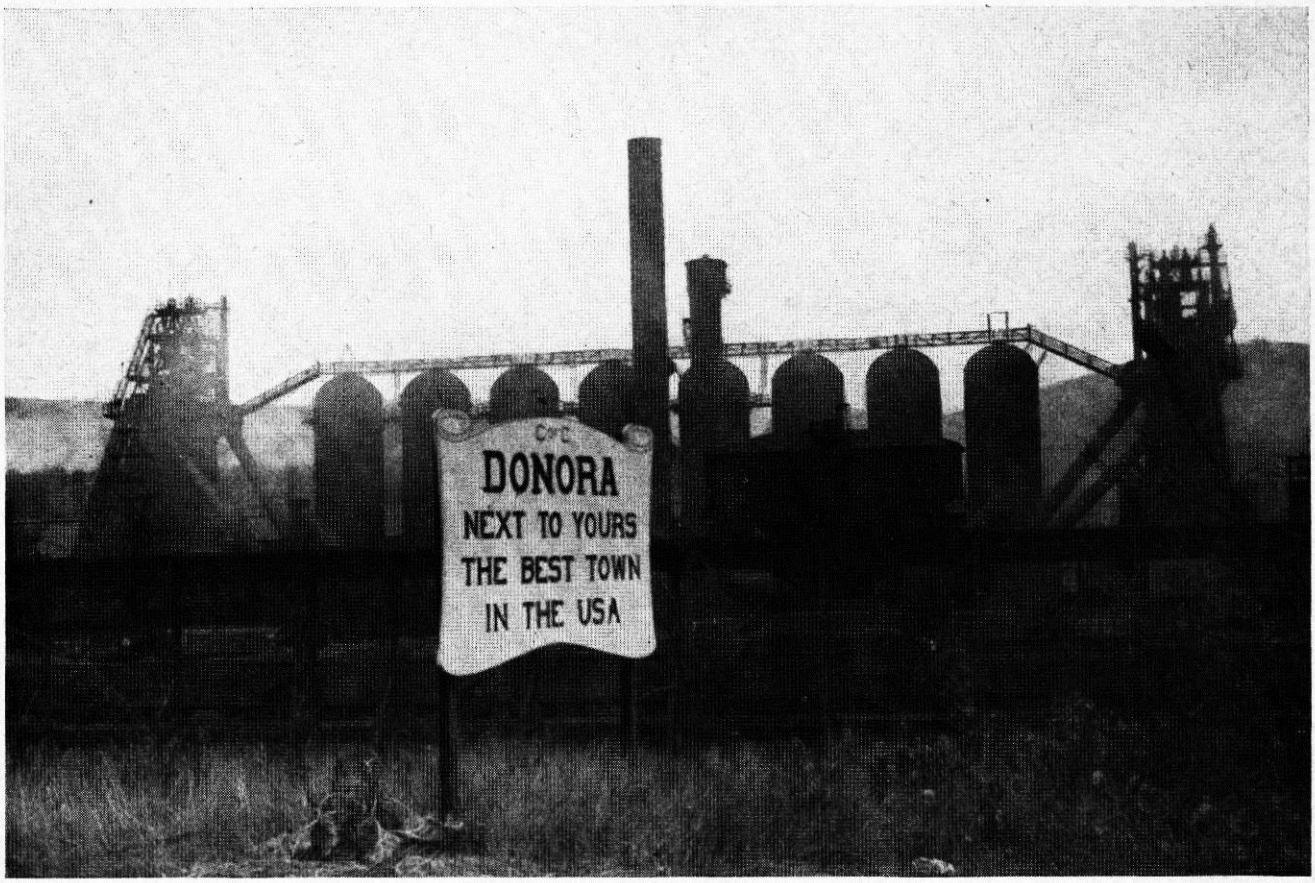
THE DONORA STUDY



Dr. Leonard Scheele, Surgeon General, USPHS, Says:

This study is the opening move in what may develop into a major field of operation in improving the Nation's health. We have realized, during our growing impatience with the annoyance of smoke, that pollution from gases, fumes, and microscopic particles was also a factor to be reckoned with. But it was not until the tragic impact of Donora that the Nation as a whole became aware that there might be a serious danger to health from air contaminants.

Before the Donora episode there had been only one other similar incident in history. In 1930, in the Meuse Valley of Belgium, a period of intense fog in a heavy industrial area resulted in the death of 60 persons. Although several studies were made of those fatalities, the Donora study is the first thorough investigation into every facet of an air-pollution problem including health effects as well as deaths.

The Donora report has completely confirmed two beliefs we held at the outset of the investigation. It has shown with great clarity how little fundamental knowledge exists regarding the possible effects of atmospheric pollution on health. Secondly, Donora has emphasized how long-range and complex is this job of overcoming the problem of air pollution—after we get the basic knowledge on its effects. This intensive piece of work by the Division of Industrial Hygiene of the Public Health Service will have its greatest value as the blueprint for our plan of proceeding to get that knowledge.

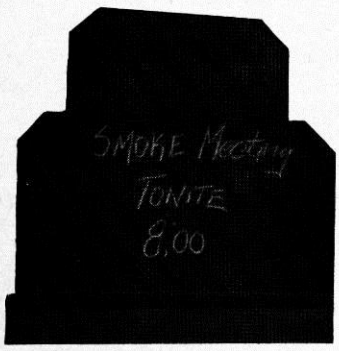
Our first step now, of course, is immediate basic research. We need to investigate, for instance, what long-range effect continued low concentrations of polluted air have on the health of individuals—not only healthy individuals, but also those with chronic diseases and the aged and children. We know nothing about the indirect effect of air pollution on persons with diseases other than those of the respiratory tract. We also need immediate research into another indisputable effect of air pollution: its ability to shut out some of the healthful rays of the sun.

When we find the answers to all of these unknowns, we can proceed to the problem of eliminating the causes. As a proof that air pollution is a health matter, as a model for future studies in air pollution, and as an important phase of our increasing efforts in the field of environmental health, this study will be invaluable.

This photograph was taken in July 1949 on a hill in Donora back of the zinc plant and across the river from the town of Webster. Donora is only one of thousands of towns, large and small, having air-pollution troubles.

The week of the smog

During the last week of October 1948 a heavy smog settled down over the area surrounding Donora, Pa. Weather men described it as a temperature inversion and anticyclonic conditions characterized by little or no air movement, prevailing over a wide area encompassing western Pennsylvania, eastern Ohio, and parts of Maryland and Virginia. This prolonged stable atmospheric condition was accompanied by fog and permitted the accumulation of atmospheric contaminants resulting in dense smog, particularly in highly industrialized areas. Smogs of short duration are not unusual and except for discomfort due to irritation and nuisance of the dirt and poor visibility, no unusual significance is attached to such occurrences.



Bulletin boards in Donora and Webster announced the meetings called by citizens to discuss the smoke problem.

This particular smog encompassing the Donora area on the morning of Wednesday, October 27, it was even then of sufficient density to evoke comments by the residents. It was reported that streamers of carbon appeared to hang motionless in the air and that visibility was so poor that even natives of the area became lost.

The smog continued through Thursday, but still no more attention was attracted than that of conversational comment.

On Friday, however, a marked increase in illness began to take place in the area. By Friday evening the physicians' telephone exchange was flooded with calls for medical aid, and the doctors were making calls unceasingly to care for their patients. Many persons were sent to nearby hospitals, and the Donora Fire Department, the local chapter of the American Red Cross, and other organizations were asked to help with the many ill persons.

There was, nevertheless, no general alarm about the smog's effects even then. On Friday evening the annual Donora Hallowe'en parade was well attended, and on Saturday afternoon a football game between Donora and Monongahela high schools was played on the gridiron of Donora high school before a large crowd.

The first death attributable to the smog had already occurred, however, early Saturday morning—at 2 a. m., to be precise. More followed in quick succession during the day and by nightfall word of these deaths was racing through the town. By 11:30 that night 17 persons were dead. Two more were to follow on Sunday, and still another who fell ill during the smog was to die a week later on November 8.

On Sunday afternoon rain came to clear away the smog. But thousands were still ill, and the rest of the residents were still stunned by the number of deaths that had taken place during the preceding 36 hours. That night the town council held a meeting to consider action, and followed with another on Monday night. By this time emergency aid was on its way to do whatever possible for the stricken town.

On Tuesday morning a telephone call came to the Division of Industrial Hygiene of the Public Health Service in Washington, requesting that the Division take steps immediately to bring to bear on the Donora crisis its experience in combatting atmospheric pollution hazards. The following day a staff member of the Division arrived in

Donora to make a preliminary survey of what could be done.

This telephoned request to the Division of Industrial Hygiene was later formally repeated on behalf of the Borough Council of Donora, the Department of Health of the State of Pennsylvania, and the United Steelworkers of America, CIO.

The Division of Industrial Hygiene threw every available resource into an investigation of the Donora smog. Some 25 persons were assigned to the field team sent in to make an exhaustive study of what happened during the smog. Dr. Helmuth H. Schrenk was placed in general charge of the investigation, Dr. Harry Heimann was named to direct the medical aspects, and Mr. George Clayton was placed in charge of the field team in Donora. The complete report presents the results of 5 months' intensive field work by that team, the personnel assigned by the United States Weather Bureau, and many others who assisted.

A very brief summary of this study is presented in this issue of the *Industrial Hygiene Newsletter.*

The complete report of the Donora study by the Public Health Service is available from the Government Printing Office, Washington 25, D. C. Price per copy $1.25.

A description of the Donora area

The Borough of Donora is located on the Monongahela River in Washington County, Pa., about 30 miles south of Pittsburgh. Other industrial towns in the nearby vicinity are Charleroi and Monessen upstream and Monongahela City a few miles downstream. Adjacent to Donora is Carroll Township, and the community of Webster is situated directly across the river from Donora, the latter two being connected by a bridge.

Donora is located on the inside of a sharp horseshoe bend in the Monongahela River. The area along the river bank is occupied by a steel and wire plant, and by a zinc plant. The steel plant extends for about 2 miles south of the Donora-Webster bridge, and the zinc plant for about 1 mile north of the bridge along the river. The main business district lies adjacent to the plants and the residential area extends to the top of the hills.

The Donora burgess meets with the PHS team to offer Donora's complete cooperation.

At river bank level the altitude above sea level is 760 feet. Hills on the east bank of the river rise abruptly to a height of about 1,100 feet. The hills on the Donora side of the river rise more gradually to a height of 1,150 feet.

The population of the Donora area is about 14,000, approximately 13,000 living in Donora proper, and about 1,000 in Webster. The majority of the people are of Slavic descent with small Spanish and Negro minorities present. Of the 5,000 people gainfully employed, about 3,000 work at the steel and zinc plants.

The homes in Donora are almost all of wood or brick construction. Very few of the estimated 2,300 houses are over two stories high.

A greater part of the land in the area beyond the towns is comprised of small farms. A number of coal mines are located throughout the area.

Donora's industrial life is dominated by a steel and wire plant, and a zinc plant. The steel and wire plant had its beginning in 1900, when the construction was started of the blast furnaces, open hearth department, and blooming mill. In 1901, two looping rod mills, a wire-drawing department, and a wire-finishing department were constructed.

Donora residents who were associated with smog victims volunteer information to help the physicians piece together all contributing factors.

The finished products of the plant include wire, nails, barbed wire, bale ties, welding rods, stranded cable, welded concrete reinforcing, and woven fence. The zinc plant was built in 1915, and is of the horizontal-retort type. The products of the plant include zinc, cadmium, unrefined lead, and sulfuric acid.

Other heavy industries in the nearby area include two steel companies and one byproduct coke plant in Monessen, a steel and byproduct coke plant in Clairton, a glass company in Charleroi, a power company, and a railroad yard in Elrama.

Two railroads run through the Monongahela Valley, one on the Donora side of the river and the other on the opposite bank. The river traffic on this section of the river is relatively heavy.

A Public Health Service team goes to work

The Public Health Service team had two objectives: (1) To ascertain the cause of the Donora episode, and (2) to obtain information applicable to preventing future occurrences. During the study the team hoped to obtain additional information of a fundamental nature which would be applicable to the general problem of atmospheric pollution.

Plans were made to investigate the three major factors: (1) Effects on people and animals, (2) contaminants, and (3) meteorological conditions. Since the full-scale study began sometime after the acute episode had subsided, it was necessary to try to reconstruct the picture from data collected after the occurrence of the illnesses and deaths.

THE BIOLOGICAL STUDIES

The biological studies covered the acute episode and the long-term effects of life in Donora, insofar as information could be secured. The physician, nurse, dentist, statistician, veterinarian, and sanitary and housing engineers worked together on these studies.

THE STATISTICIAN

Statisticians helped to plan the main phases of the study with a view to collection of adequate and representative data with a minimum expenditure of time and labor. They were concerned with the development of a house-to-house survey covering a population sample which would yield information relative to the effect of the smog upon the population in the Donora area. Statisticians assisted in deciding upon the location of the air-sampling stations and in the delineation of subregions which would make possible the consolidation of the community survey, air contamination and weather data.

The analysis of long-term health trends in the Donora area was primarily a statistical study of available morbidity and mortality records in that community compared with similar records in nearby communities. It was designed to show whether any causes of illness or death were more common among residents of the Donora area.

THE NURSE

Nurses of the Public Health Service played an important role in the collection of clinical and epidemiological data on the Donora smog episode. Their chief task was the conduct of a household survey that reached a total sampling of 1,308 households in Donora and nearby Webster.

A PHS dentist examined large numbers of Donora people for oral manifestations that might offer helpful evidence in solving the cause of the mysterious smog.

PHS nurses called on 1,308 families to get first-hand knowledge of how the smog affected them. Animals, too, came in for their share of attention.

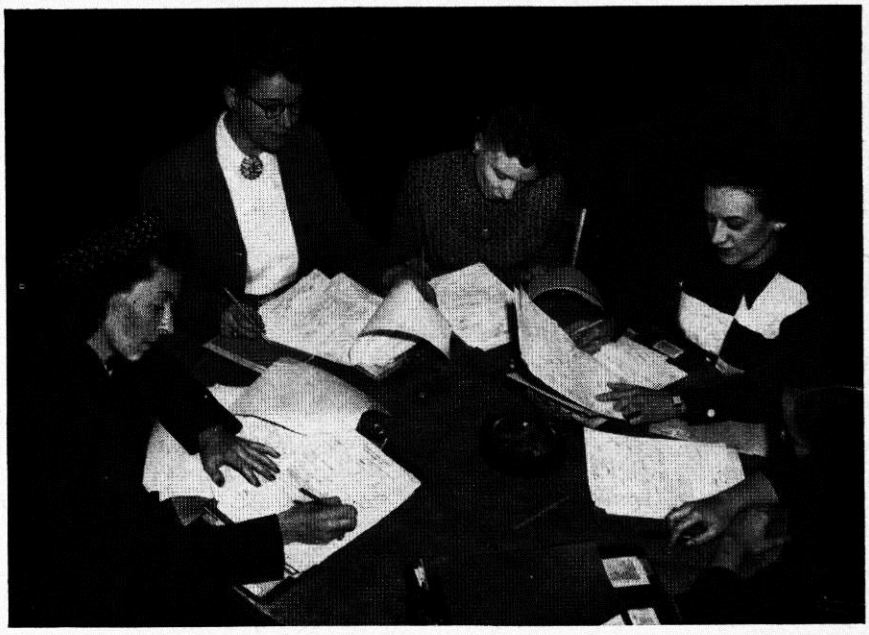
Six registered nurses, with a background in industrial or public health or both, carried on the survey which was a house-to-house canvass. A complete record of all illness and deaths during the smog was obtained in an interview with the housewife or other responsible member of the household. The population of Donora is approximately 12,300 persons, living in 3,500 households. To secure a representative sample of the population, every third household was taken from a list prepared by the Donora tax assessor. A similar list was furnished by the town of Webster.

The data collected included a household census, with the name, sex, race, age, marital status and occupation of each member of the household. Special forms for recording this information and a manual describing their use were furnished each nurse.

After citizens of the area had become acquainted with the project through newspaper and radio publicity, the household visits began on December 2, 1948, and continued through March 30, 1949.

When she arrived at the home, the nurse introduced herself and told the purpose of her visit. The standard opening for the interview was the question, "Were you affected by the October smog?" This prepared the way for a discussion of previous and present health status and the other data required, which were recorded as they were obtained in the home. During the early part of the survey the nurses were charged with the responsibility of selecting from their household visits persons to be interviewed by physicians of the study team.

At the completion of the day's interviews the nurses reported to headquarters, where their filled-in forms were checked for completeness and the following items tabulated: (*a*) All persons affected by the smog; (*b*) all deaths during and after the smog; and (*c*) all affected animals and pets. Finally, the households for which data were completed were spotted on a large street map of the area.



Nurses and statisticians meet in the evening to check the day's findings.

THE PHYSICIAN

What was the clinical picture presented by the Donora smog incident? To answer that question it was necessary for the investigation team to make a study of individuals who had been ill during the smog and to study the relationship of their symptoms to the factors of age, sex, race, residence, time of onset, previous health status and source and concentration of air pollutants.

Setting up headquarters in a private room in the Donora Borough Building, the physicians embarked upon a round of interviews with affected persons that ultimately reached a total of 516. These interviews, extending over a 5-week period, ran concurrently with the early part of a house-to-house survey conducted by the nurses on the team. Names of persons to be interviewed came from four sources. These were the nurses' household survey, the Donora Borough survey, a local physician's list and voluntary cases.

The technique of each interview consisted of asking the individual to talk at length about what happened to him as a result of the smog episode. The physicians then asked questions which were of a general nature so as to avoid prompting the informant.

At the conclusion of the interview, blood specimens were taken for study of their influenza antibody titer, differential white blood count, and for spectographic analysis. At a later date chest roentgenograms of a selected series of adults were made to evaluate the part which lung disease may have played in the illness.

To round out the clinical picture the physicians sought information from every other possible source. Local doctors were interviewed concerning their findings and therapy. Visits were made to relatives and friends to obtain additional information about the affected individuals. Hospital records were reviewed and local pharmacists, policemen, and undertakers were questioned.

Further detail was added to the clinical picture by the performance of autopsies on the bodies of some of the 20 persons who had died during or shortly after the smog. As might be expected, the task of obtaining permission to conduct necropsies on the bodies of persons who had died and been buried 5 months previously presented difficulties. Such permission was granted in only two instances. In addition, one autopsy was done shortly after death by the authorization of the county coroner. These were the only ones performed on the bodies of persons who had died during or shortly after the smog. A fourth was performed on the body of a man who died 2 months after the smog and a fifth on a man who died 8 months after the episode.

THE DENTIST

Since damage to the teeth and periodontal tissues may result from atmos-

pheric pollutions of fluorides or acid aerosols, a dentist of the investigating team examined a selected group of persons from Donora and Webster, Pa.

Acid aerosols are known to cause acute symptoms of hemorrhagic gingivitis and chronic symptoms of dental erosion. Fluorides when taken in sufficiently high quantities during the tooth-development period will cause a condition known as mottled enamel. Therefore, this study was made to establish whether or not fluorides or acid aerosol contaminants were present in sufficiently high concentration to cause harmful effects on the oral structures or to produce any systemic manifestations.

For convenience the persons examined were limited to two groups—male adults and male school children. The adults were chosen from workers in one of the plants in the area and numbered 262. From the ranks of the city's students, 375 boys between the ages of 12 and 20, were examined. In addition, students from the Webster Consolidated School were also examined.

In addition to the information obtained relative to the oral picture, supplemental studies were made of the fluoride content of the drinking water used by the Donora residents and fluoride content of the bone specimens obtained from three persons and a number of animals that had died allegedly as a result of the smog.

Findings of the study covered four main points. These were: (1) Fluoride intake during the period of tooth development by the 427 children examined was insufficient to cause mottled enamel. Fluoride exposure from sources other than water was insufficient to alter the normal inverse variation of caries attack rate and fluoride content of the communal water.

(2) The fluoride content of the urine from persons examined from Donora was within normal limits in accordance with the fluoride content of the communal water supply, which is evidence that a fluoride exposure from sources other than water was not sufficiently high to alter this direct variation.

(3) Quantitative analyses of human and animal bones for fluoride showed that amounts stored in the skeletal structures were within normal limits which fail to demonstrate an abnormal exposure by inhalation or ingestion.

(4) Acid aerosols were not in sufficient concentration to cause detectable ill effects in the oral structures of the 262 male adults and 427 school children examined.

THE VETERINARIAN

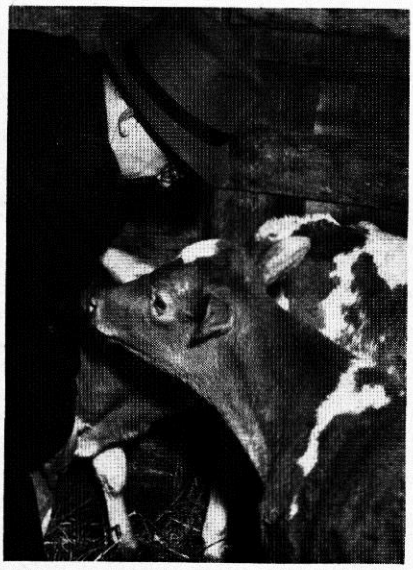
Because the effect of the smog on Donora's animal population might yield valuable clues to account for the human illnesses, the veterinary aspects of the problem received careful attention.

Directed by a trained veterinarian physician, this phase of the study had two sources of information. These were the community survey made by nurses of the study team and persons in the community who believed they had significant information. Supplemental data were collected through conferences with local veterinarians, technicians in a local dairy cattle-breeding association, county agents of the United States Department of Agriculture, poultry dealers and the operator of a slaughterhouse. In addition, four retail milk plants were visited to determine if there were any record of decline in milk production during or shortly after the smog.

Visits by the veterinarian were made to those households which had reported to the nurses of the study team that they kept or had kept pets at the time of the smog. The veterinarian also made a random sampling of farms within a 3-mile radius of one of the plants and inspected the animals for evidence of disease.

Results of the farm studies showed that there had been no unusual incidence of illness among farm animals during the smog and that there had been no significant drop in milk production during or after that period.

A less cheerful picture was revealed for the domestic animals. In this category dogs were the most susceptible to effects of the smog, with 38, or 15.5 percent, made ill. Of this number, 10



A veterinarian examines livestock for evidence of the smog affection.

To uncover all possible clues, a food sanitarian inspects public eating places.

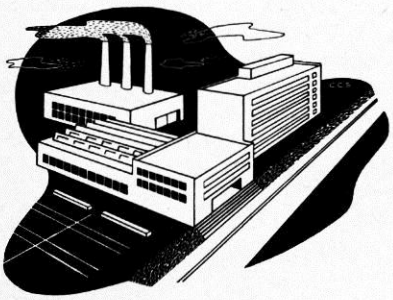
The PHS physician learns what medical supplies were sold the week of the smog.

of the animals, or 26.3 percent of those ill, died. Of 131 householders who reported that they kept cats on their premises, 12 had cats who became ill during the smog, and in three instances the cats died. Other fatalities included two canaries and two rabbits.

Conclusions reached by the study indicated that (1) the syndrome as observed among animals was of a nature which could be attributed to an irritant of the exposed mucous membranes and, more specifically, the respiratory tract; (2) among the domestic animals for which information was available the attack rate for dogs was 15.5 percent, while the fatality rate among the affected dogs was 26.3 percent; (3) the role which distemper played in the high incidence of morbidity and mortality among the dog population appeared to be considerable, but there was no way open to measure this role; (4) the economic loss due to smog effects on farm animals was minimal.

THE SANITARIAN

Since it is known that certain types of epidemic disease may have their origin in water supply, food intake and mode of sewage disposal, a study was made of these factors in the Donora area. The findings revealed, among other things, that none of these factors appeared to have contributed to the acute episode.



A summary of the findings of biological studies

1. A total of 5,910 persons, or 42.7 percent of the population, were affected by the October 1948 smog. The degree of affection ranged from slight to extremely severe. Affected persons were classified as mildly, moderately, or severely affected, dependent on the number and kind of symptoms reported, length of disability, need for medical attention as determined by successful or unsuccessful attempts to obtain a physician, and outcome of illness.

2. The affection was essentially an irritation of the respiratory tract and other exposed mucous membranes. Cough was a predominant single symptom during illness.

3. Classified as to degree of affection, 2,148 persons, or 15.5 percent of the total population in the area, were mildly affected, and 1,440 persons, or 10.4 percent, were severely affected.

4. Neither incidence nor severity of affection appeared to be influenced by sex, race, occupation status, length of residence in the area, or degree of physical activity at the time of the onset of affection.

5. Both incidence and severity revealed a direct relationship with increasing age. Over 60 percent of persons 65 years of age and over reported some affection from smog and almost one-half of those were in the severely affected group.

6. The population of Webster reported a higher incidence of affection of each degree than the area as a whole. Age-specific rates for Webster revealed an age pattern similar to the corresponding area pattern but at a higher level.

7. Although the onset of affection began in some instances as early as S-day (first day of severe smog), a larger number of persons became ill on day No. 2 (second day after S-day). About 40 percent of affected persons reported onset of affection between 6 p. m. and midnight of day No. 2.

8. Twenty persons died in the Donora area during or shortly after the smog of October 1948; 17 died on day No. 3.

9. Based on data available for 18 of those who died, the death rate was significantly higher in the nonwhite than in the white population, and was significantly higher for Webster than for the area as a whole.

10. The ages of persons who died ranged from 52 to 84 years with a mean of 65 years.

11. Principal past employment, duration of residence in the community, and sex played no significant part in the occurrence of fatal illnesses.

12. Only in the degree of severity and in the outcome were the fatal cases different clinically from those of the severely ill persons who did not die.

13. Preexisting disease of the cardiorespiratory system appeared as a single significant factor among the fatally ill, although in four cases no history of any chronic disease prior to the smog was obtained.

14. In spite of the apparent association between cardiorespiratory disease and smog affection, no significant difference appeared in the occurrence of pulmonary emphysema in a group of persons who had been ill during the smog, and in a nonaffected group.

15. Epidemic influenza did not play a part in the illnesses which occurred during the smog.

16. Some relationship appeared between severity of affection and certain characteristics of housing quality.

17. In addition to the persons who became ill during the smog, domestic animals became ill and some died. These illnesses resembled those observed in the human in that there was evidence of irritation of exposed mucous membranes of the respiratory tract.

18. Studies for dental caries, dental fluorosis, urinary excretion of fluoride and fluoride content of bone revealed no evidence that there was excessive inhalation or ingestion of fluoride in the community.

19. With the exception of such episodes as that of the October 1948 smog, long-term studies of mortality records and plant morbidity records indicate that the health of the people of Donora appeared essentially no different from that of nearby towns.

20. Although bronchial asthma and heart disease appeared to be somewhat more prevalent among persons in the Donora area than in the United States as a whole, studies of mortality data, when compared with those of nearby communities, indicated that death due to disease of the heart and respiratory system was not increased in Donora.

21. Mortality records showed that crises have occurred in Donora creating occasionally higher death rates due to cardiovascular disease. These crises were probably related to atmospheric conditions.

22. Among autopsies performed there were three made on persons who died during the smog and these showed acute changes in the lungs characterized by capillary dilatation, hemorrhage, edema, purulent bronchitis, and bronchiolitis.

23. Chronic cardiovascular disease, the origin of which antedated the smog incident, was a prominent feature in the autopsies.

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THE ENVIRONMENTAL STUDIES

A thorough knowledge of the sources of pollutants is essential in a study of atmospheric pollution so all possible factors which may have contributed to the October smog were carefully studied. To determine the sources of contaminants in Donora, the engineers sampled the air in and around the plants, and in many areas of the town, near the railroads, and up and down the river. Consideration was also given to sources of pollutants other than those in the immediate vicinity, such as slag heaps, mines, and gob piles. It was necessary to learn the kinds of contaminants, the amounts produced and their distribution in the general atmosphere.

The largest industries in Donora are the zinc plant and the steel plant, which together employ about 3,000 people. In these two plants, the engineers spent many hours of sampling and testing. Information was also obtained on raw materials, production methods and finished products from other industries in the Monongahela Valley.

THE ENGINEER

In an effort to measure the degree of atmospheric pollution from the zinc and steel plants, the procedure used was, in some respects, quite different from the usual methods employed by the industrial hygienist. Many of the conventional methods of air sampling would not suffice under the wide variations of conditions encountered. In most instances, each stack sampled was handled as a separate problem and equipment or apparatus was adapted for the particular stack under study.

The two plants were divided for sampling purposes as follows: *Zinc plant*—roasters, sintering plant, zinc spelters, waste heat boilers, Waelz plant, dross plant, sulfuric acid plant and cadmium plant; *steel plant*—blast furnaces, boilers and sintering plant, open hearth furnaces, soaking pits, desurfacer and boilers, and wire mill.

The atmospheric contaminants to be studied were deduced from the raw materials used and the processes to which the pertinent materials were subjected. Raw materials and intermediate products were analyzed by the spectrographic method for the following toxic elements:

Antimony	Phosphorus
Arsenic	Selenium
Cadmium	Sulfur
Germanium	Tellurium
Indium	Thallium
Lead	Zinc

From this information, it was decided to sample for the following constituents:

Total particulate matter	Fluoride
Lead	Arsenic
Cadmium	Sulfur dioxide
Zinc	Total sulfur
Iron	Carbon dioxide
Chloride	Carbon monoxide
	Oxygen

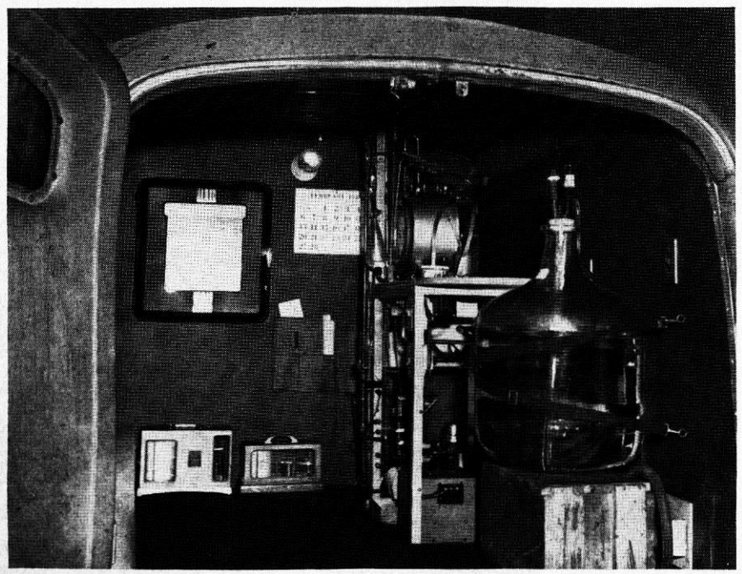
In addition to the above, samples for the following contaminants were collected in those stacks where their presence was indicated:

Oxides of nitrogen	Stibine
Acid gases	Manganese
Hydrogen	Iron carbonyl
Arsine	

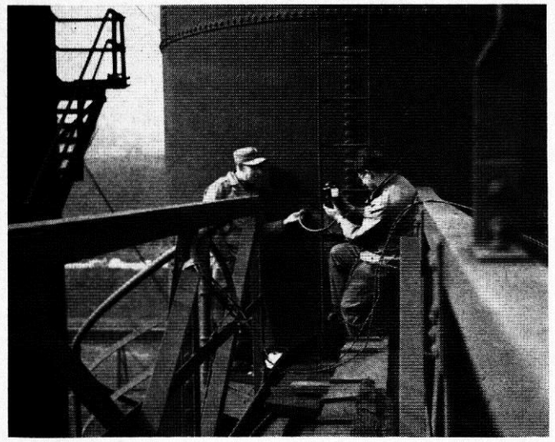
Qualitative tests for hydrogen sulfide and cyanide were made in stacks at the cadmium plant.

Much thought was given to the selection of air-sampling stations. Factors considered were major sources of contamination, altitude, density of population, location with reference to contaminants coming from outside sources and relationship of air-sampling stations to the temporary United States Weather Bureau stations established for the study. Twelve air-sampling stations were selected since this seemed an optimum number from the standpoint of the factors to be considered, and the personnel and equipment available. Of these, five were located across the valley on a line through the zinc plant, each one being associated with a major weather bureau station.

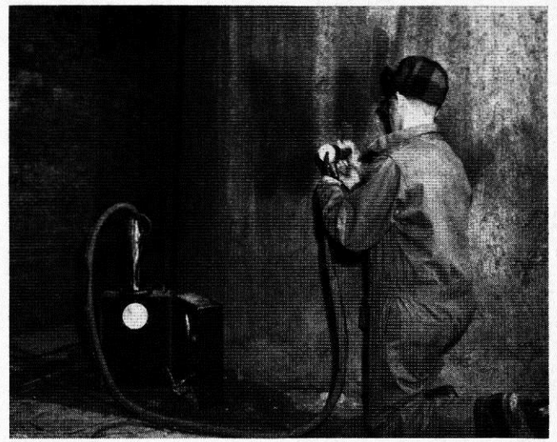
The low concentrations of airborne contaminants and the wide variety of weather conditions found while taking samples outdoors necessitated the development of a specialized technique. During the period that samples were taken, air temperatures varied from 18° to 81° F. Snow, sleet, and rain were frequent at the beginning of the study and wind speed varied from zero to 30 miles per hour.



The use of a mobile laboratory, lent the PHS by the Utah State Health Department, facilitated the engineers' research. The picture shows a Thomas Recorder.



Two PHS engineers take a static pressure reading of a stack at the steel plant for the purpose of calculating the air flow.



An engineer takes an electrostatic precipitator sample in a stack of the steel mill.

Two automobiles were equipped as mobile laboratories. Gasoline-driven electric generators, capable of generating 500 watts at 110 volts alternating current, were used as a power source; the generators were located in the trunks of the cars. This equipment provided sufficient power to operate simultaneously the electrostatic precipitator, the standard impinger pump and a light source for the analytical work. The rear seat of the car was removed and the space converted into a miniature laboratory. This equipment was used for sampling regularly at the 12 selected stations.

THE CHEMIST

The analysis of samples was made in the Division laboratories at Bethesda, Md. The samples collected in Donora and sent to the laboratory required 4,000 individual determinations. A wide variety of chemical methods of analysis was required to make all of the necessary determinations. When more than one constituent was determined on a single sample, separate aliquots were taken for each such determination.

The total number of samples taken at the 12 air sampling stations was as follows: Sulfur dioxide, 250; total sulfur, 267; total particulate matter, including lead, cadmium and zinc, 205; chloride, 247; and fluoride, 249. The routine sampling time for these samples was one to two hours.

The laboratory set up in the Municipal Building served principally as a preparation center for the engineers and chemists. The two automobiles, converted into mobile laboratories, were used at the air sampling stations and for other outdoor work.

Atmospheric pollution from domestic sources

To evaluate the role of domestic smoke in relation to atmospheric pollution in the Donora area, a study was made of the heating equipment of the homes and business buildings. In the Donora area there are approximately 2,300 buildings exclusive of heavy industry. Most of the buildings are relatively small and are heated by simple types of furnaces. Mine-run coal is used extensively for heating in Donora, and gas and electricity for cooking.

To decrease atmospheric pollution from this source, consideration should be given to smoke-prevention measures. For example: (1) Local building ordinances might include provisions which would assure less smoke from the heating units of all the new buildings; and (2) owners of buildings from which there is frequent dense smoke should be given the benefit of an educational program on proper firing methods.

The Monongahela River is one of the world's most important waterways in terms of tonnage of freight transported on it. Consequently, boats were considered as contributors to the atmospheric pollution and a study was made of fuel consumption of boats during passage through the Donora area. Two-thirds of the boats are coal-burning steamboats, and one-third are Diesel powered.

During the period of the Donora incident, there was an average of 22 boats per day as compared to an average of 32 boats per day for the rest of October. This decrease probably was due to the smog, since conversations with steamboat men revealed that all but the radar-equipped boats had great difficulty in navigating the Donora-Webster bend in the river during that period.

A study was made on the air pollution from trains that pass through Donora daily, as well as the switch engines which work there continuously. Air pollution from automobiles and trucks was also estimated.

Sanitary engineers conducted an evaluation of housing to provide information on the descriptive characteristics, quality and important deficiencies of dwellings in the Donora area, in an attempt to ascertain possible relationships between housing conditions, and illnesses and deaths occurring at the time of the smog. Weather-tightness and general state of repair of dwellings were considered of special importance. Included in the 241 dwellings inspected were 20 homes which served as residences of persons deceased during the smog. The engineers found that housing conditions in the Donora area compared reasonably well with conditions in other urban communities of similar size in the United States.

A PHS engineer holding a cup anemometer, taking wind velocity measurements.

THE METEOROLOGICAL STUDIES

Realizing the critical importance of weather in producing smog conditions, the Public Health Service requested the United States Weather Bureau to study the micrometeorology of the Donora area. The purpose of the meteorological study was (1) to investigate the physical processes which cause rapid dilution of the industrial airborne waste products or their retention in dangerous concentrations in the Monongahela River Valley at Donora; (2) to determine the general weather type favorable to retention of airborne contaminants in the Donora area in order that the onset of these periods may be forecast; and (3) to correlate the meteorological findings and the air sampling analyses.

Based on a detailed analysis of the data obtained on atmospheric pollutants and meteorological conditions, the following program to prevent recurrence of affections from unusual smog conditions is presented:

1. An alert shall be issued when an anticyclone of an extent similar to the one of October 25–30, 1948, approaches the eastern United States, is slowly moving, and shows indications of stagnation.

2. A warning to take preventive measures such as outlined below, shall be issued when the following conditions occur simultaneously for 1 day and show no indication for improvement.

a. An anticylonic model as in (1) moves to the eastern United States;

b. Valley stability factor as determined by valley top and bottom temperatures and defined by $\triangle\ominus$/1,000 feet becomes and remains greater than 5.5° F.;

c. Valley winds less than 5 miles per hour and upper air winds less than 10 miles per hour;

d. Moderate to dense fog in the valley continues some time past noon.

The industries in the Donora area and adjacent communities should curtail production during a stable-stagnant valley air condition as outlined above. The extent to which production should be curtailed is dependent on the extent to which measures are instituted to control atmospheric pollutant; the greater the control attained, the less the curtailment that will be needed.

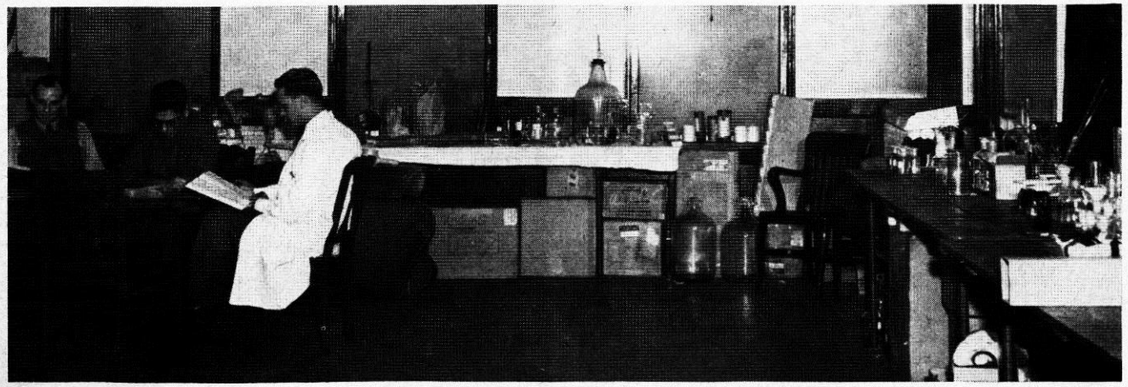
A committee of interested persons should be formed to carry out this recommendation and establish a program of action.

A summary of the findings of atmospheric studies

1. The zinc spelters are major contributors to the atmospheric pollution load with special reference to particulate matter and carbon monoxide.

2. The amount of contaminants discharged from the zinc spelters during the "test period" was approximately twice that which occurred during the "curtailed production" period.

3. The zinc plant waste heat boiler stacks are major contributors of atmospheric pollution with special reference to particulate matter and sulfur dioxide.



In a makeshift laboratory and study set up in the Municipal Building, the engineers and chemists delve into many scientific books for information that will contribute to the solution of air pollution questions.

4. The zinc plant sintering operation is a major contributor to the atmospheric pollution load with particular reference to sulfur dioxide.

5. The acid plant is the main source of discharge of oxides of nitrogen into the atmosphere.

6. The contribution of the zinc ore roasters, Waelz plant, zinc dross and cadmium plants to the general atmospheric pollution load of the valley is not considered significant.

7. The blast furnace department, including the sinter plant, is a major contributor to the general atmospheric pollution load with special reference to particulate matter and carbon monoxide.

8. The open hearth furnace stacks are significant contributors of particulate matter to the atmospheric pollution load.

9. The blooming mill and wire mill, including nail galvanizing, are not considered important contributors to the general atmospheric pollution of the valley.

10. The blooming mill and steel mill boiler stacks are major sources of sulfur dioxide.

11. Domestic heating systems and local steam locomotives are significant contributors to the general atmospheric pollution of the valley with special reference to carbon monoxide, sulfur dioxide, and particulate matter.

12. The distribution of concentrations in the general atmosphere of sulfur dioxide, total particulate matter, zinc, lead, and cadmium showed variations which may be roughly correlated with sources of contaminants.

13. Sulfur dioxide showed the most even distribution, indicating the wide distribution of sources of sulfur dioxide.

14. Total particulate matter showed even distribution with the exception of the areas closest to the zinc plant, which were higher than the others.

15. Concentrations of zinc, lead, and cadmium were highest in the vicinity of the zinc plant.

16. Air-sampling station No. 4 (representing an area in Webster directly across the river from the zinc spelters) showed higher concentrations for all contaminants than the other stations.

17. Concentrations of various contaminants when considered by time of the day indicated that the greater air stability at night and fluctuation in plant operations influenced concentrations found.

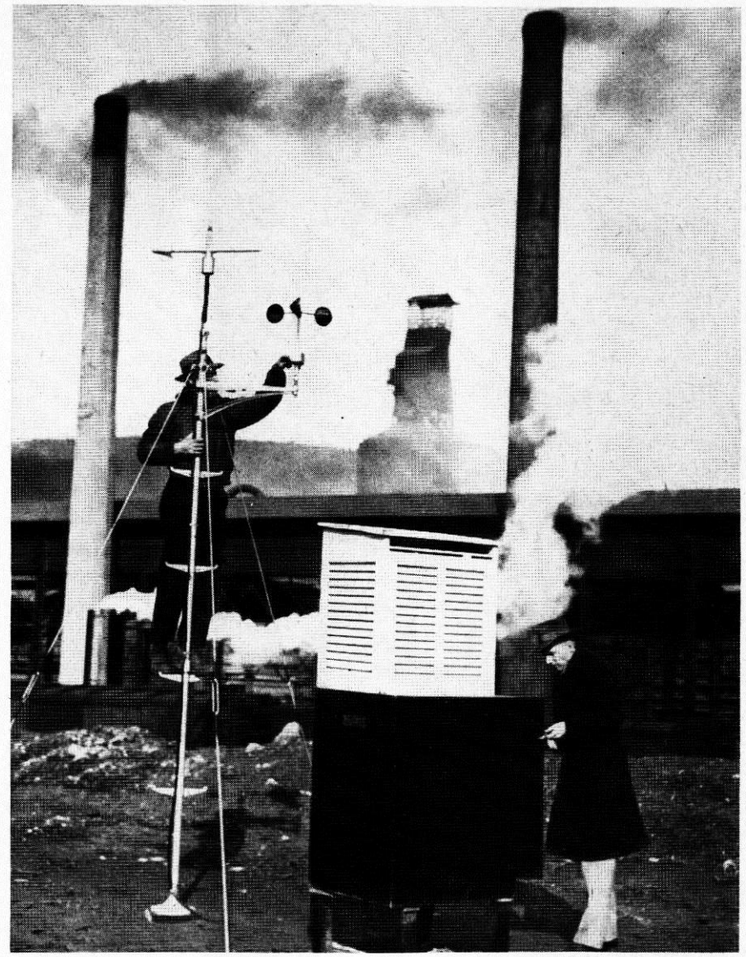
18. Low concentrations of chloride, fluoride, and oxides of nitrogen were found in the general atmosphere.

19. Samples of particulate matter obtained from home filters in Donora and a home filter in Monessen showed no significant difference in the composition of the samples with the exception of sulfur. A higher concentration of sulfur was found in the particulate matter collected during the smog period than in samples obtained from filters in operation after the smog.

20. A combination of a high degree of atmospheric stability and stagnation was found to be necessary and sufficient to cause an accumulation of airborne pollutants in the valley at Donora.

21. Local micro-turbulences within the valley at night appeared to distribute the particulate matter evenly throughout the valley as determined by morning visual observations.

22. Wind speeds during windy periods within the valley were lower than those at hill top with the decrease being greater for cross-valley flow than for parallel-to-valley flow.



The United States Weather Bureau cooperated on the study to determine wind velocity and direction.

23. Similarity of average concentrations at all stations for various wind directions for sulfur dioxide, total sulfur, and total particulate matter showed multiple sources of these contaminants while definite high concentrations of zinc and cadmium were found only downwind from the zinc plant (except for variable, low speed wind periods), indicating a single source for these elements.

24. In general, a greater percentage of higher concentrations was found in the wind speed range of 0–3 miles per hour and the next highest in the 10–22 miles per hour range; lowest values being found in the 4–9 miles per hour range.

25. The concentration of contaminants showed no significant relationship to relative humidity or temperature.

26. A definite relationship was found to exist between the concentration of contaminants and atmospheric stability.

What the evidence indicates

The data presented in the biological studies indicate that the clinical syndrome was characterized essentially by irritation of the respiratory tract which was especially severe in elderly persons and those with known chronic cardiorespiratory disease. The data indicate, furthermore, that this condition was not due to an accidental occurrence but rather resulted from the accumulation of atmospheric pollutants during an unusually intense and prolonged stable air condition. While the weather alone cannot be blamed for the episode, the fact that it played a significant role cannot be denied.

Following analysis and study of all available data, it does not appear probable from the evidence obtained in the investigation that any one substance, such as sulfur dioxide, *by itself* was capable of producing the syndrome observed. However, a combination of two or more of these substances may have contributed to that syndrome.

It is well known that one substance may influence the physiologic action of another, and it is possible that there was a summation of the action of the individual irritant constituents which produced an effect greater than would be anticipated for any one of the individual constituents. Moreover, there is evidence which indicated that the effect of irritant gases can be enhanced by adsorption on particulate matter. In addition to enhanced action, gases may be carried deeper into the respiratory tract than they would normally be carried in the absence of such particulate matter. This action then would carry the noxious substance into the lower levels of the respiratory system where the more damaging effects would be produced.

It is known that irritant gases exert their effect in the respiratory tract depending largely on their solubilities; that is, compounds which are highly soluble exert their effect in the upper respiratory tract while compounds which are less soluble exert their primary action in the deeper parts of the lung. A gas, therefore, such as sulfur dioxide which would normally exert its primary action in the upper part of the respiratory tract might produce more serious effects if it were transported to the deeper parts of the lungs, as for example, by particulate matter. Both solid particulate matter and liquid particulate matter (fog) were present in the atmosphere in large quantities during the October 1948 episode.

Another influencing factor to be considered is carbon dioxide, which was a significant contributor to the over-all atmospheric pollution load. Because carbon dioxide is a respiratory stimulant, it may have contributed to the effects produced by other contaminants by virtue of the increase in depth of respiration which it induces.

SUMMARY

It seems reasonable to state, on the basis of the previous discussion, that while no *single* substance was responsible for the October 1948 episode the syndrome could have been produced by a combination, or summation of the action, of two or more of the contaminants. Sulfur dioxide and its oxidation products, together with particulate matter are considered significant contaminants. However, the significance of the other irritants as important adjuvants to the biological effects cannot be finally estimated on the basis of present knowledge.

It is important to emphasize that information available on the toxicological effects of mixed irritant gases is meager and that data on possible enhanced action due to adsorption of gases on particulate matter is limited. Further, available toxicological information pertains mainly to adults in relatively good health. Hence, the lack of fundamental data on the physiologic effects of a mixture of gases and particulate matter over a period of time is a severe handicap in evaluating the effects of atmospheric pollutants on persons of all ages and in various stages of health.

What can be done to prevent another "Donora"?

The following recommendations were made by the Division of Industrial Hygiene:

1. Reduce the gaseous contaminants, especially sulfur dioxide and particulate matter, discharged from the sinter plant Cottrell stacks.
2. Reduce the particulate matter and carbon monoxide from the zinc spelters.
3. Reduce the particulate matter and sulfur dioxide discharged from the waste heat boiler stacks.
4. Reduce the discharge of oxides of nitrogen and acid mists from Gay-Lussac stacks.
5. Reduce the amount of particulate matter and carbon monoxide from the waste blast furnace gas.
6. Reduce the amount of carbon monoxide discharged from the stove and sinter stacks.
7. Reduce the amount of particulate matter discharged from the sinter plant and open-hearth stacks.
8. Reduce the amount of particulate matter discharged from the waste heat and blast furnace boilers and the sulfur dioxide from the waste heat, steel and wire plant boilers.
9. Reduce the amount of particulate matter discharged from domestic heating systems, steam locomotives and steamboats.
10. Establish a program of weather forecasts to alert the community of impending adverse weather conditions so that adequate measures can be taken to protect the populace.