INDOOR COMBUSTION POLLUTANTS: 
A PROPOSAL FOR A REGULATORY PROGRAM

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Man's recognition of pollution and the degradation of the Earth's resources eventually led the United States to environmental legislation through the 1970's in order to protect both the environment and man. This legislation concerned itself primarily with the ambient environment. Little attention has focused on indoor pollution until recently, yet on the average a person spends sixteen hours a day indoors.(1) Since so much time is spent indoors, concern for indoor air quality appears rational. A regulatory approach may be needed in the future, especially as a better understanding of the nature of indoor pollutants evolves. As an attempt to devise such an approach, this paper focuses on the products of indoor combustion and proposes a method for regulation of these combustion products.

Characteristics of Combustion Pollutants

Indoor combustion appliances produce emissions in varying quantities of carbon monoxide (CO), carbon dioxide (CO₂), formaldehyde, hydrogen cyanide, sulfate particles, organic particulates, organic vapors, nitric oxides (NOₓ), nitrogen dioxide (NO₂) and other products of both incomplete and complete combustion.(1) Carbon monoxide binds with the hemoglobin of the blood to form carboxyhemoglobin (COHb) much more readily than oxygen binds to the hemoglobin. Oxygenation of body tissues is reduced with the presence of high COHb levels. The Environmental Protection Agency (EPA)
standard for ambient CO is 9 ppm maximum for an 8-hour average exposure and 35 ppm for a 1-hour exposure. The point where adverse effects were found in cardiac and peripheral vascular disease patients and the effect on oxygenation of skeletal muscles by CO in normal subjects helped set the basis for these standards. The National Research Council Report on indoor pollutants reported exposures of 50 ppm for up to an hour can occur in kitchens with gas stoves especially when cooking utensils come in contact with the flame. Public buildings such as ice-skating rinks may have mean concentrations as high as 100 ppm. Chronic exposure to CO, especially when combined with cigarette smoke, can cause increased levels of COHb but the effects on human health are relatively unknown. Since cigarette smoking encompasses health hazards widely reported elsewhere and smoking is a more voluntary action, smoking will not be considered to any extent.

Nitric oxides binds to hemoglobin producing methemoglobin which may increase cardiovascular stress due to hypoxia. At levels of 3 ppm (3.75 mg/m^3), nitric oxides appear physiologically comparable to CO at 10-15 ppm (11-17 mg/m^3) though nitric oxides do not shift the oxygen binding equilibrium of hemoglobin. G. D. Case found indoor combustion appliances in households responsible for a large fraction of total methemoglobin in human blood. Nitrogen oxides can change heme by producing polycythemia with increased hemocrit and decreased mean corpuscular volume. Leukocytosis and other abnormalities may result from nitrogen oxides along with vascular membrane injury and leakage. Nitrogen dioxide exposures may decrease erythrocyte membrane acetylcholinesterase, increase peroxidized erythrocyte lipids and increase glucose-6-phosphate dehydrogenase.
Sources

Sources of indoor combustion pollutants include items common in many homes. Space heaters, gas stoves, gas water heaters, wood fires, oil and kerosene lamps, exhaust from automobiles in attached garages and even candles may contribute emissions into the home environment. In addition to these sources, humans produce 30-60 g of CO₂ per hour which adds to total pollutant burden. One problem in determining pollutant rates is that data collected so far has been site specific and related to activities at that specific situation. Indoor concentrations vary according to generation rates, the volume of the indoor environment, the air exchange rate with the outdoors, the mixing efficiency within the indoor space and the decay rate of the pollutants. The CO₂ concentration in indoor environment may rise above the normal range of 0.03-0.06%. Unvented space heaters rated at 10,000 BTU/hour or about 2,500 kcal/hour produce around 750 g of CO₂ per hour. The indoor environment under occupied conditions may typically be around 0.07-0.20%. Concentrations above 1.5% will affect respiration, however, reactions to long term exposure to lower concentrations is relatively uncertain.(1)

Space heaters are usually externally vented in the United States and when properly designed and maintained prevent entrance of emissions indoors. Problems occur when a negative pressure accumulates indoors or problems may develop in an exhaust system such as with a blocked flue. Especially in some rural areas in the southern United States, unvented gas and kerosene heaters are used which emit emissions directly into the home environment. Yocom in a 1969-1970 study found one home with a leaking flue in an old coal central heating system. The SO₂ emissions neared
1 ppm and CO exceeded 50 ppm for time periods of one hour and longer. Hollowell found in his study one home with a gas heating system had higher indoor concentrations of NO\textsubscript{x} and NO\textsubscript{2} than outdoor concentrations even though vented to the outside. Neither of these two studies attempted to determine emission rates indoors from these sources.\textsuperscript{(1)}

Cote and his associates in a 1973-74 study determined pollutant emission rates of CO, NO\textsubscript{x} and NO\textsubscript{2} from an unvented gas-fired space heater during low flame states and high flame states. Cote's results are summarized below in a chart taken from the National Research Council Report, Indoor Pollutants:

<table>
<thead>
<tr>
<th>Operation</th>
<th>Heat Input (kcal/hr)</th>
<th>Pollutant Emission Factors (μg/kcal)</th>
<th>Pollutant Emission Rates (mg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low flame steady state</td>
<td>2,800</td>
<td>NO 76.4 NO\textsubscript{2} 46.4 CO 632</td>
<td>NO 214 NO\textsubscript{2} 130 CO 1,770</td>
</tr>
<tr>
<td>High flame</td>
<td>6,200</td>
<td>135 43.8 319</td>
<td>837 272 1,982</td>
</tr>
</tbody>
</table>

Yamanaka measured NO in vented and unvented space heaters used in Japan. He found radiant kerosene-fired space heaters averaged 46μg/kcal and convection type space heaters averaged 251μg/kcal. These values, however, may not be representative of all such space heaters.\textsuperscript{(1)}

Fireplaces and wood stoves emit products which may be highly irritating to the eyes, nose and respiratory system. These problems are intensified by improper installation, cracks and leaks in stovetops, negative air pressure indoors and down drafts. Emissions from residential wood-fired stoves based on a study by Duncan listed particles emission average 30.3 lb/cord, SO\textsubscript{x} averaged 0.7 lb/cord, NO\textsubscript{x} averaged 1.6 lb/cord, hydrocarbons
averaged 41.6 lb/cord and CO averaged 598.3 lb/cord. (1)

Concerns over emissions from gas stoves have surfaced in recent years. A brief EPA study in 1972 found peak NO₂ concentrations of 1 ppm (about 1,880 µg/m³) and one hour averages of 0.25-0.50 ppm (about 470-940 µg/m³) in closed kitchens with no ventilation. (4) Wade and co-workers studied homes with gas stoves from 1973-74. They found kitchen concentrations of NOₓ, NO₂ and CO responded to stove use. Pollutant concentrations during winter months were more uniformly distributed than during warmer months. Houses were closed up more often during these winter months. A diffusion experiment in one house found a half-life for NO₂ only 1/3 that of CO and NOₓ which suggests NO₂ may decay through reaction or adsorption along with dilution. (1) In a study to determine exhaust hood efficiency in removing pollutants, Cote found varied removal efficiencies from 4% with the hood fan off to 49% with the fan on the highest speed. (1)

Another study of NO₂ concentrations compared homes with either gas or electric stoves. A personal sampler dependent only on molecular diffusion was used to sample 19 houses of which ten had gas stoves and nine had electric stoves. The results of this study by Palmes, Tomczyk and DiMattio found results similar to Wade's study. An average of 49 ppb. in kitchens with gas stoves compared to an average of 8.3 ppb. in kitchens with electric stoves. (5) An epidemiological study by the Harvard University School of Public Health measured indoor pollutants in six cities and some 73 houses. Gas cooking homes measured had NO₂ concentrations over 500 µg/m³ for as long as hours at a time in some cases. According to John Spengler, member of the study, an increase in respiratory disease and decreased lung volume occurred among the group using gas cooking. (6)
The Harvard Study also measured respirable particles and sulfates. The indoor levels of particles and sulfates depend on infiltration of outside air plus indoor sources. The long term infiltration of outside air was approximately 70% but could be reduced to approximately 30% in air conditioned buildings. Indoor concentrations varied but indoor mean levels in general exceeded outdoor levels which stayed approximately the same. A Boston Study agreed with the Harvard Study that indoor mean levels of respirable particles exceed outdoor concentrations. Indoor concentrations varied in different homes on the same day. The influence of indoor sources and structure characteristics appear to affect concentrations in a particular home.

A New York City Study indicated that many apartment dwellers may use gas stoves as a source of supplemental heating besides cooking. An association between outdoor temperatures and use of gas stoves was observed over a two year period. Many people using gas stoves kept a pan of water on a top burner to increase humidity but this may increase the amount of CO produced when the stove is in use. The use of gas stoves appears to contribute to high levels of pollutants. Besides the before mentioned sources of space heaters, gas stoves and wood stoves, other combustion sources include water heaters and clothes dryers which produce NO₂, and hobbies which involve soldering with LPG torches or welding with an oxyacetylene torch.

Since indoor pollutants apparently often equal or exceed outdoor concentrations, a person's actual exposure to pollutants may not be adequately protected by ambient standards alone. Ambient standards may represent protection for only a small amount of the average person's total exposure to such pollutants. In order to be adequately protected, a person's total environmental exposure may need to be evaluated.
Controls

Control of quality in the indoor environment presently does not rest with any individual or governmental body exclusively. As far as combustion air pollutants are concerned, no regulatory approach controls them. On the basis of the results of research carried out so far, the relatively unknown but possibly harmful effects of combustion pollutants and the vast availability of combustion sources in the general public, some attention appears deserving to the possible controls which might be applied to indoor combustion pollutants. Controls might be considered on different levels of responsibility including individual, the product's manufacturers, building designers, contractors and owners of buildings, and government responsibilities.

Ventilation and dilution with outdoor air provide an economical solution to reducing worker exposure to pollutants in many industrial settings. Various air cleaning procedures and exhaust systems may also be used. The energy to move and condition air can be as much as 90% of the total energy demand. A cost effective way of conserving energy is to reduce ventilation but by doing so the pollutant concentrations increase. Concerns for energy conservation in homes has led to tighter insulation to prevent heat loss but this insulating reduces natural ventilation present in homes around windows, doors, cracks, etc. The individual may take responsibility by maintaining gas heating and exhaust systems against clogged flues or other obstructions which would reduce the system's effectiveness in removing emissions. The home owner using a hood regularly when gas cooking can lessen pollutant emissions ($NO_2$ and $CO$) from stoves.

Source removal and substitution would help protect the general pop-
ulation from exposure to combustion pollutants. An example might be the substitution of electric ranges for gas stoves. This approach, however, might not meet with approval or be easily implemented in the general public. Natural gas as a source of fuel for cooking and heating is preferred by many as the fuel of choice. The push for gas use increased in recent years for economic and political reasons. Supplies of gas are presently available in Canada, the U.S. and Mexico.(9) Substitution must be moderated by the economic realities involved in removing an existing source. Electric stoves generally cost a little more than gas stoves of comparable quality. Limited income families may not be able to afford a source change while the old source works. Families in a renting situation often have no choice on heating or cooking sources. Substitution also in no way guarantees that the substitute will not be a worse pollutant problem than a present pollutant.(1)

Limiting population exposures to contaminants could be achieved by various approaches. Identification and targeting of high exposure groups in the population might be one approach. Identification would require extensive studies and research as effects of indoor pollutants on various exposure groups remains relatively unknown. Lowering the mean exposure of pollutants to the population involving some kind of reduction at all sources or some sort of shielding might be effective.(1)

Building designs affect dispersal and concentrations of combustion products. Gas stoves in kitchens provide high concentrations of pollutants in that space in many instances. The design of the kitchen space in relation to other living space may then affect whether pollutants remain concentrated in the kitchen area or disperse to other parts of the home.
Air-exchange rules, temperature limits, spatial requirements and air quality factors might be incorporated into building codes and standards in an attempt to develop more satisfactory indoor control situations. Location of wood burning stoves in homes might also be made a part of building codes so as to limit spatial contact with these sources.(1)

Warnings placed on consumer products could alert the buyer of potential danger and hazards. This approach would be similar to warnings now placed on cigarette packages and on products containing saccharin. Labels affixed to products in the form of a sticker would warn of the possible hazards involved with use but could be removed by the consumer who buys the product anyway. Extensive studies would be needed to justify these warnings, particularly in the eyes of the product's manufacturers. Stickers and other types of warnings placed within sight of the buyer would at least inform him of potential exposures.(1)

Economic incentives try to coerce a certain type of behavior because of advantages or disadvantages of the incentive. Taxes on the manufacturer in the form of a pollution tax for products emitting pollutants might be used but would probably cause outrage by the manufacturers because of discrimination against their product. The home owner who installs fans, hoods or other ventilation systems could be given a tax break to help offset costs. Federal aid and loans could be withheld from buildings or projects which fail to prevent or limit indoor emissions. Other economic incentives perhaps could be developed to compel reductions in exposure to indoor emissions.(10)

Development of standards involves legal establishment of limits for pollutants over a given time period. To develop a standard, criteria and goals must be established which also rely on measurement and testing of
of pollutants. Data needs to be collected on health effects including epidemiological studies, clinical research, toxicological studies, human exposures response effect studies, and evaluations of exposure-response relationships. After data has been collected and assessed, conversion to criteria may commence. Standards are developed only after the long processes of developing and researching criteria is completed.\(^{(11)}\)

Presently, economical and reliable techniques for analyzing pollutants at low concentrations found in many homes are lacking. Personal sampling devices in the form of passive diffusion samplers and passive permeation samplers are being developed which may be used for monitoring in exposure studies in the future. If such exposure studies are completed and standards eventually promulgated, enforcement would prove difficult for an agency charged with enforcing standards in all homes across the United States.\(^{(1)}\)

**Regulatory Program Proposal**

The difficulty in proposing a regulatory program rests in the many unknowns faced. According to Stern, a pollution control strategy should consist and be based upon certain qualities. A strategy should be cost-effective and fair, simple to understand, easily enforceable, flexible and capable of evolving as times and data change.\(^{(11)}\) These qualities provide an ideal to strive for in the development of an indoor combustion pollutant strategy.

Recognition of indoor pollution would be the first step of this regulatory program. This recognition would come in the form of an amendment to the Clean Air Act emphasizing exposure to indoor pollutants as a national concern. This legislation would not necessarily propose standards
or even criteria but instead could call for a coordinated research program into indoor pollutants and exposure relationships. Material such as the National Research Council's report, cited throughout this paper, could be used as evidence for the need of further research on a federally coordinated level. Emphasis should be placed on the fact that indoor pollution research need not weaken the need for ambient controls but would complement that program by providing information towards total exposure of humans to pollutants.

The coordinated research program authorized by Congress should include participation of the various agencies in government involved with the inside environment and/or pollution. The National Research Council recommends a research program with participation by the Environmental Protection Agency, the Consumer Product Safety Committee, the National Institute for Occupational Safety and Health, the Center for Disease Control, the National Institute of Environmental Health Sciences, the Food and Drug Administration, the National Center for Toxicological Research, and the Department of Housing and Urban Development. By including these various agencies, coordination of each agencies' plans could hopefully be integrated so that no agency works at cross purposes to another. These agencies could present their objectives and technical assistance to a research group exploring the effects of indoor pollutants. The research group could be made up of researchers presently working in agencies or privately pursuing research. Financial assistance might be provided by both Congress and the various agencies.

The research group establishes evidence for development of criteria to be used for regulatory purposes. The research group should include among its objectives to determine the emission rate of pollutants, effects of exposure on the human population and development of accurate and feasible
methods of measuring pollutants as suggested by the National Research Council report.(1) With the conclusion of such a research program, enough information would hopefully be available that a type of regulatory program could be established and implemented.

A regulatory program could involve regulating either the producer of sources of combustion pollutants or the consumers who buy the products. Enforcing a program directed towards consumers would be difficult from the standpoint of the sheer number of consumers involved. Inspecting each individual consumer's home would probably prove costly, time-consuming and a headache for both the regulators and the consumers. Regulation of the producers of combustion products such as gas stoves would at least reduce the number of places a regulator would have responsibility over. Products tested and inspected at the manufacturing plants would be judged on criteria developed by the research group's report. Products not meeting criteria for emissions would be subject to some form of penalty or correction. A monetary penalty might be extracted from the manufacturer or labels might be required on the product to warn of potential danger with its use. The installation of equipment such as hoods and fans sold on or with the product might be a corrective measure taken by the manufacturer and approved by an inspector.

Besides actual regulation of producers of combustion sources, another branch of the regulatory program is an educational division serving the general public. This division would oversee publications concerning research and development of pollutant controls. The public would be able to receive information through correspondence with this division. An informed public could hopefully make responsible decisions in their purchase and use of
of combustion appliances.

Development of standards could be a long-range goal in the planning stages of the regulatory program. Standards development depends upon future research which at the present remain unknown. Criteria would be the basis for the regulatory program in the beginning stages at least. Subsidies from the federal government might provide financial assistance to companies producing sources for development of technical controls, depending upon the economic situation at the time.

Problems and Conclusions

The proposed regulatory program is not without problems but represents an attempt on my part to create a feasible program. The program sounds reasonably simple on first glance but could become complicated since it is based on criteria rather than solid standards. Interpretations of criteria might lead to confusion in the implementation of the regulatory process. The program would be flexible and capable of evolutionary progress since the criteria requirements could be changed and the program would be developing with long-range goals in the planning stage. The program might be costly to implement and costs of the manufacturer will be passed on to the consumer. These costs must be tempered against costs to health and welfare if such protection was not available for the public.

Regulation of indoor combustion requires input of research not presently available if a program such as presented in this paper is to be implemented. Regardless of how a regulatory program is actually utilized in the future, I believe it is not too early to consider approaches which might be used. As man becomes more aware of his total environmental exposure, indoors and outdoors, the need for protection from pollutant sources may become more apparent and urgent.
Amendment To Clean Air Act

Research Group

Information and Criteria

Regulatory Program Based On Criteria

Regulation of Producers of Pollutant Sources

Education Publications Information

Long-Range Goals
LITERATURE CITED


