AIR POLLUTION IN SEOUL

Report of Smithsonian Consultant to AID

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I. Introduction

The terms of reference of this consultation, as I understood them, were: (a) characterization of the air pollution problems of Seoul, and of Korea generally; (b) suggestion of possible solutions; (c) identification of resources, especially human resources, for further characterization and solutions; and (d) generalization, to the extent possible, to other developing countries and other rapdily expanding cities, of findings for Seoul and Korea.

This report of information gleaned, and conclusions drawn, from 12 days spent in Seoul, obviously cannot be considered any sort of definitive study. Lack of ability in Korean decreased my mobility and made details of many scientific papers inaccessible to me. I probably also missed many nuances in conversation, despite the fact that most Korean scientists speak some English, and a very good interpreter was provided. I made no attempt at measurement on my own, and my visual observations were necessarily limited to a single period of very excellent weather.

Even within those limits, it is clear that Seoul has an air pollution problem. With a population of nearly 6,000,000, it would be surprising if this were not so. It is not as severe as I had thought from data sent me prior to the trip (a matter which will be discussed later), and is probably not at the crisis stage. Nevertheless, it is sufficiently acute that there are unquestionably a few very bad days during the winter, and that the long-term effects are detrimental to health.

It is clear that what cannot be done is the imposition of American (or other Western) solutions. Korea is fighting for markets, and her people have a mean income perhaps one-twentieth of the U. S. Figure. High-technology solutions will place an intolerable burden on the people and the economy. The suggestions made below are only that, where they relate to air pollution control. I feel fairly confident that I have identified the sectors in which the major problems exist. I feel no such assurance that the solutions I propose are acceptable. Besides, the Korean solutions might well solve some of the problems of the U. S.

Before proceeding with the technical portion of this report, I should like to extend thanks to those in Seoul who made this study at

all possible by their help: Dr. Newman Hall, of the Science office of USAID; Miss Julia Worthington, the embassy nurse who kept me healthy by worrying for me about my health; Mr. T. J. Pak, who arranged most of my travels and contacts around Seoul, and acted as interpreter when needed; and Dr. I. K. Yang, an old friend who is now Director General of the Korean Central Meteorological Office, who both arranged some scientific contacts, and entertained me royally. Finally, thanks are due to many members of the AID staff who rendered minor services, and to all those named in the material that follows for generously giving their time to instruct me.

II. Diary

The following is an outline, in chronological order, of the places visited and the contacts made. Korean names are rendered in Korean order here, surname first. Some inconsistencies in spelling have been changed from the spelling on personal cards; the same Korean name, for example, can be rendered as Lee, Li, Ri, Ree, or Rhee. In most cases, a single spelling has been used.

20 April 1972. Arrival. Briefing by Dr. Newman Hall. Health briefing by Miss Julia Worthington. Discussion with fellow consultant Dr. Joan Nelson. Trip to "Sky-Line Drive" and Nam-san for two views of the city from above.

21 April 1972. Seoul Metropolitan Government, City Hall. Mr. Lim Song-Ki, Chief, Environment Section; Mr. Rhee Ju-In, Vehicle Control Section, and members of their staffs.

22 April 1972. Korean Institute of Science and Technology. Mr. Rhee Chan-Ju, Head, Environmental Planning Group, and Mr. Keith D. Christian, a U. S. Peace Corpsman assigned to him.

24 April 1972. Trip to Inchon to see industrial development along Seoul-Inchon corridor. Central Meteorological Office. Dr. Yang In-Ki, Director General, Mr. Kim Chin-Myun, Chief, Weather Service Department, and other staff members.

25 April 1972. Atomic Energy Research Institute. Dr. Rho Chae-Shik, Director, Health Physics Division; Mr. Pak Kyong-Yoon, Health Physics Division; and Dr. Kim Yu-Sun, Chemistry Division.

National Institute of Health. Mr. Hu Yong, Director; Mr. Rho Chung-Bai, Chief, Department of Hygiene, and several additional staff members.

26 April 1972. Return to Vehicle Control Section, Seoul Metropolitan Government, City Hall. Mr. Rhee Ju-In. Return to Central Meteorological Office. Gave a seminar on "Air Pollution" to an audience of about 30.

27 April 1972. Seoul Metropolitan Government, Institute of Hygiene, Yongsan-Ku. Dr. Pak Chae-Ju, Director; Mr. Kim Hyo-Sang, Chief, Public Nuisance Measurement Section; Mr. Kim Jong-Suk, Deputy Chief Examiner, Public Nuisance Measurement Section.

28 April 1972. Seoul National University, College of Medicine, Dr. Cha Chul-Hwan, Associate Professor of Preventive Medicine and Director of Health Center.

29 April 1972. Yonsei University, College of Medicine. Dr. Kwan Sook-Pyo, Professor, Department of Preventive Medicine and Director, Institute for Environmental Pollution Research.

III. Findings

It was originally hoped to prepare this section with complete documentation, citing papers and other sources. However, this is truly impossible; too much material has come from too many sources and been synthesized. Key sources of numerical data will be cited where possible. In a few cases the source is a few pages of a document written otherwise in Korean, and no citation can be recovered.

A. Pollutant concentrations in Seoul.

A number of reports exist on measurements of specific pollutants in Seoul. A typical one is by Cha et al., Korean Journal of Preventive Medicine, 4 (1), 41-64 (1971). This gives the following mean data for Seoul for the period July-November 1970: Dustfall, 33.2 metric ton/km^2/month; sulfation, 1.64 mg/day/100 cm^2; suspended dust, 3.14 mg/m^3; daily mean SO_2, 0.092 ppm; daily mean CO, 33.4 ppm.

These data require some explanation. Dustfall is measured by a fair copy of the British "Standard Deposit Gauge", and is fairly comparable to U. S. data. The equivalent in English measure is about 90 short tons/mi^2/month; other reports give figures nearer 100 tons/mi^2/month. This is just about typical of a fairly dirty city anywhere. I observed that sweepers at various buildings swept up quite a lot of dust, pretty much in accord with these figures. Sulfation rate, a not very accurate index of sulfur dioxide content, is also not atypical. It suggests a real SO_2 problem, but not a crisis. The technique is the British "Lead Peroxide Candle", which has the advantage of simplicity, but the disadvantage that it cannot be directly related to SO_2 concentrations in the air. Nevertheless, several agencies in Seoul have accepted an old British equation, and do report SO_2 concentrations in parts per million from these data. Such figures are probably correct to no more than an order of magnitude. The daily mean SO_2 concentration reported here, however, was obtained by the "indicator tube method", which is still poor at these concentrations; it was intended for the much higher levels found inside industrial plants. However, the figure is reasonable, and is probably good to a factor of two.

The figure for suspended dust, however, is starkly incredible. It corresponds to a mean visibility, over the entire city, and for the entire period, of not much more than one city block. It would probably also correspond to a ten-fold increase in dust-fall. It is apparently this figure which has resulted in publicity naming Seoul as the world's most polluted city. Seoul has persistent atmospheric haze, certainly, but no such impenetrable murk. The clue is that all measurements to date have been made with a single instrument, a Japanese-built "Digital Dust Indicator", which apparently has been handed from one group to another. I finally saw the instrument in the laboratory of the Seoul Institute of Hygiene. It is a 45-degree light scattering particle counter. This draws a very fine stream of sampled air through an intense light beam. A photocell picks up the flash of light as each dust particle passes, and these are counted. Now if the size distribution of the particles is fixed, the number concentration can be simply transformed into a mass concentration. However, if size is variable, as it is likely to be, this transformation is impossible. But some salesman gave them a single conversion factor. The result is that these figures are high by a factor I would estimate at 10 to 20. They are really almost useless, although their trends have some meaning, in that they reflect changes in number concentration.

Carbon monoxide data seem a bit high, but may be correct. The indicator tube method was used here. The concentrations are high enough to be within the range of air accuracy for the method; accuracy is probably $\pm$ 30 percent. The figures are consistent, also, with data obtained verbally at the National Institute of Health for nitrogen dioxide of about 0.2 ppm, apparently by the Jacobs-Hochheiser method. These NO_2 measurements were made in late 1968. There is a trick in calculating data using that technique, and it is impossible to learn whether or not the analysts were aware of this. However, the systematic error introduced is only about 30 percent, but might be systematically in either direction. It is most probable that the figure is low. The precision of the method itself is probably about 20 percent. The mean has doubtless increased in the past three years.

Variation of all pollutants from one area of the city to another were in the expected sense; dustfall, for example, was highest downtown and lowest in residential areas, with a span from 52.3 ton/km^2/month to 15.41 ton/km^2/month. Suspended dust varied in the same sense. Not surprisingly, CO was higher downtown than in an industrial area. Less conventionally, the same was true of SO_2. Both showed morning and evening maxima with the latter the larger.

I was told that there was a Beckman Instruments-designed mobile laboratory now available, but nobody offered to show it. Almost every group gave the impression that it was theirs; some said it was now fully operational, some said it had just arrived. Finally Dr. Kwon Sook-Pyo of Yonsei University clarified matters: (a) The unit belongs to the National Institute of Health; (b) it still does not work.

In summary, there are relatively few data for Seoul, a very few for Pusan and Daegu, and I found none for other cities. Inchon appears to have the potential for very severe pollution from a large, uncontrolled steel mill at one edge of town. The day I was there the wind was blowing its effluent out of town, but I was told that the opposite (easterly) wind direction is not especially uncommon.

B. Meteorological Data.

In the last three years, some 70 additional meteorological stations have been installed in Korea; there are three radiosonde stations. This is something of the order of a 250 percent increase in data gathering capacity during this period. The level of education and ambition in Korea being what it is, I suspect data quality is high, within the limitations of equipment. The Central Meteorological office has weather radar and APT equipment. Archived data are being placed on microfiche with provision for encoding by some sort of criteria and automatic sorting. Staff seem to know their jobs. Some interesting research is in progress on evaporation control for rice paddies.

Probably one ingredient in the Seoul air pollution problem is the extremely seasonal rainfall. Seoul receives a nominally ample total annual rainfall of about 170 cm., or half again that of the American Midwest. However, it all falls between June and October. The balance of the year is dry. Now, in April, the major rivers are trickles by comparison with the capacity of their obvious river beds. The summer obviously brings floods, since there is much publicity about dam building and expansion of both research and services in hydrometeorology.

However, from the standpoint of air pollution, there is almost no meteorological information to be had. So far as I could ascertain, no micrometeorology has been done on the Seoul area. There was an obvious inversion virtually every morning which did not break until nearly (and sometimes after) noon. The mountains and the Han river valley doubtless make for very complex circulation patterns. There is a sort of saddle between Nam-San (South Mountain) and the general range to the west, and I got the visual impression that a good deal of the haze stayed south of that saddle. I also have a bad copy of a 1970 annual wind rose for Seoul, showing northeast and northwest as preferred directions, and a tendency toward low wind velocities. However, I am sure that a site a few km distant would show a different pattern.

In short, no studies have been made because no funds have been available. The Director is interested, and has proposed to the Special Fund of the United Nations Development Program the funding of a Meteorological Research and Training Institute. Air pollution meteorology is included in the plans. I pointed out the utility of such interim techniques as low-altitude aerial photography, lapse time cinematography from a mountain top or TV tower, and installing a cheap thermograph on

the cable-car which runs up the north side of Nam-San. It will be interesting to see if any of this is done, but help is clearly needed here, as it is with chemical monitoring.

C. Effects of Pollution.

Even less information is available here. A survey, reported by Lee Hyo-Jae (Transactions of the Royal Asiatic Society, 46, 1-104 (1971), stated that during October, 1966, 35 percent of the population had a respiratory disease at any given time. Dr. Cha Chul-Hwan of Seoul National University expressed to me his unqualified opinion that air pollution is an important cause of illness in Seoul. I was given an abstract of a published paper by Cha, showing a higher incidence of illness, by a factor of about 1.5, in Seoul than in the much smaller city of Suwon. The highest factor came from hillside areas, which tend to be squatter setter settlements. Other factors are not seriously inconsistent with air pollution as a contributing factor, especially as the survey was taken during the winter of 1970-71. Unfortunately, the reference for the paper cannot be determined, and the paper itself is, of course, in Korean.

Visually, air pollution and/or haze restricted visibility to perhaps 5-10 km during most of my stay, and soiling of buildings was obvious. I did not notice any excessive attack on statuary, but of course nearly all monuments in Korea are relatively recent--i.e., since 1945. During the trip to Inchon, at no point was there any striking improvement in visibility. Clearly some significant fraction of the airborne particulate matter is natural or comes from sources in China. The previously cited paper on pollutants in Seoul by Cha, et. al., reveals that the dustfall is about one-third water soluble, which is in line with a substantial natural component.

In summary, very few effects studies have been made, and those available are not definitive. No observations on plants or animals were found, although Dr. Kwan Sook-Pyo of Yonsei University has published work [(Yonsei Medical Journal, 10 (1), 37-47 (1969)] on enzymatic effects of high (250 ppm) concentrations of SO_2 on rats.

D. Sources of Pollutants.

Very little has been compiled on this subject. Under a newly effective city air pollution ordinance, the Environment Section, Seoul Metropolitan Government, has registered, I was told, 5,737 pollution sources. Nobody seems to be equipped for source sampling, and it was unclear whether "registration" includes supplying any information on emissions. In any case, nobody seemed to feel that a real emission inventory would be available in the near future. The "Seoul Statistical Yearbook" for 1971, reporting 1970 data, reported 3,856 manufacturing establishments in the city.

The typical manufacturing enterprise listed appeared to have around 20 employees, be valued at something around ₩ 4,000,000 (about $10,000) and be privately owned.

There has been until this year no requirement for control of pollutants. However, a law was passed in January, 1971, to be effective this January. It set a limit of Ringelmann 2 (40 percent black) on smoke shade, with 8 minutes out of any hour allowed for firing, soot blowing, etc., with no limit during that period. In addition, emission and ambient standards were set for a number of materials (Table I). Ambient standards here specify maximum concentrations that can occur outside the property line of the emitter. Fines of up to ₩ 5,000,000 and jail sentences up to 2 years can be levied against the responsible individual in some sorts of violations.

Table I. Present legal limits to emissions and to pollutants at ground level, under Korean and Seoul city regulations

Substance	Ambient limit at plant boundary	Emission limit
Ammonia, NH_3	40 ppm	600ppm
Carbon monoxide, CO	40 ppm	3,000ppm
Hydrogen chloride, HCl	2 ppm	60ppm
Chlorine, Cl_2	0.5 ppm	50ppm
Sulfur oxides, SO_x	1.5 ppm	3,000ppm
Nitrogen oxides, NO_x	1.5 ppm	250ppm
Carbon disulfide, CS_2	7 ppm	120ppm
Fluoride, F^-	1.0 ppm	10ppm
Formaldehyde, CH_2O	2.0 ppm	70ppm
Hydrogensulfide, H_2S	4 ppm	150ppm
Arsenic, As	0.03ppm	
Benzene, C_6H_6	15. ppm	
Phenol, C_6H_5OH	4. ppm	
Chromium, Cr	0.05mg/m^3	
Cyanide, CN^-	2 mg/m^3	
Phosphate, $PO_4^{\equiv}$	0.4 mg/m^3	
Dust	10 mg/m^3	2g/m^3
Soot	25 mg/hr or 50mg/m^3	1.2g/m^3

Some training in the use of the Ringelmann chart is apparently provided by the National Institute of Health, and in the absence of any source testing program, escessive smoke is probably the only offense that will be prosecuted for several years. The standards are used primarily in the design of new facilities. Since neither industry nor government have any real competence in the design of pollution control equipment, personnel at Yonsei University have been assisting here.

Many industrial emissions seem to reflect utter disregard for life and limb. For example, I commented on the astonishingly high permitted fluoride level. I was told that there were very large discharges from the glass industry. A discharge that produced 1 ppm of soluble fluoride at the plant fence would kill many varieties of vegetation for some miles downwind, and make surviving vegetation dangerous to man or beast. Nobody seemed to have heard of cattle fluorosis, much less the typical leaf tip necrosis in pine, gladiolus and the rose family, but I should expect it to be evident. Yonsei University scientists are hopeful of being able to tool up for some fluoride analysis within the next year. Fluoride standards should be nearer one part per billion. Similar comments could be made about most of the other standards. (I heard nothing, and in fact sought nothing, with regard to industrial hygiene practices; I was rather afraid of what I would learn!)

Emissions from manufacturing processes are thus very difficult to estimate. They are clearly high, considering the scale of manufacturing. That is to say, in the U. S. it is possible to guess fairly accurately the effluent from any industry, knowing only its nature and the amount of production. Such "emission factors" would give only a lower limit to emissions here.

This is less true of fuel combustion. A paper by Chae Il-Suk [(Korean Journal of Public Health, 6 (1), 33-43 (1969)], a student of both Dr. Cha and Dr. Kwon, computes emissions for all of Korea from heating and similar energy conversion processes. More to the point, a set of emission factors are given which appear to have been adjusted for the particular conditions of Korea. It was impossible to ascertain the details of this adjustment, but it seems reasonable to assume that computations from them will be correct to within 50 percent; U. S. emission factors, applied to U. S. cities, appear to be within perhaps half of that tolerance.

Before making the calculation, it would be well to discuss the principal classes of pollution sources in Seoul which involve combustion. Industry and electrical power plants use heavy petroleum oils, predominantly Bunker-C. Korean petroleum products are all made from Near East crudes of high sulfur content, so Bunker-C oil, as used here, contains about 4 percent sulfur. Power plants do not produce much smoke,

so far as I was able to observe, and of course ash is not a serious problem. However, the major downtown buildings are heated by heavy oils as well, and produce heavy smoke during startup.

Diesel fuel, like much similar oil sold in Mexico, contains about 2 percent sulfur. Diesel engines in Korea are operated almost universally at full load or above; I was told that a large city bus might well have a 100-150 horsepower engine. Most diesel vheicles are old, maintenance occurs only when they do not operate, and there is a high tendency to employ used, rather than new, replacement parts.

The roughly 4,500 busses in Seoul are the principal form of transportation for the people. They are owned by 52 bus companies. This sounds chaotic, and is to some extent, but the chaos is minimized by the organization of these companies into 2 groups. (I was unable to learn precisely what word best described these groups, but "union", "cooperative", or even "cartel" may be appropriate). These allocate routes and set fares. Trucks appear to number around 20,000, although a large fraction seem to be the little tricycle pickups from Japan, and are gasoline-powered. All exhaust pipes discharge at bumper level; apparently the elevated exhaust stack is unknown here.

The balance of vehicles in Seoul are some 40,000 autos. I saw no figures, but a visual inspection suggests that about half of these are taxis. Of these, a large fraction constitute one-man-one-car taxi companies, so that there are some thousands of firms involved. The balance of the autos are, by some definition or other, fleet vehicles, operated by government offices, embassies, livery companies, commercial enterprises, and the like. I did not see anything identifiable as a private auto, in the U. S. sense.

The result is to generate an incredible traffic crush with very few cars. I was told that the average day's travel for an auto in Seoul is something over 200 km. Hence, these vehicles travel an average on the order of 50,000 miles per year, nearly all of it within the city. The average traffic volume is thus equivalent to some 10-20 times as many vehicles as are in an American city.

With such large mileage, autos age rapidly, but do not retire. As with the diesel vehicles, repairs are made only when essential, and then usually with used parts. It is probably unnecessary to state that per-vehicle emissions are high. Emissions are made still higher by the driving habits of Koreans, which are unique. It is probably out of place to try to detail the entire driving etiquette, but the result is maximization of those parts of the operating cycle giving the highest emissions. Probably the respective time percentages would be 20 percent hot idle, 40 percent accelleration, 40 percent decelleration, and almost no cold idle or cruise. I suggested that smoother traffic flow would improve

the situation; the idea seemed a new one. Pedestrians operate by rules that are also unique, and cause a lot of panic stops; I commented that Seoul must have the world's worst pedestrians, and the world's most skilled drivers, otherwise the pedestrians would all be dead.

There is a law, I was told, that a vehicle (I think this is limited to gasoline vehicles) that emits smoke in excess of Ringelmann 4 must be removed from the road, and that Ringelmann 3 elicits a notice to repair. It is not clear that this is enforced. There is also a law requiring a test for carbon monoxide emissions as part of the six-monthly safety inspection, the limit being 5.5 percent CO in the exhaust. However, no facilities exist for such tests, and the Korean Institute of Science and Technology apparently has the job of finding out how to do it. Actual testing is perhaps two years off at best.

Other consumption of petroleum (jet aircraft, etc.) is negligible, as is use of bituminous coal.

Korean anthracite is low in sulfur but very high in ash content. Nearly all of it is used in home heating, using the unique ondol system. In a typical Korean home, two or three rooms are so heated. The kitchen is excavated below ground level, and is also the "furnace room". The interior kitchen walls have three to five openings, one or two into the space under the floors in each of the ondol rooms. Heat and combustion gases from fires stoked the kitchen are led through these openings to heat the floors, and finally reach a chimney. The fuel was originally wood, but is now, except in extremely remote areas, anthracite briquets. These are cylindrical, roughly 15 cm in diameter and about the same in height and weigh about 4.4 kg. There are a number of holes through the briquet, each about 1-2 cm in diameter, parallel to the cylinder axis, to promote burning. Two briquets fit into a metal, clay-lined pot with adjustable air inlets at the bottom. The fire is started at the bottom of the lower briquet; when that has burned out, some 8-12 hours later, and the upper briquet has started to burn, the upper briquet is removed with special tongs, the ash from the lower briquet is removed, the burning (previously upper) briquet is replaced on the bottom, and a new upper briquet is put in place. The burning pot has a rim with some projections to support cooking pots.

After a house has been largely completed on the outside, including the chimneys, the earth is excavated under the rooms that are to be heated. This is done so as to leave a slope, lowest next to the kitchen, and highest at the openings into the chimneys. There is one chimney per room. Stone slabs are placed on edge, sunk into the ground for stability, in one of several patterns, but generally leading from the wall abutting the kitchen toward the chimney. These will serve as the side walls of heating ducts, and as supports for the floor. Accordingly, they do not touch the walls; a plenum space is left at both ends.

On top of these goes a layer of flat granite slabs. Openings where these meet are chinked with clay, then the entire layer is covered with fine gravel, followed by a layer of clay, about 1-2 cm of concrete, and a layer of paper, which is subsequently lacquered. The lacquered paper is the final seal to prevent combustion gases from leaking into the house. The importance of this layer probably accounts for the shedding of shoes at the doorway of a Korean home.

There are two principal designs beyond this point. In the traditional system, the fire-pot is physically in the kitchen in a pit, and above it are several clay pipes leading through the wall into the space under the ondol room. The fire is used for cooking with all its gases going directly into the kitchen. When it is not being so used, a metal hood directs the heat and smoke into the pipes. In a more advanced form, there is a door with some dampers which leads through the wall, the fire-pot has four wheels, and once lit it is rolled through the door to sit directly under the floor. In this design, much thicker granite is used for the spot above the burner, so as to even out the heating of the floor.

The result is an extremely comfortable system of radiant heating, well adapted to the bitter Korean winter climate.

There are something like 600,000 dwelling units in Seoul. Large apartment buildings are in evidence, and many more are being built, but even some of these use ondol heating, which the Koreans prefer. From the standpoint of comfort, I agree with them; the cold floors of my own home make me feel that the U. S. is a primitive country by comparison. But there are other problems. One is that the combustion of one 4.4 kg anthracite briquet leaves a residue of 1.8 kg of ash to dispose of. Each ondol requires about 2 briquets per day, or 6-10 per typical house. Total anthracite consumption in Seoul last year was over 5,000,000 metric tons. Consumption for purposes other than home heating is negligible. This leads to the interesting consequence that Seoul, with a mean annual per capita income of around $200, generates 350 kg of solid waste per person per year. In most of the world, solid waste production is closely correlated with affluence, but Seoul's waste is comparable with that of a typical, fairly affluent European city. Incineration is of little help, since most of this is incombustible ash. This ash is also probably an important ingredient in dustfall.

A second consequence is a high deathrate from indoor carbon monoxide poisoning. When the air vents at the bottom of the pot are partially closed, the burning anthracite becomes a very efficient generator of CO. If there is any imperfection in the sealing of the ducts, or if the chimneys fail to draw, CO enters the house at a high concentration. The standards of wall construction are not high. For example, most chimneys have no liners, and one side is the wall of the room. Educated Koreans

spend some time after moving into a new house painting the walls, calking the door jambs, and the like. Some install flue liners. However, in the event of a real malfunction this is self-defeating; the ventilation rate is often as little as 1-2 changes of air per hour. I was told that there were 500 deaths in Seoul last winter from this cause. (Some of these were deliberate; tampering with the ondol seems to be a favorite form of suicide.) There are few data of consequence on the prevalence of sub-lethal effects, and none on the subclinical consequences of this sort of carbon monoxide exposure.

The final consequence is that home heating is the largest source of pollution in Seoul, causing over one-half of the total (combustion-derived) emissions. The only major pollutant category in which it is not the major source is hydrocarbons; here gasoline and diesel fuel (i.e., transportation) accounts for over 70 percent.

With this information as prologue, it is now time to look at the actual computation. The emission factors of Chae, previously mentioned, were combined with 1970 fuel sales data from the "Seoul Statistical Yearbook, 1971." The results constitute Table II. Probably no meaning should be attached to anything beyond two significant figures in any number, but all data are given as computed, to the nearest metric ton.

Table II. Calculation of total combustion emissions from the City of Seoul, metric tons per year.

POLLUTANT*

FUEL	SO_x	NO_x	CO	Partic.	HC	TOTAL
Gasoline	254.	5,217.	67,680.	310.	9,278.	82,739.
Kerosene	36.	3,158	122.	199.	91.	3,606.
Diesel Oil	1,891.	4,499.	1,956.	4,792.	10,041.	23,179.
Heavy Oil	352.	172.	14.	31.	6.	575.
Bunker-C	27,303.	7,472.	623.	1,341	240.	36,979.
Anthracite	31,101.	22,062.	70,196.	27,076.	7,521.	157,956.
TOTAL	60,937.	42,580.	140,591.	33,749.	27,177.	305,034.
% from Anthracite	51.0	51.8	49.9	80.3	27.7	51.8

* SO_x = total sulfur oxides, presumable as SO_2, which predominates.

NO_x = total nitrogen oxides, presumably as NO_2. Most emissions are of NO, but (a) this is converted to NO_2 in the atmosphere, and (b) NO is determined by conversion to NO_2.

CO = carbon monoxide

Partic. = particulate matter

HC = hydrocarbons, probably including a certain amount of oxygenated organics.

It is clear that domestic heating is the overwhelming source of air pollution in all categories except hydrocarbons, 70 percent of which come from transportation sources. One might expect that hydrocarbons and nitrogen oxides would be present in sufficient concentrations to cause "Los Angeles-type" photochemical smog during the summer, and a few subjective reports of eye irritation suggest that this is true. However, no measurements have been made of any ingredients except nitrogen dioxide, which is not very diagnostic. It was neither warm enough or sunny enough for my own experience to be indicative.

The percentages of Table II give clear priorities but no help in solutions. An award of ₩ 1,000,000 offered by the government for an acceptable solution to the ondol problem is unclaimed. This problem will be further discussed in the next section.

IV. Recommendations

A. Administrative

I did not devote much attention to the underlying legal structure of pollution control; to have done so would virtually demand the services of a bilingual lawyer, since not only the laws and regulations, but the underlying constitutional and common-law questions would need to be explained in English. However, it is my clear impression from my talk with technical personnel that the basic laws are sound. Apparently, at least some air pollution standards have been written into law, and this is generally undesirable. As conditions change, it is cumbersome to keep amending the law. It may be dangerous as well; a law up for amendment may be weakened instead of strengthened. It is therefore preferable to delegate standard-setting to a technical body, merely setting forth guidelines for their deliberations and setting limits to their authority. Some minimum standards should also be written into the law concerning the makeup of this body; e.g., that more than half of the members must hold advanced degrees in science, medicine or engineering, or some similar method to guarantee that appointees have the requisite knowledge. On the other hand, too rigid specification of the personnel is to be avoided. A law that says that one member of the body must be, for example, a professor of preventive medicine at Yonsei University, ignores the fact that the one highly qualified person meeting that description will one day retire, die, or change his interests. His replacement may be far less desirable. There are clearly enough qualified persons among those I interviewed to make up a seven- or nine-man body of this sort.

Some competent and interested scientific administrator must assume responsibility for coordinating research on air pollution throughout Korea. To date, a number of groups have gone out on their own and measured one or more pollutants, more or less at random. Nearly every single group with whom I talked has done so. This is desirable up to a point; it is good experience. Nearly everyone should try it, if only to instill a properly agnostic attitude toward the accuracy of such measurements. However, with scarce resources, only limited competition can be tolerated. Someone needs authority to tell a medical research group that

they are not chemists and will not receive money for chemical monitoring, but for studies in environmental epidemiology. However, he must also have the authority to tell chemists that they will not receive money to make measurements in Yongsan, but in the area where the epidemiological studies are to be done, and at the same time as those studies. In short, research coordination is essential, at least until far more resources are available.

There also seems to be little sharing of laboratory equipment between institutions. Some have good analytical facilities that are very lightly used; others have none. I am aware that this is a universal problem, but if it could be solved in Seoul, a great deal more work could be accomplished. There is apparently already some sharing of monitoring equipment, which is commendable, and possibly a useful precedent.

Every effort needs to be made to upgrade personnel everywhere in air pollution research, and especially in control activities. Sending Kim Jong-Suk to the U. S. is a good beginning, but training is also needed for key personnel among the enforcement staff. Once trained, they need to be paid enough to keep them, and keep them relatively honest. Industries should also be urged to send key engineers to counterpart industries in countries where controls are strict, or, in the case of foreign firms, to import experts to provide training to local staffs.

Despite some hazards of creating still another organization, consideration should be given to forming a Korean Air Pollution Association. Meetings would provide a specialized channel of information exchange, and membership in the International Union of such societies would allow at least a few members to attend worldwide conferences like the one next year in Düsseldorf, and to meet counterparts from other countries. In addition, sponsorship should be sought, whether through USAID, UNESCO, or a Korean agency, for a periodic review of programs by knowledgeable but sympathetic outsiders. This review should not be imposed from outside, but sought. Perhaps face could be saved for those reviewed if reviews were available only at the level of the directors of the organizations visited. The whole idea is to avoid a punitive aspect to a poor review. The intent should instead be advisory, with a clear implication of the fallibility of even an expert from out of town.

Finally, it must be accepted that the present rate of investment in air pollution research and air pollution control is too low. Many of the recommendations to follow will cost Korea money. In the long run, however, there should be a monetary gain from investment in research and control <u>now</u>, rather than later, when the problems are critical, a great many more inherently dirty industries are built in the wrong places, and there is a vested interest in spreading and disseminating the private automobile.

B. Research and Development.

There are two fundamental pieces of information, as previously noted, that are truly lacking, and which must be obtained as soon as possible, probably meaning within the next 2-3 years. The first of these is adequate qualitative and quantitative information on the nature of Seoul air pollution. This calls for a sustained monitoring effort, and probably should be carried out by the municipal Institute of Hygiene. Mr. Kim Jong-Suk will learn how it should be done during his visit to the U. S., but on his return he will require a minimum of W 5,000,000 to put his knowledge to use. Probably like amounts of money should be available to each of the major research laboratories--the groups interested in air pollution at Yonsei University, Seoul National University, etc.,-- for a well-chosen assortment of more specialized equipment to permit non-routine studies of pollutants that cannot be measured on such a routine basis. Purchases should be reviewed before being made on two grounds: (1) As noted before, duplication is probably a luxury; each group should pick its own area and stick to it; (2) an experienced air chemist should be contacted to be certain that the equipment will actually do what it is supposed to do, is not a salesman's dream, and that if possible, it will do some other things as well. For example, there is a specialized commercial instrument that will measure peroxyacetyl nitrate, an ingredient in photochemical smog. For a slight additional cost, an instrument can be gotten that will also measure chlorinated hydrocarbon pesticides and a number of other environmental contaminants. Furthermore, since it is notoriously difficult to get instruments serviced, it will pay in the long run to buy good quality.

The second piece of information that is needed is a picture of the micrometeorology of the Seoul air basin. The logical agency to do this is the Central Meteorological Office, with assistance from the Institute of Meteorological Research and Training, when it is established. Three early and relatively inexpensive things can be done: (1) A site can be sought on a mountain top which commands a view of at least a good portion of Seoul and which is much of the time above the local haze layer. Lapse-time cinematography will show the diurnal movement patterns of the pollution, as well as some strong sources that might otherwise be missed; (2) If it is possible under Korean law, systematic, low-altitude (700-1000 m.) aerial photogrammetry on high-pollution days will also show the movement of the cloud of pollution. The aircraft should fly a pattern over the city that can be repeated at intervals of 30 min. to 1 hr. from first full daylight until inversion breakup. Perhaps the assistance of the Korean Air Force can be enlisted, and, if there are problems of security, a single cleared individual can trace off patterns of the pollution "fronts" onto maps without the photos ever being released; (3) Use should be made of the presence of Namsan in the middle of the city. The cable-car can be equipped with a simple (W 50,000) temperature recorder; its travels up and down the hill will give "vertical" profiles of

temperature at very low cost. At slightly greater cost, this can be extended in the vertical by putting temperature recording equipment on one of the television masts at the top of Namsan.

For the longer pull, presently planned work at the Korean Institute of Science and Technology to develop means of testing autos for CO emissions and to evaluate simple devices to improve carburetion should be encouraged. If a solution to the ondol problem is really desired, the present prize of W 1,000,000 should be doubled, and publicized outside Korea. Possible practical uses for briquet ashes could also be studied.

C. Control.

Clearly the present Korean economy would not support the mandatory installation of the sort of high-technology pollution controls required of industries in Los Angeles. However, there are several purely practical steps that could be taken immediately.

Industries generally can be made to "tighten up" their operations. Many Korean industrial plants do not just emit pollutants from their chimneys, but from every chink in the building, every exposed valve, every ventilator and door. If these are simply better confined and exhausted to the stack to the maximum extent possible, surface pollutant concentrations near the plant would drop sharply.

This could well be coupled with another step. There are numerous techniques for computing necessary chimney heights, given emission concentration, chimney exit temperature, and desired maximum ground concentration. The British have developed a very simple nomogram for the purpose. Better confinement and higher chimneys do not reduce pollutant mass discharged, but they do make possible much more restrictive and healthy ambient standards than those presently in force.

If ambient fluoride levels actually reach 1 ppm, that is intolerably dangerous. I believe a simple loose bed of coarse limestone would remove hydrogen fluoride down to safe concentrations. A schedule would have to be worked out and enforced to replace spent limestone. If hydrofluoric acid has to be imported, or is made from imported fluorspar, it might be worthwhile to reprocess the resulting calcium fluoride. Refinery waste gases should be flared.

Finally, despite all the previous comments concerning the lack of meteorological data for Seoul, there are surface wind data. These can be used, with consultation with the Central Meteorological Office, for planning future plant locations. The recent study of Denver by Herbert Riehl and Loren W. Crow, "Meteorological Aspects of Denver Air Pollution," Colorado State Univ., Paper No. 158, (1970) could be furnished as a model. It is

likely that some areas should be totally closed to new industry, and old industry encouraged to move by means, and with a strength of encouragement, better judged by the appropriate Korean authorities than by an outsider.

The transportation sector will yield much more slowly. One thing that could be done rather soon is to require trucks and busses to have an exhaust pipe extending above the vehicle. Like the tall factory chimney, this would not decrease pollution, but it would improve dispersion. Present discharges at bumper level blast right at the vehicle behind, greatly increasing individual exposure. It must be kept in mind that, while the overall contribution of diesel engines is relatively small, the individual driver following a diesel is getting all diesel exhaust.

On a longer time scale, the total concentration from transportation can be decreased markedly by simply smoothing traffic flow. This means some technique to inhibit "cowboy" driving, synchronized traffic lights, through bus lanes on streets wide enough for them, control of pedestrians, and all means possible to discourage growth in the number of vehicle-miles driven in the city. The subway will certainly help.

Meaningful vehicle inspection and enforcement of vehicular smoke regulation are both good ideas, but may prove too unpopular to sustain because of the high cost of repairs that will actually cure the problem. It may be better to require better performance in new cars and let replacement do the job. All Korean auto makers are affiliates of foreign companies that sell in the U. S. market and have the knowhow to produce less polluting autos. An added first cost is likely to be more acceptable than a bill for a major engine overhaul enforced by an agent of the government. It is also possible to force makers of new trucks and busses to install larger engines; the less load on a diesel engine, the less it smokes.

Still further in the future, desulfurization of diesel fuel would be desirable. It would be worthwhile to learn the experience in Mexico City, which has had a similar problem. Possibly the added fuel cost would be offset to an acceptable degree by longer engine life.

The heating of major buildings by Bunker-C fuel oil (or coal, for that matter) is presently accompanied by an unacceptable amount of black smoke. Training of firemen together with citations to owners for smoke violations, with suitable publicity, will help greatly.

Really not much can be done about the ondol until the basic problem is solved. Upgrading of housing to decrease the number of old-form ondol will decrease the acute indoor problem. Flue liners in chimneys should be

required, but this will be hard to enforce. Probably a building code, building inspectors and a building permit system will all have to be worked out. If, as I suspect, flue liners improve the draft as well as decreasing leakage, better dispersion will again result.

Finally, the nuisance dust (dustfall) problem can be ameliorated by paving streets and particularly by a major effort to stabilize disturbed soil. The practice of bulldozing an entire building area bare is lamentable, but perhaps excusable in view of the enormous housing shortage. The lack of any reseeding, tree planting, or any practice that would hold the disturbed earth in place is apparently ingrained, but must be changed. Present rates of denudation and wind and water erosion have already closed most of the Han River to navigation, and could turn most of the country into a desert in a small number of generations.

As previously mentioned, some of the dust is also briquet ash, and the best solution is a use for the ash.

D. Miscellaneous.

I am now left with a few odd thoughts that do not clearly fit anywhere, but probably should be included. For example, nowhere does there seem to be one good set of western books and journals on pollution, especially the more technical ones. Nearly everybody seems to have seen the rather poor World Health Organization monograph, but only a few people had seen the three-volume treatise by Stern. Several major workers in air pollution apparently never see Environmental Science and Technology, Journal of the Air Pollution Control Association, Atmospheric Environment, or Staub, all major journals in air pollution. USIS seems to get a few, but of course only the U. S. ones. Some arrangement must be devised; Stern's treatise costs about $130 in the U. S., and an annual institutional subscription to Atmospheric Environment costs $65.00/yr. Possibly the total Smithsonian consulting team should devise a basic library on environment, AID or Smithsonian staff can price it and then a sponsor can be sought when both the first cost and the continuing cost is known. The physical location of the collection may well be determined by the sponsorship, but should probably be at one of the institutions doing environmental research, and free inter-institutional loans should be guaranteed.

In any work that affects life-styles, education and information of the public is a major need. I saw none; the English-language Korea Times was devoid of mention of environmental problems in the issues I saw; I was told that there were sporadic stories in the Korean-language newspapers, but of course I could not check that, and I lacked time to get any of them translated. Possibly generating this sort of material should be an

activity of the Air Pollution Association previously proposed; Koreans appear somewhat cynical about announcements by bureaucrats. Other groups could sponsor Plant a Pyong of Grass Day, and marksmanship contests for nightsoil collectors; the main thing is to get environmental thinking started at all levels as rapidly as possible. If this can be done, the rest of the program outlined above will tend to take care of itself.

I have not specifically addressed the question of the transfer of this information to other developing countries and urban areas. It appears that the technique of sending a consultant on a short visit may be a valid one; the final judgment must await the passage of time to see whether my visit, and this report, ever produce results. It is considerably less clear whether an engineer in, say, Tanzania not specifically trained in air pollution, could solve his problems by reading this report. Possibly some of the methods of approach, at least, are sufficiently clear to be helpful.

The AID/Smithsonian groups involved might consider commissioning a series of simple, "how-to-do-it" books, perhaps based on this trip and one other, to another developing country. There are obviously some basic lists of things that need to be known in air pollution, and I assume in the other environmental fields. A fair number of them were not known in Seoul.