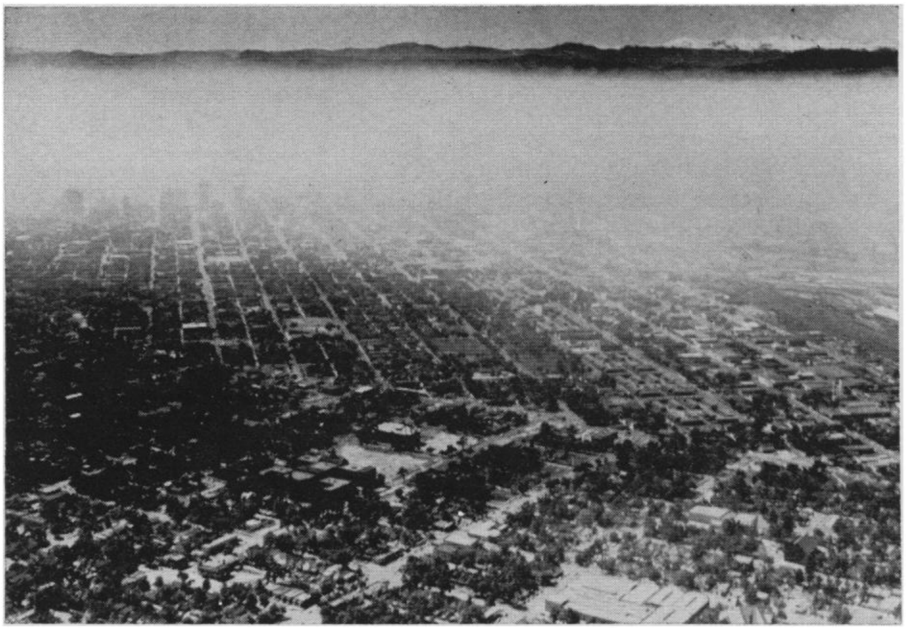

Fig. 1. Inversion and stagnation in the Denver basin.

Fig. 2. St. Louis Missouri, 14 November 1966. Smog shrouds buildings and part of the Mark Twain Expressway in part of downtown St. Louis. The Gateway Arch rises above the smog as it begins to lift. [Wide World Photos, Inc.]

Motor vehicles account for most of the carbon monoxide and hydrocarbon emissions which result from the incomplete combustion of the fuel used. Estimated emissions of particulates and the principal gaseous pollutants for the United States for 1968 are shown in Table 1 (*2*).

Particulates are emitted by a diverse group of sources and vary over a wide range of sizes, shapes, densities, and chemical compositions. Combustion of fuels, incineration of waste materials, and industrial process losses are responsible for the major share of particulate pollutants. Abrasion and wear of materials plus reentrainment resulting from vehicular traffic and wind action make a small contribution to the total burden. Even though particulates make up only 10 percent of the total quantity of pollutants released to the atmosphere, they are a significant problem because of their widely varying economic and biological effects (*3*).

Particulate pollutants are readily transported and dispersed by the wind (*4*). Small particles essentially become permanent residents in the atmosphere until removed by some process such as rainout, or by agglomeration into larger particles. Included in this size range are the respirable particulates, that is, those particles smaller than about 10 micrometers (*5*). This range also includes the particles that increase atmospheric turbidity, which attenuates both solar and terrestrial infrared radiation, and thereby is capable of affecting climate on a global basis (*6*).

Given suitable conditions, many of the primary pollutants (those gases and particulates that are emitted directly from sources) will participate in reactions in the atmosphere that produce secondary pollutants such as those found in photochemical smog. One example of the production of secondary pollutants is the combination of water vapor with acid anhydrides to produce an acid aerosol that is corrosive. Particulates may provide a substrate for such atmospheric reactions or may contain metallic catalysts. Solar energy, primarily the ultraviolet portion of the spectrum, accelerates these reactions.

Concentrations of pollutants are extremely variable from one city to another and also within a given urban area. The relative intensity and spatial configuration of sources, the topography, and the meteorology of an area affect pollutant concentrations. Zones of heavier pollution in each city are caused by the clustering of major sources of air pollution, that is, traffic-congested central business districts and industrial sectors (Fig. 1). In cities characterized by good ventilation, emissions are dispersed more rapidly than in cities that are surrounded by hills or where the winds are low and temperature inversions are frequent.

Table 1. Estimated emissions of principal pollutants in the United States during 1968 (in metric tons per year × $10^6$).

| Source | Particulates | Sulfur oxides ($SO_x$) | Nitrogen oxides ($NO_x$) | Carbon monoxide | Hydrocarbons (HC) |
|---|---|---|---|---|---|
| Stationary fuel combustion | 8.1 | 22.1 | 9.1 | 1.7 | 0.6 |
| Mobile fuel combustion | 1.1 | 0.7 | 7.3 | 57.9 | 15.1 |
| Combustion of refuse | 0.9 | 0.1 | 0.5 | 7.1 | 1.5 |
| Industrial processes | 6.8 | 6.6 | 0.2 | 8.8 | 4.2 |
| Solvent evaporation | | | | | 3.9 |
| Total | 16.9 | 29.5 | 17.1 | 75.5 | 25.3 |

Even areas with typically good dispersion can occasionally suffer pollution episodes when a stagnant high-pressure air mass persists (Fig. 2). The Environmental Science Services Administration (ESSA), in cooperation with the National Air Pollution Control Administration (NAPCA), provides forecasts of stagnant conditions through the issuance of High Air Pollution Potential Advisories. An example of the forecast maps which can be produced from these data is shown in Fig. 3 (*7*). The extensive area covered by the advisory report indicates the need for nationwide forecasting and coordinated control strategies.

## Surveillance

The first national air surveillance system was implemented in 1953 when the Public Health Service, in cooperation with state and local health departments, set up air sampling stations in 17 communities. Samples were collected primarily to permit the determination of total airborne protein. In addition, they were analyzed for total suspended particulates, organic matter soluble in benzene and acetone, and several inorganic pollutants. At present NAPCA is collecting air quality data for the pollutants listed in Table 2. Table 3 presents some typical average concentrations of some of these pollutants for the period from 1964 to 1965.

The present-day surveillance of the nation's air quality is a cooperative effort involving local, state, and federal air pollution control agencies. There are over 7,000 sampling stations, with some 14,000 samplers, located throughout the United States (Table 4). They range in complexity from simple static sampling devices to continuous sampler-analyzers that record the concentrations of numerous gaseous air pollutants. Most of these sampling stations are located in the major metropolitan areas of the country. Table 4 provides an analysis of current sampling activities in the United States by type of sampler and pollutant.

The surveillance conducted by state and local air pollution control agencies is directed toward enforcement activities. Aerometric data are used to appraise concentrations of specific pollutants to determine if they exceed the standards, to provide direct control actions, to determine ambient air quality in nonurban areas of a region, and to provide air quality data during air pollution episodes. These surveillance systems are primarily designed to sample for pollutants for which criteria documents have been issued, that is, total suspended particulates, sulfur dioxide, carbon monoxide, total oxidants, and total hydrocarbons. The placement or location of sampling stations within the surveillance network must be such that ensuing data can be gainfully employed to meet the following objectives: (i) Stations must be oriented to define air quality in heavily polluted areas; (ii) stations must be oriented to define air quality in heavily populated areas; (iii) stations must be located to provide area-wide representation of ambient air quality; (iv) stations must be oriented with respect to the source category or source, or both, to provide feedback relative to the effectiveness of adopted control strategies.

Table 2. Atmospheric pollutants currently being measured by NAPCA.

*Elements*

Antimony
Arsenic
Barium
Beryllium
Bismuth
Boron
Cadmium
Chromium
Cobalt
Copper
Iron
Lead
Manganese
Mercury
Molybdenum
Nickel
Selenium
Tin
Titanium
Vanadium
Zinc

*Radicals*

Ammonium
Fluoride
Nitrate
Sulfate

*Others*

Aeroallergens
Asbestos
β-Radioactivity
Benzene-soluble organic compounds
Benzo[*a*]pyrene
Pesticides
Respirable particulates
Total suspended particulates

*Gases*

Carbon monoxide
Methane
Nitric oxide
Nitrogen dioxide
Pesticides
Reactive hydrocarbons
Sulfur dioxide
Total hydrocarbons
Total oxidants

The federal monitoring system provides a uniform data base throughout the country against which all other air quality data can be verified; this system measures pollutants that are expensive or unusually difficult to analyze, identifies and quantifies new or newly recognized pollutants, conducts research in measurement techniques, and demonstrates the impact of pollutant emissions on the air quality of both urban and nonurban areas.

## Instrumentation

Solid-state or advanced sensors that have sensitivity, specificity, and reliability are urgently needed and would overcome the problems that now exist with present wet chemical methods. In addition, new techniques will be needed as the air pollution control effort is expanded to encompass the less abundant and newly recognized air pollutants. Examples of some of the pollutants for which adequate or economical instrumentation and analytical techniques are not yet available include asbestos, pesticides, mercury, odors, and selenium. It is important that measurement methods be capable of providing information for averaging times (*8*) consistent with established air quality standards.

A variety of sampling devices are currently being used to evaluate ambient air quality. Table 5 illustrates the general classes and their applicability. Mechanized samplers are the most generally used in surveillance systems to collect integrated samples in the field. The most common of these devices is NAPCA's high volume (Hi-Vol) sampler which collects particulates on glass-fiber filters. Analysis of these samples provides information on concentrations of total suspended particulates, trace metals, and other organic and inorganic pollutants. In addition to the glass-fiber

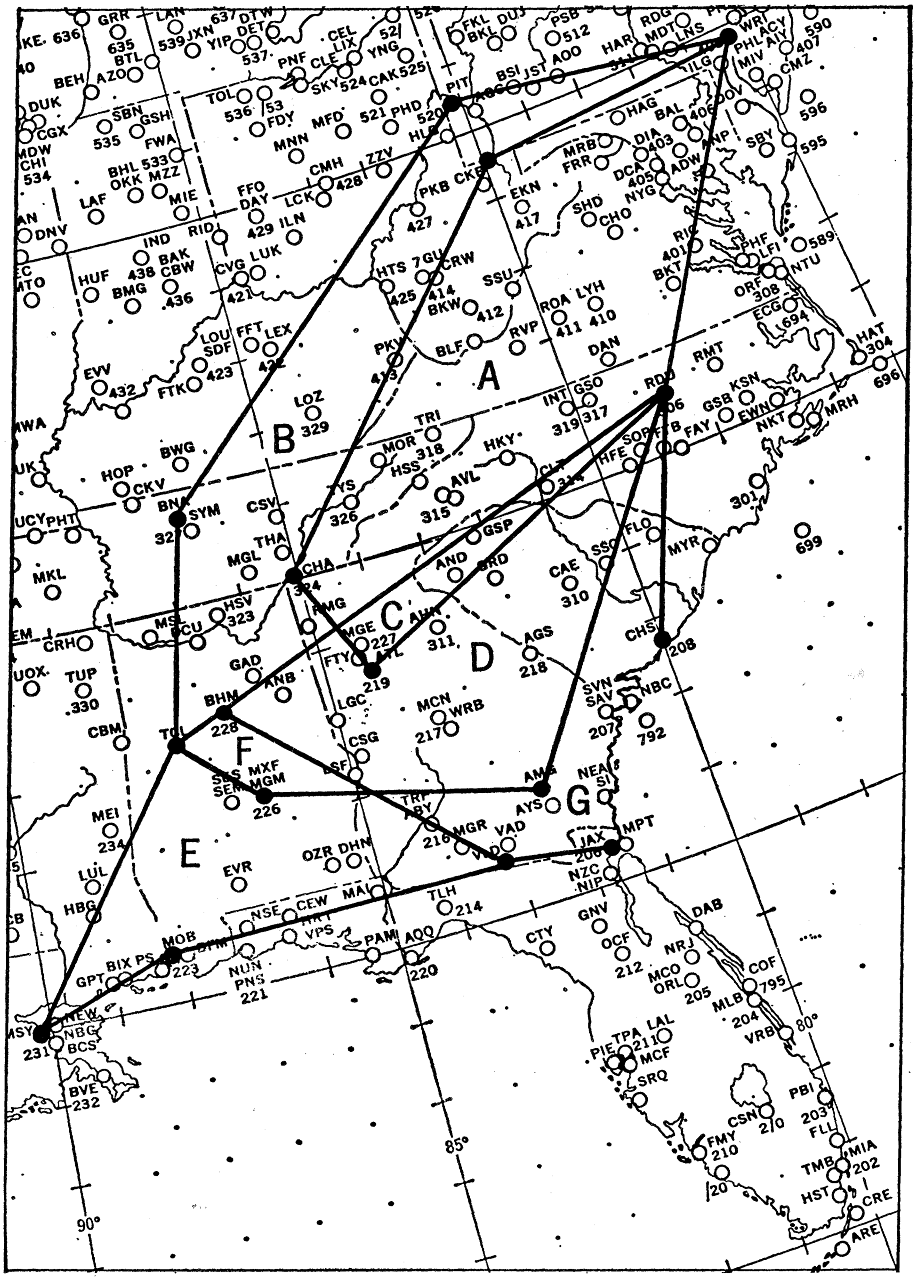

Fig. 3. Advisory No. 122 (National Meteorological Center Advisory of High Air Pollution Potential, 28 July to 1 August 1970, 1300 E.S.T.).
28 July: begin areas *A*, *C*
29 July: continue areas *A*, *C*
begin areas *B*, *D*, *F*
30 July: continue areas *C*, *D*, *F*
begin areas *E*, *G*,
end areas *A*, *B*
31 July: continue areas *E*, *F*,
end areas *C*, *D*, *G*
1 August: end areas *E*, *F*
ESSA Meteorological Support Unit statements of local high air pollution potential, 27 July to 30 July 1970.
27 July: Washington, D.C. (and Baltimore, Md..), begin 1130 E.D.T.
28 July: Washington, D.C. (and Baltimore, Md.), continue;
Philadelphia, begin 1300 E.D.T.
29 July: Washington, D.C. (and Baltimore, Md.), continue;
Philadelphia, continue;
New York City, local statement on dispersion conditions (not local high air pollution potential) were issued at 1100 and 1500 E.D.T.
30 July: Washington, D.C. (and Baltimore, Md.), end 1700 E.D.T.;
Philadelphia, end 1200 E.D.T.

filter, the membrane filter is used to collect for subsequent analysis pollutants such as zinc, asbestos, boron, and silicates. Impactors of different designs are used to measure fractions of suspended particulates of various particle sizes in the respirable range.

Mechanized bubbler devices may be employed to collect sulfur dioxide, nitrogen dioxide, oxidants, hydrogen sulfide, aldehydes, carbon dioxide, and ammonia. These samplers, although typically designed for the collection of 24-hour integrated samples, can be modified to collect 1- or 2-hour samples in sequence, for the definition of diurnal variations. In the automatic sampler-analyzer the collection and analytical processes are combined in a single device. This type of instrument produces a continuous analysis with the output in a machine-readable format or in a form suitable for telemetry to a central data-acquisition facility. Continuous analyzers of this type are now available for carbon monoxide, carbon dioxide, nitric oxide, nitrogen dioxide, sulfur dioxide, total hydrocarbons, methane, oxidants, ozone, and hydrogen sulfide. Although a large number and variety of these analyzers are on the market, only a few have been properly field-tested to determine their limitations, reliability, and durability and to provide necessary information on interferences.

The National Air Pollution Control Administration, in cooperation with the Intersociety Committee (*9*), is actively engaged in the development of standard methods. In the interim, the criteria documents published by NAPCA under the provisions of the Clean Air Act of 1967 include recommendations that reference methods be used for the intercomparison of analysis schemes.

For the production of valid data, by whatever method, it is vital that calibration of the sensors be maintained by use of a dynamic system. Pollutants are commonly found in the atmosphere in such low concentrations that the production of calibration standards is a problem. The National Air Pollution Control Administration has developed permeation devices for a few gases (*10*) which, when properly employed in a dynamic calibration system, can be used to deliver known quantities of certain gases for spiking ambient air. Techniques for the dynamic calibration of particulate samplers, especially with regard to size fractionation, are poorly developed at this time.

## Future Instrument Development

In the past, the operation of most mechanized and automatic analyzers has been based on wet chemical methods. These methods have inherent problems and are not entirely satisfactory for typical field applications because they must be attended frequently, reagents are unstable, and the instrumentation requires complex plumbing and accurate solution pumps with the result that the instruments are heavy and bulky. Future instruments hopefully will utilize the physical or physicochemical properties of pollutants for identification and quantification.

The following new instruments are now in the final stages of development and field-testing by NAPCA:

1) A chemiluminescent method for determining ozone.

2) A flame-luminescent method for measuring sulfur.

3) A triple system for continuously measuring carbon monoxide, sulfur dioxide, and nitrogen dioxide. The sensors in this system are based upon the fuel-cell principle and time-share the circuitry.

4) An automated gas chromatograph for the simultaneous determination of carbon monoxide, methane, and total hydrocarbons.

5) An automated gas chromatograph for measuring hydrogen sulfide and certain organic sulfides.

6) A special adaptation of lidar (light detection and ranging) instruments for estimating concentrations of atmospheric particulates.

7) An atomic absorption method for continuously measuring lead.

8) A piezoelectric instrument for the continuous measurement of particulate concentrations.

9) A specific-ion electrode method for the continuous measurement of fluorides.

10) A method for determining oxides of nitrogen in which ozone is titrated in the gas phase with a reactive gas and the reaction produces light by chemiluminescence.

Extensive research is in progress to develop remote sensing devices to be used at ground level, in aircraft, and in earth satellites for area-scanning and profiling. The application of newer laboratory techniques such as microwave absorption spectrometry (*11*), electron or ion microprobe analysis (*12*), and neutron activation analysis (*13*) have recently been reported. In NAPCA's

Table 3. Arithmetic mean and maximum urban particulate concentrations in the United States, biweekly sampling, 1964 to 1965 (*16*, p. 16).

| Pollutant | Number of stations | Concentrations ($\mu$g/m$^3$) | |
|---|---|---|---|
| | | Arithmetic average* | Maximum |
| Suspended particulates | 291 | 105 | 1254 |
| Fractions: | | | |
| Benzene-soluble organic compounds | 218 | 6.8 | † |
| Nitrates | 96 | 2.6 | 39.7 |
| Sulfates | 96 | 10.6 | 101.2 |
| Ammonium | 56 | 1.3 | 75.5 |
| Antimony | 35 | 0.001 | 0.160 |
| Arsenic | 133 | 0.02 | † |
| Beryllium | 100 | $< 0.0005$ | 0.010 |
| Bismuth | 35 | $< 0.0005$ | 0.064 |
| Cadmium | 35 | 0.002 | 0.420 |
| Chromium | 103 | 0.015 | 0.330 |
| Cobalt | 35 | $< 0.0005$ | 0.060 |
| Copper | 103 | 0.09 | 10.00 |
| Iron | 104 | 1.58 | 22.00 |
| Lead | 104 | 0.79 | 8.60 |
| Manganese | 103 | 0.10 | 9.98 |
| Molybdenum | 35 | $< 0.005$ | 0.78 |
| Nickel | 103 | 0.034 | 0.460 |
| Tin | 85 | 0.02 | 0.50 |
| Titanium | 104 | 0.04 | 1.10 |
| Vanadium | 99 | 0.050 | 2.200 |
| Zinc | 99 | 0.67 | 58.00 |
| | *Gross β-radioactivity* | | |
| | 323 | 0.8 pc/m$^3$ | 12.4 pc/m$^3$ |

* Arithmetic averages are presented to permit comparable expression of averages derived from quarterly composite samples. † No individual sample analyses performed.

Table 4. Estimated number of air surveillance devices in routine operation in the United States, June 1970. Static equipment passively depends upon the natural movement of air currents to bring pollutants to the collector. Mechanized collection devices accumulate samples continuously or intermittently for subsequent laboratory analysis. Automatic devices are continuously operating sampler-analyzers that produce results directly in numerical or visual form, or both.

| Pollutant and method | Nonfederal agencies | NAPCA | Total |
|---|---|---|---|
| | *Static* | | |
| Gases: sulfation rate | 2,933 | 214 | 3,147 |
| Particulates: | | | |
| Settleable (dustfall) | 3,220 | | 3,220 |
| Windblown (sticky paper) | 897 | | 897 |
| | *Mechanized* | | |
| Gases: | | | |
| Aldehydes | 271 | | 271 |
| Ammonia | 262 | | 262 |
| Nitrogen dioxide | 362 | 200 | 562 |
| Oxidants | 395 | | 395 |
| Mercury | | 50 | 50 |
| Sulfur dioxide | 515 | 200 | 715 |
| Hydrogen sulfide | 153 | | 153 |
| Particulates: | | | |
| Suspended (Hi-Vol) | 2,074 | 293 | 2,367 |
| Membrane filter | | 55 | 55 |
| Cascade-fractional | | 15 | 15 |
| Soiling (spot tape) | 461 | 10 | 471 |
| | *Automatic* | | |
| Gases: | | | |
| Aldehyde | 16 | | 16 |
| Carbon monoxide | 218 | 10 | 228 |
| Carbon dioxide | 10 | | 10 |
| Hydrogen sulfide | 83 | | 83 |
| Nitric oxide | 117 | 17 | 134 |
| Nitrogen dioxide | 189 | 17 | 206 |
| Oxidants | 122 | 14 | 136 |
| Sulfur dioxide | 235 | 44 | 279 |
| Particulates: | | | |
| Soiling (automatic tape) | 367 | 7 | 374 |
| Total | 12,900 | 1,146 | 14,046 |

laboratories emission spectrometry, atomic absorption spectrometry, chromatography, and several other techniques are now computer-interfaced and in routine use.

## Data Handling and Analysis

A vital part of any successful surveillance system is the processing and reporting of the data in a format that can be used conveniently by the control official or researcher. The National Air Pollution Control Administration is developing a National Aerometric Data Information Service (NADIS) which will incorporate the present National Aerometric Data Bank (NADB) and a software system for the Storage and Retrieval of Aerometric Data (SAROAD), which provides a system for reporting, storing, and analyzing aerometric data from a wide variety of sources. All agencies collecting air quality and emission data are urged by NAPCA to use this format. These efforts will put all aerometric data on a comparable basis and will permit data from various regions of the United States to be compared.

## Current Air Quality and Trends

A recent summary of data on suspended particulates from 60 urban stations (*14*) for the period 1957 to 1966 shows a slight downward trend at most

Table 5. Classification of air pollution sampling techniques. Cost basis: low, 0 to $500; moderate, $500 to $2000; high, above $2000. Personnel training: low, maintenance level; moderate, technician; high, experienced technician or professional with professional support staff.

| Type | Use | Specificity | Common averaging time | Relative cost | Required training of personnel | Remarks |
|---|---|---|---|---|---|---|
| | | | | *Static* | | |
| Settleable particulates (dustfall) | Mapping and definition of special problem areas | Total settled particulates and general classes of pollutants | 1 month | Collection, low; analysis, high | Collection, low; analysis, moderate | Well-equipped laboratory required for analysis only for definition of problem areas where a chemical analysis will pinpoint a particular source. Sensitive to temperature, wind, and humidity. |
| Sulfation devices | Mapping and general survey for sulfur dioxide | Responds to oxides of sulfur, hydrogen sulfide, and sulfuric acid | 1 month | Collection, low; analysis, high | Collection, low; analysis, moderate to high | |
| | | | | *Mechanized* | | |
| Hi-Vol | Integrated quantification of suspended particulate | Total suspended particulate and multiple specific pollutants | 24 hours | Moderate | Moderate | Detailed chemical analysis of Hi-Vol and gas samples requires sophisticated laboratory, trained chemists; cost is high. |
| Gas sampler | Integrated quantification of gases | Sulfur dioxide, nitrogen dioxide, ammonia, total oxidants, aldehydes, and other gases | 24 hours | Moderate | High | |
| Spot tape sampler | Relative soiling index | Unknown | 2 hours | Low | Low | Provides only a rough, relative index of particulate soiling. |
| | | | | *Automatic* | | |
| Gas | Continuous analysis of gaseous pollutants | Single gas or group of related gases | Continuous; sample integration usually 1 to 15 minutes | Moderate to high | Moderate to high | Continuous measurements allow use of any desired averaging time by computation. Accuracy is generally much better than other methods. Calibration is simplified. Data are available instantaneously. |
| Particulate: soiling (automatic tape) | Continuous analysis of soiling rate | Unknown | Continuous; sample integration usually 1 to 15 minutes | Moderate | Moderate | |

Table 6. Distribution of National Air Surveillance Network data from stations that monitor suspended particulates for 1968. Entry in body of table shows number of center-city stations, grouped by city population, whose annual geometric means fall in each concentration range. Boldface values indicate concentration range in which urban U.S. standards were being set as of July 1970 (*17*).

| Population | Suspended particulates ($\mu g/m^3$) 0–19 | 20–39 | 40–59 | 60–79 | 80–99 | 100–119 | 120–139 | 140–159 | 160–179 | 180–199 | 200 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | *Urban* | | | | | | | |
| > 3,000,000 | | | | | | 2 | | | | | | 2 |
| 1,000,000 to 3,000,000 | | | | | | 1 | 2 | | | | | 3 |
| 700,000 to 1,000,000 | | | 1 | **2** | 3 | | 3 | | | | | 9 |
| 400,000 to 700,000 | | | 1 | **4** | 9 | 1 | 1 | **1** | **1** | | | 18 |
| 100,000 to 400,000 | | | 6 | **25** | 16 | 17 | 5 | **1** | **2** | **1** | 1 | 74 |
| 50,000 to 100,000 | | | 5 | **18** | 19 | 12 | 4 | **3** | | | 1 | 62 |
| 25,000 to 50,000 | | 4 | 13 | **16** | 7 | 2 | 2 | | | | 2 | 46 |
| 10,000 to 25,000 | | 3 | 12 | **15** | 7 | 5 | | **1** | | | | 43 |
| < 10,000 | | **7** | 8 | **18** | 11 | 1 | 1 | | **1** | | | 47 |
| Total | | 14 | 46 | **98** | 72 | 41 | 18 | **6** | **4** | **1** | 4 | 304 |
| | | | | | *Nonurban* | | | | | | | |
| | 10 | 16 | 4 | | | | | | | | | |

Table 7. Distribution of National Air Surveillance Network data from stations monitoring sulfur dioxide for 1968. Entry in body of table shows number of center-city stations, grouped by city population, whose annual arithmetic means fall in each concentration range. Boldface values indicate concentration range in which urban U.S. standards were being set as of July 1970 (*17*).

| Population | Sulfur dioxide ($\mu g/m^3$) 0–9 | 10–19 | 20–29 | 30–39 | 40–49 | 50–59 | 60–69 | 70–79 | 80–89 | 90–99 | > 100 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *Urban* | | | | | | |
| > 3 million | | | | | | | | | | | 2 | 2 |
| 1,000,000 to 3,000,000 | | | | | | | 1 | | | 1 | | 2 |
| 700,000 to 1,000,000 | 1 | 3 | | 1 | | | 1 | | 3 | 1 | | 10 |
| 400,000 to 700,000 | 2 | 5 | 5 | 3 | | **1** | | 1 | | | 1 | 18 |
| 100,000 to 400,000 | 7 | 5 | 11 | 2 | **5** | **4** | 2 | 2 | 2 | | 2 | 42 |
| 50,000 to 100,000 | 1 | 4 | 2 | 2 | | | 2 | 1 | 1 | | | 13 |
| 25,000 to 50,000 | 1 | 1 | | | **1** | | | | | | | 3 |
| 10,000 to 25,000 | 1 | 2 | 1 | | | | | | | | | 3 |
| < 10,000 | 13 | 1 | 2 | | | **1** | | | | | | 5 |
| Total | | 21 | 21 | 8 | **6** | **6** | 6 | 4 | 6 | 2 | 5 | 98 |
| | | | | | | *Nonurban* | | | | | | |
| | 2 | 3 | | | | | | | | | | |

center-city sites. This trend results primarily from urban renewal, replacement of coal by fuel oil and gas for space heating, and more effective control of particulate emissions. In comparison, an analysis over a period of 10 years of data on suspended particulates from 20 nonurban locations shows an upward trend at stations that are considered rural.

A comparison of Tables 6 and 7 indicates two distinct patterns of pollution. The incidence of suspended particulates is not directly related to city size; in fact, stations with the highest levels are found in medium-sized, heavily industrialized cities. In large urban areas, the sources of particulate pollution are dispersed, whereas in heavily industrialized, medium-sized cities sources generally are clustered in areas proximate to the urban core. In contrast, sulfur dioxide concentrations are usually higher in large cities because of the combustion of fossil fuels for space heating and power. These sulfur dioxide sources are also more evenly distributed than particulate sources. A linear relationship exists between population and sulfur dioxide pollution. This relationship is quite evident for areas where high-sulfur fuels are in general use.

The numbers in boldface type in Tables 6 and 7 indicate the approximate range for yearly averages of total suspended particulates and sulfur dioxide at which ambient air quality standards are being set (*15, 16*). The data in Tables 6 and 7 represent center-city sites, and in many cases the concentrations are not necessarily the highest concentrations existing within the community.

Table 8 shows average concentrations of carbon monoxide, nitric oxide, nitrogen dioxide, sulfur dioxide, hydrocarbons, and oxidants at NAPCA's six continuous-monitoring stations. No clear trends have been identified in the concentration of these gaseous pollutants at these six center-city sites, an indication that for some time emissions have essentially reached a plateau, probably because of source saturation of the centers of most cities.

## Summary

Atmospheric surveillance is necessary in order to identify airborne pollutants, to establish ambient concentrations of these pollutants, and to record their trends and patterns. Air pollutants may occur in the form of gases, liquids, and solids, both singly and in combination. Gaseous pollutants make up about 90 percent of the total mass emitted to the atmosphere with particulates and aerosols accounting for the remaining 10 percent. Small particulates are of particular importance because they may be in the respirable size range. These small particles may contain biologically active elements and compounds. Furthermore, they tend to remain in the atmosphere where they interfere with both solar and terrestrial infrared radia-

Table 8. Average 1968 concentrations of carbon monoxide, nitric oxide, nitrogen dioxide, sulfur dioxide, hydrocarbons, and total oxidants at NAPCA's continuous monitoring stations.

| Concentration | CO (mg/ $m^3$) | NO ($\mu g$/ $m^3$) | $NO_2$ ($\mu g$/ $m^3$) | $SO_2$ ($\mu g$/ $m^3$) | HC (mg/ $m^3$) | $O_x$ ($\mu g$/ $m^3$) |
|---|---|---|---|---|---|---|
| | | *Chicago* | | | | |
| Annual av. | 7.1 | 89 | 90 | 310 | 1.9 | 47 |
| Max. monthly av. | 8.2 | 130 | 110 | 700 | 2.2 | 86 |
| Max. 24-hr. av. | 18.0 | 280 | 190 | 1340 | 3.5 | 220 |
| Max. 1-hr. av. | 46.0 | 750 | 340 | 2300 | 8.1 | 350 |
| | | *Cincinnati* | | | | |
| Annual av. | 6.4 | * | 60 | 45 | 1.7 | * |
| Max. monthly av. | 8.9 | 95 | 90 | 89 | 2.1 | * |
| Max. 24-hr. av. | 37 | 420 | 190 | 210 | 3.7 | 98 |
| Max. 1-hr. av. | 48 | 1250 | 1100 | 1000 | 9.5 | 270 |
| | | *Denver* | | | | |
| Annual av. | 6.2 | 46 | 68 | 34 | 1.9 | 58 |
| Max. monthly av. | 8.4 | 89 | 98 | 71 | 2.7 | 78 |
| Max. 24-hr. av. | 24 | 260 | 230 | 130 | 4.2 | 160 |
| Max. 1-hr. av. | 91 | 750 | 510 | 630 | 11.3 | 510 |
| | | *Philadelphia* | | | | |
| Annual av. | 9.9 | 66 | 73 | 210 | 1.4 | 45 |
| Max. monthly av. | 13.2 | 120 | 100 | 430 | 1.6 | 60 |
| Max. 24-hr. av. | 27 | 460 | 170 | 940 | 3.1 | 160 |
| Max. 1-hr. av. | 40 | 1750 | 380 | 2300 | 6.4 | 410 |
| | | *St. Louis* | | | | |
| Annual av. | 5.3 | 39 | 43 | 73 | 2.2 | 43 |
| Max. monthly av. | 6.4 | 60 | 70 | 140 | 3.1 | 57 |
| Max. 24-hr. av. | 10 | 160 | 94 | 420 | 6.4 | 98 |
| Max. 1-hr. av. | 30 | 500 | 340 | 1800 | 10.8 | 450 |
| | | *Washington, D.C.* | | | | |
| Annual av. | 3.9 | 43 | 88 | 97 | 1.5 | 53 |
| Max. monthly av. | 7.6 | 94 | 100 | 250 | 2.0 | 84 |
| Max. 24-hr. av. | 16 | 380 | 150 | 470 | 3.7 | 200 |
| Max. 1-hr. av. | 31 | 850 | 450 | 1100 | 8.8 | 490 |

* Insufficient data for a representative value.

tion, which may affect climate on a global basis.

Gases and particulates may undergo a variety of reactions to produce secondary pollutants that in some cases are more toxic than the parent pollutants. This is particularly true in the case of photochemical smog. Pollutant concentrations are directly related to the density of industry and the use of fossil fuels for power and space heating. Cities that have poor ventilation or frequent temperature inversions are plagued with air pollution episodes.

States have the primary responsibility for atmospheric surveillance. Surveillance systems are usually established on a city or regional basis. The federal monitoring system is to provide a base of uniform data for verification of data from the various agencies and to quantify pollutants that are difficult or expensive to measure.

Presently, the operation of most of the devices and analyzers used for measuring air pollutants is based on wet chemical methods. New techniques are needed in which solid-state or advanced sensing techniques that are based upon the physical or physicochemical properties of pollutants are used. A number of new instruments are presently being developed by NAPCA. In addition, NAPCA has automated and computer-interfaced some of its more sophisticated laboratory and field instrumentation.

Data presented indicate that concentrations of small particulates in the rural or nonurban parts of the country are increasing. Gaseous pollutant concentrations in center-city sites show no particular trend, an indication that downtown areas probably are, and have been for some time, source-saturated.

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# Earth Strain Measurements with a Laser Interferometer

## An 800-meter Michelson interferometer monitors the earth's strain field on the surface of the ground.

Jon Berger and R. H. Lovberg

Geophysicists are interested in the earth's strain field over a very broad band, from frequencies of less than 1 cycle per year to those in excess of hundreds of hertz. Many different geophysical phenomena contribute to this spectrum, but certain strain sources are dominant in particular frequency bands.

At the very lowest frequencies, the cosmologies of Dirac (*1*) and Brans and Dicke (*2*) predict a strain rate of approximately $10^{-10}$ per year due to the secular decrease in the gravitational constant, which causes an expansion of the earth. From independent geological evidence, other investigators have arrived at the same value (*3*). However, observations of long-term strain rates are very sparse, and, compared with the cosmological or geological time scales, the periods over which they have been made are short. Strain rates of $10^{-5}$ per year in Japan (*4*), $10^{-6}$ per year in California (*5*), and $10^{-7}$ per year in New Jersey (*6*) have been reported. The differences in these rates presumably reflect the varying state of tectonic activity in the respective areas. Seasonal effects such as snow loading, groundwater variations, and thermal expansion are also present in the lower part of the spectrum, but with amplitudes that vary widely with site.

From periods of a week to a few hours, the earth tides dominate the spectrum. These tides are caused by the time-varying perturbations in the earth's gravitational field due to motions of the moon and the sun. The spectrum of earth tides is a line spectrum; the dominant lines are the semidiurnal, with a strain amplitude of $10^{-8}$, and the diurnal, with an amplitude of $5 \times 10^{-9}$. The literature is replete with observations of earth tides (*7*), since the well-determined nature of the driving source provides a large and ever-present cali-

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