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REDUCING ADVERSE HEALTH EFFECTS AND IMPROVING PERFORMANCE OF STOVES ON THE NAVAJO RESERVATION—A PLAN FOR ACTION

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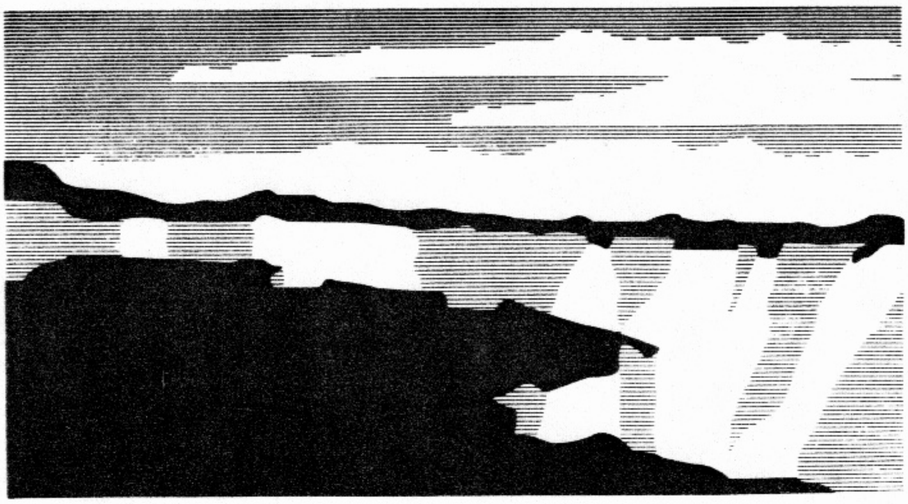

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ACRONYMS

ASTM	American Society of Testing and Materials
BHP	Broken Hill Proprietary (Broken Hill Proprietary Minerals, also known as BHP Minerals, is a resource extraction company)
CCPS	Center for Chemical Process Safety of the American Institute of Chemical Engineers
EPA	U.S. Environmental Protection Agency
NAAQS	National Ambient Air Quality Standard
NCC	Navajo Community College
NHA	Navajo Housing Authority
OSHA	U.S. Occupational Safety and Health Administration

GLOSSARY

Ambient air. "That portion of the atmosphere, external to buildings, to which the general public has access" (*Federal Register* 40 CFR 50.1).

Creosote. A thick black substance formed by the condensation of cooling smoke. It is the major cause of chimney fires.

Emergency Response Planning Guidelines for Air Contaminants (ERPGs). These are issued by the American Industrial Hygiene Association. ERPG-3 is the maximum airborne concentration below which, it is believed, nearly all individuals could be exposed for up to 1 hr without experiencing or developing life-threatening health effects. ERPG-2 is the equivalent concentration for not experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action, and ERPG-1 is the equivalent concentration without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.

Fly ash. Fine solid particles of noncombustible ash with or without accompanying combustible particles carried out of a bed of solid fuel by the draft and deposited in quiet zones within a furnace and flues or carried out of a chimney with the waste gases (adapted from Merriam-Webster 3rd International Dictionary of the English Language).

Hazard. A chemical, physical, or radiological condition that has the potential for causing damage or loss to people, property, or the environment (adapted from CCPS 1989).

Permissible Exposure Limit (PEL). Part of the OSHA air contaminant standards, these are the allowable concentrations, specified as either a time-weighted average (TWA) or ceiling concentration (CL), or both. "These are the concentrations to which a person can be exposed for a normal 8-hr day, 40-hr work week without ill effects" (Lewis 1992).

Primary air. Air that enters the combustion zone at the level of the fuel bed, or from below when a grate is used (Baldwin 1987).

Risk. Exposure to the chance of injury or loss from a process, facility, or accident. It is quantitatively expressed by the frequency of the exposure times the consequence, and typically has units of consequence/time, such as deaths/yr.

Secondary air. Air that enters the diffusion flame from above the fuel bed (Baldwin 1987).

Short-term exposure limit (STEL). "Usually a 15-minute time-weighted average, which should not be exceeded" (Lewis 1992).

Threshold Limit Value (TLV). "Either time-weighted average or ceiling value ... to which workers can be exposed for a normal 8-hr day, 40-hr work week without ill effects" (Lewis 1992).

Volatile Matter. Substances that evaporate from a coal particle while it is being heated to combustion temperature.

REDUCING ADVERSE HEALTH EFFECTS AND IMPROVING PERFORMANCE OF STOVES ON THE NAVAJO RESERVATION—A PLAN FOR ACTION

by

L. F. Brown, D. D. Hickmott, R. P. Currier, S. C. Semken, T. Lameman, S. Martin, and S. Yazzie

ABSTRACT

Many on the Navajo reservation use local subbituminous and bituminous coals for home heating and cooking. Burning this coal emits the contaminants sulfur dioxide, oxides of nitrogen, carbon monoxide, polynuclear aromatics, and particulate matter containing trace metals. The resulting pollution may cause health problems. The pollution is both outdoor and indoor in the Shiprock area, and indoor elsewhere on the reservation. Shiprock's outdoor pollution results from atmospheric temperature inversions, and resembles that of large urban areas worldwide with similar inversions. Modern stoves are a rarity on the reservation. Stoves have evolved significantly over the last fifty years in the direction of reduced contaminant emission, but modern stoves are expensive and still emit significant pollution. Stoves that can effectively burn both wood and coal do not appear to exist, but the Navajos do burn both fuels in their stoves. A program is proposed with the goals of meeting the Environmental Protection Agency's National Ambient Air Quality Standards both indoor and outdoor on the Navajo reservation and creating an economical, pollution-free stove that burns both wood and coal effectively.

I. EXECUTIVE SUMMARY

Residents of the Navajo nation receive free coal from local mines, so this is the fuel of choice for many who live there. Adverse health effects may well result from using the present stoves on the Navajo reservation. Outdoor air quality in the Shiprock (New Mexico) region is poor during the winter months because of emissions from power plants and stoves combined with a temperature inversion layer. In addition, indoor air quality throughout the reservation is poor because of leaking chimneys. Sulfur, nitrogen, and trace metals are the major pollutants present in coal. Burning of coal creates sulfur dioxide, oxides of nitrogen, carbon monoxide, polynuclear aromatics, and particulate matter. The U.S. Environmental Protection Agency (EPA), in its National Ambient Air Quality Standards (NAAQS), provides standards for acceptable purity of ambient air. These standard specify upper limits for CO, NO_2, SO_2, and particulate matter. These standards are appropriate goals for the outdoor and indoor air quality in regions where stoves are used.

High concentrations of trace metals may be found in the particulate matter. No standards have yet appeared for toxic trace metals in ambient air. There are known morbidity effects from ingestions of toxic trace metals, but dose-response data are lacking for ingestion of small amounts of these materials.

There are large differences between coal and wood stoves; coal stoves should not burn wood, and vice versa. Nevertheless, most Navajo stove owners burn both wood and coal in their stoves.

Technical improvements in coal and wood stoves have followed different paths. A "smokeless" bituminous-coal burning stove was developed in the 1940's, burning the smoke by direction of air flow and clever baffling. Commercial exploitation did not follow because the U.S. largely switched to oil and gas. Recent high-grade commercial coal stoves direct primary and secondary air to minimize emission of pollutants. Cheaper coal stoves do not have this feature. EPA has no standards for coal stoves, but EPA regulations mandated changes in wood stoves in the 1990's, and progress in their development continues.

This report suggests a program whose goals are reduction of outdoor pollution in the Shiprock area and indoor pollution everywhere on the Navajo reservation to EPA NAAQS levels. Part of the program is the creation of a pollution-free stove that can burn wood, coal, or other biomass effectively, and is affordable by residents both of the Navajo Nation and of industrializing nations. Meeting these goals requires that relative contributions of power plants and stoves to pollution in the Shiprock area be evaluated, that stove-caused pollution effects on indoor air quality on the Navajo reservation be evaluated, and that an economical, pollution-free coal and biomass stove for space heating and cooking be designed. The report identifies actions required to implement the program.

II. SCOPE OF REPORT

Residents of the Navajo Nation receive free coal for use in their stoves. This report presents a plan to improve stoves on the Navajo reservation that will diminish adverse health effects caused by using coal in these stoves and will better the stoves' performance. The report recommends the evaluation of health risks associated with these stoves. Although a quantitative estimate of the risk does not appear feasible, a comparison can probably be made between appropriate ambient air quality and governmental standards. Further studies can distinguish the stoves' contribution to ambient pollution. Stove design and available technology would be studied concurrently with the study of ambient air quality. The final step would be the design of new stoves or modification of existing ones to reduce the risks associated with them. A necessary portion of the program is education in how to use improved or refitted stoves. The program would also improve performance of the stoves.

Results of this study would apply outside the Navajo reservation. Significant pollution from coal burning occurs in third world countries, particularly China. As an underdeveloped region industrializes, there is a shift from residential use of wood to residential use of coal for both cooking and space heating. Pollution similar to that observed on the Navajo reservation results. Reducing the pollution and increasing the efficiency of stoves worldwide would be a significant step toward ameliorating problems caused by residential use of coal.

III. AIR QUALITY ON THE NAVAJO RESERVATION

A. Type of Evidence Available

Studies of air quality on the Navajo reservation do not exist, so anecdotal evidence is all that is available. Nevertheless, the unanimity of the anecdotal evidence lends credence to its validity. This evidence is, of course, qualitative in nature. One of the first steps in the proposed plan is the acquisition of more reliable and quantitative air-quality data.

B. Outdoor Air Quality

1. Different air-quality regions on the Navajo reservation. On the Navajo reservation, air quality of the Shiprock area differs from the remainder of the reservation. The Shiprock region is in the valley of the San Juan River. Polluted air accumulates under atmospheric temperature inversions over the region. Inversion periods occur most frequently in the December-March interval. The remainder of the Navajo Nation does not experience such inversions, as prevailing winds throughout the remainder of the reservation tend to sweep away polluted air.

According to the 1990 U.S. census, the Navajo reservation has a population of about 146,000 people. Current estimates place the population of the Shiprock region at about 13,000. This includes the San Juan valley in the vicinity of the town.

2. Outdoor air quality in Shiprock area. The previous section stated that temperature inversions during the December-March period cause buildups of polluted air near ground level. The symptoms experienced by the populace are those typical of heavy industrial smog—burning sensations in eyes and throat, tears in the eyes, coughing, etc. The December-March interval is the period when the majority of coal and wood burning occurs in the Shiprock region, so a relationship between home heating and adverse health effects is likely.

Thus the Shiprock region may be regarded as representative of many large urban areas with significant pollution problems caused by atmospheric temperature inversions. Well-known examples are Los Angeles, Denver, Mexico City, and Quito, Ecuador.

Outside of the times when Shiprock and its environs experience temperature inversions, the air quality is generally regarded by the area inhabitants as good.

3. Outdoor air quality outside of Shiprock area. As mentioned above, outdoor air quality in the Navajo Nation outside of Shiprock appears to be good.

C. Indoor Air Quality

Observation of a limited number of stoves on the Navajo reservation suggests that leaking chimneys are endemic throughout the region. Because of this, indoor air quality during the winter months is probably poor.

D. Sources of Air Pollution on the Navajo Reservation

1. Electricity generating stations. There are two large coal-fired electricity generating stations in the Four Corners area. One is the Four Corners plant of Arizona Public Service Company, with a capacity of 2040 MW, the other is the San Juan plant of Public Service Company of New Mexico, with a capacity of 1614 MW (DOE 1994). The two plants are about six miles apart. During the months December 1995 through March 1996, the two plants together burned slightly over four million tons of coal to generate electricity (DOE 1996). If the two plants are regarded as a single entity, together they are the second largest consumer of coal in the nation (DOE 1996).

2. Stoves. Stoves, both coal- and wood-burning, present a possible source of air pollution in the Shiprock area during periods of temperature inversions. An order-of-magnitude scenario shows that these stoves can be a possible source of pollution. If the area population of 13,000 has 2,000 stoves that burn five pounds of coal per stove in one day, and if this coal has 0.5% organic sulfur, then the 10,000 lbs of coal burned will have 50 lbs of organic sulfur. If this sulfur is converted to sulfur dioxide, then about 1½ lb-moles of SO_2 will be emitted. This 1½ lb-moles of SO_2 will occupy approximately 500 cu ft of air space in the Shiprock region. If the region is about 30 sq mi in area, the inversion layer about 30 feet high, and one day's emission of SO_2 collects in the layer, then the SO_2 concentration is 0.02 ppm. This is 2/3 of the EPA recommended standards for maximum SO_2 concentration in ambient air (cf. Section IV.C.2 below). This leaves almost no margin for sulfur oxides from other sources, such as power plant or automobile emissions. The observed poor air quality in Shiprock during the winter months also suggests that home-scale wood and coal burning creates a health problem.

Measurements will have to be carried out to confirm or refute this possibility.

IV. THE BURNING OF COAL AND AMBIENT AIR QUALITY

A. Potential Pollutants in Coal

1. Sulfur and nitrogen. A listing of sulfur content of coals of different ranks from different parts of the U.S. gives a range of total sulfur percentages from 0.45% to 3.50% (on a moisture- and ash-free basis) (Yohe and Blodgett 1947). In a different list (Finkelman 1995), data from 7214 samples from the U.S. Geological Survey's National Coal Resources Data System give a mean sulfur content of 1.8%, a standard deviation of 1.8%, and a maximum value of 25% (on a whole-coal basis). Sulfur in coal exists in two principal forms: as part of the coal structure in the organic coal matrix, and in inorganic mineral forms, physically mixed as impurities. The latter is principally pyritic (e.g., FeS_2), although significant amounts of sulfate also occur. The pyritic sulfur usually forms part of the ash, while the organic sulfur normally burns to form sulfur oxides in gaseous combustion emissions.

Yohe and Blodgett's (1947) listing of coal analyses gives nitrogen contents of coal from 0.67% to 1.80%, while Finkelman's (1995) nitrogen data from 7153 samples give a mean of 1.3%, a standard deviation of 0.4%, and a maximum of 13%. The fate of a coal's nitrogen during combustion is not clear; it may form oxides of nitrogen from combining with oxygen in the coal or in the air, or it may assume the molecular structure and move into the gas phase. The former appears more likely.

2. Trace elements. In a listing of potentially hazardous elements in coal resource development, Finkelman (1995) ranks arsenic, beryllium, boron, cadmium, lead, mercury, selenium and tin as the trace elements of greatest concern. Chromium, copper, fluorine, nickel, polonium, radium, radon, thorium, uranium, vanadium and zinc are trace elements of moderate concern.

The hazards presented by these elements stem from their toxic responses in humans. Finkelman (op.cit.) also gives known toxic responses of trace elements emitted by coal-fired power stations. The list of trace elements having known toxic responses includes arsenic, beryllium, cadmium, mercury, manganese, nickel, lead, selenium, and vanadium. Appendix A repeats Finkelman's list of toxic responses.

Table 1 lists the quantities of some trace elements present in coal. The elements chosen are those mentioned in the previous paragraph as being of greatest concern, together with some of moderate concern. Finkelman (op. cit.) reports the data as coming from the U.S. Geological Survey's National Coal Resources Data System.

Table 1

AMOUNTS OF TOXIC TRACE ELEMENTS IN COALS[(a)]

(Amounts are in parts per million)

(In all cases, the numbers come from between 6000 and 8000 coal samples)

Element	Mean	Standard Deviation	Maximum Value
arsenic	24	60	2200
beryllium	2.2	4.1	330
boron	49	54	1700
cadmium	0.47	4.6	170
lead	11	37	1900
mercury	0.17	0.24	10
manganese	43	84	1500
nickel	14	15	340
selenium	2.8	3.0	150
tin	1.3	4.3	140
vanadium	22	20	370

(a) From Finkelman (1995)

The morbidity effects of the ingestion of large amounts of trace elements are well documented. As mentioned above, Appendix A lists these. Quantitatively, however, morbidity from ingesting smaller amounts of trace elements is uncertain. What Gehrs et al. said in 1981 remains true today, "The current understanding of trace metal toxicity is not adequate to permit assessment of the long-term effects..." Prevailing controversies about the toxicity of trace metals testify to the contemporary validity of this statement (Davis 1992).

B. Pollutants Created by the Burning of Coal

1. Air pollutants in the flue gas. The major pollutants from the combustion of coal are sulfur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), polynuclear aromatic hydrocarbons (PAHs), and particulate matter. The oxides of nitrogen usually measured are nitric oxide (NO) and nitrogen dioxide (NO_2). There can also be a release of particulates, and the particulate matter may contain significant amounts of trace metals.

One fourth of the sulfur oxides in the atmosphere are attributed to the combustion of coal (Finkelman 1995).

2. Pollutants in the ash. Ash is "the earthy or mineral residue that remains after combustible substances (as coal) have been thoroughly burned" (Merriam-Webster 3rd International Dictionary). "Coal ash is composed primarily of oxides and sulfates, and it should not be confused with mineral matter, which is composed of the unaltered inorganic minerals in coal" (Gluskoter et al. 1981). "The predominant minerals in coal are usually kaolinite, detrital clay, pyrite, and calcite, and they give rise to the oxides of silicon and other compounds, and oxides of aluminum, iron, and calcium in the ash. Lesser but appreciable quantities of compounds of magnesium, sodium, potassium, manganese, phosphorus, and sulfur are likewise found in coal ash generally" (Elliott and Yohe 1981). "Except for oxygen and sulfur, elements that normally constitute the ash residues derived from coal combustion can arbitrarily be grouped as follows: *Major elements*—elements in concentrations greater than 0.5% in the whole coal; these normally include aluminum, calcium, iron, and silicon; *minor elements*—those in the range of concentrations of about 0.023-0.5% in the whole coal; these usually include potassium, magnesium, sodium, and titanium, and sometimes phosphorus, barium, strontium, boron, and others, depending on the geologic area; and *trace elements*—all other inorganic elements usually detected in coal at less than 0.02% (200 ppm) down to parts per billion and below" (Gluskoter et al. 1981).

Thus hazardous trace elements are found not only in the particulate matter, but also in the ash. It is principally the particulate matter, however, that presents a danger to people other than those that handle the ash.

C. Ambient Air Quality Standards

1. Particulate matter standards. EPA's present national ambient air quality standards (NAAQS) for PM-10 particulate matter (particles with aerodynamic diameters a nominal 10 μm or smaller) are 50 $\mu g/m^3$ averaged annually and 150 $\mu g/m^3$ averaged daily. "EPA is currently considering a new standard for PM-2.5 (particles with aerodynamic diameters a nominal 2.5 μm or smaller) with proposed concentration levels ranging from 12.5 to 20 $\mu g/m^3$ averaged annually and 18 to 65 $\mu g/m^3$ daily. This standard shifts the focus to control measures reducing the level of fine particles so that air pollution reduction programs will concentrate on combustion sources (e.g., chemical plants and automobiles) rather than coarse particle producers (e.g., wood burning stoves and road construction)" (Anon. 1996).

2. Noxious gas standards. Appendix A gives the exposure limits for the substances in flue gases resulting from coal combustion. The exposure limits specified by the regulatory or advisory agencies are usually for short periods of time or weighted averages over a 40-hr week. Appendix A also gives the EPA-specified NAAQS values for nitric oxide and sulfur oxides. As would be expected, the ambient air standards are far more stringent than the exposure limits for workplaces. Table 2 gives a comparison of the two standards for CO, NO_2, and SO_2.

Table 2

EXPOSURE LIMITS AND AMBIENT AIR QUALITY STANDARDS

	OSHA PEL, ppm	NAAQS, ppm
CO	35	9
NO_2	5	0.053
SO_2	2	0.03

3. Trace metal standards. In the 1990 amendments to the Clean Air Act, the EPA was mandated to develop standards for trace metals. As of mid-November 1996, these standards had not yet been promulgated. These standards will probably consider emissions from major pollution sources, and not specify air quality standards, however.

Section IV.A.2 above tells how the trace-element hazard from the use of coal stoves is unknown at the present time. No standards exist for judging air quality in this area.

V. STOVES ON THE NAVAJO RESERVATION

A. Types of Stoves on the Navajo Reservation

A limited survey was carried out at Navajo Community College (NCC) to give an approximate picture of the types and distributions of stoves in the Navajo Nation. Of the 42 valid replies to the survey, 9 said they had no stove, and 33 said they possessed a stove. Many of the stoves were inherited or fabricated by relatives. Most stove users burned both wood and coal in their stoves; burning either only wood or only coal was unusual. Of the people who reported that they purchased their stove , most said that the seller did not specify the type of fuel. Thirteen remembered costs ranged from $120 to $1200, with $411 being the average.

Shiprock probably does not represent the reservation very well. As a border town, there are more people with jobs, hence the stoves will tend to be more costly and of higher quality than further out in the reservation. The population surveyed was small.

The survey leads to the conclusion that a large fraction of the Navajo Nation owns stoves, and that they burn both wood and coal in them.

Appendix B gives details of the survey, including the questions and spreadsheets containing the answers.

B. Emissions Study on the Navajo Reservation

1. Description of the experiments. A series of scouting tests was carried out to determine the orders of magnitude of pollutants in different fuels and emissions. The test sampled some coal from the Shiprock area, stack gases from one of the power plants in the region, and off gases from a residential stove in Shiprock.

On February 9, 1996, samples of coal being fed to the San Juan Power Plant were taken and later analyzed. On February 8, samples from both Stack 2 and Stack 3 from the San Juan Power Plant were taken and later analyzed. The study also analyzed samples of fly ash from the plant taken on February 6. The San Juan Power Plant is described above in Section III.D.1.

The stove tested was a "Warm Morning" cast iron stove, popular in the region. The stove is perhaps about 20 years old. A dark region on the ceiling above the stove indicated leaks in the system. On January 19, investigators from Los Alamos and NCC sampled the gas in the operating stove within the flame, 6 inches above the flame, and 18 inches above the flame. On March 21, the investigators operated the stove, intermittently placing coal on the fire. A portable Quintox detector analyzed 49 samples of the off gases from the stove. The Quintox detector analyzes for SO_x, NO_x, NO_2, CO, and O, and can measure these substances at either low or high temperatures.

2. Results—coal analyses. The coals of the region are low-sulfur coals, averaging significantly less than 1% total sulfur (cf. Section VII.A.I and Table 5 below). The sulfur analysis is consistent with this, showing about 0.4% sulfur in the coal.

The other elements of interest are the toxic trace elements. Of the toxic trace elements listed in Table 1, beryllium, cadmium, lead, manganese, and vanadium contents are about the average for U.S. coals. The mercury content is higher, the selenium content is somewhat lower, and arsenic, boron, and nickel contents are much lower than the U.S. coal averages listed in Table 1.

3. Results—analyses of power plant stack gases and fly ash. The CO contents of the gas coming from Stack #2 averaged about 0.01%, while the CO content of the gas from Stack #3 averaged about 0.04%. The NO_x content of the gas coming from Stack #2 averaged about 0.04%, while the NO_x content of the gas from Stack #3 averaged about 0.02%. The SO_2 content of the gas from Stack #2 averaged about 0.01%, while the SO_2 content of the gas from Stack #3 averaged about 0.015%.

The fly ash contains significant amounts of the toxic trace elements. Samples of the ambient air, together with a set of standards, will be required to determine if harmful amounts of these elements are in the air due to the fly ash from the power plants.

4. Results—analyses of stove gases. A comparison of the CO, NO_x, and SO_2 contents of the gases in the stove shows that the amounts of all three drop significantly from the flame to the regions 6 inches and 18 inches above the flame. The contents of the gas in the regions above the flame are within the ranges seen in the later March 21 analyses.

The March 21, 1996, test yielded analyses of 49 samples of the gases within the coal stove. Appendix C gives the 49 analyses. Table 3 (next page) gives the mean percentages and standard deviations for the CO, NO_x, and SO_2 in the gases in the stove.

As noted later (Section VI.A.2), combustion of coal occurs in two stages, the first being the emission and combustion of volatile matter and the second the burning of char. During the test, whenever fresh coal was added to the fire, gases were emitted from the fresh lumps for a short period. This resulted in wide swings in the gases' pollutant contents in the stove during the test (Appendix C). The large standard deviations reported in Table 3 attest to this.

Table 3

POLLUTANT CONTENTS IN GASES EMITTED FROM COAL-STOVE FIRE

(data from 49 samples)

	mean content of gas in stove, ppm	std. deviation,, ppm
CO	3346	6319
NO_x	62	48
SO_2	72	123

VI. GOALS FOR THE OPERATION OF STOVES ON THE NAVAJO RESERVATION

A. Approaches Considered for Deciding on Goals

1. **Standards for emissions from coal stoves.** *The EPA has issued no standards for emissions from coal stoves*. The EPA has stated that free standing and fireplace-insert airtight stoves without a catalytic combustion device sold after July 1, 1991 shall not have smoke containing more than 7.5 g/hr of particulates (*Federal Register* 40 CFR 60.532). Stoves with a catalytic combustion device are limited to a maximum of 4.1 g/hr (*Federal Register* op. cit.). Exempted from these rules are cook ranges and fireplaces that lack doors and dampers to operate in airtight mode. *Also exempted are coal stoves* (*Federal Register* 40 CFR 60.530). This regulatory relief occurs ostensibly because coal stoves do not emit significant particulate matter (Vivian 1993). This, however, assumes that the coal stoves are burning anthracite (Vivian op. cit.), which is not true on the Navajo reservation. As mentioned above, Navajos burn subbituminous or low-rank bituminous coals from the San Juan Basin, Gallup, or Black Mesa coal fields. Since there are no standards for coal stoves, and the local stoves probably emit significant amounts of contaminants because (among other factors) they are burning bituminous or subbituminous coals, the EPA standards for wood stoves may be a reasonable starting point for evaluating stoves for the Navajo reservation.

2. **Effects of using stoves on ambient air quality.** As mentioned in Section III.B above, the EPA, through its National Ambient Air Quality Standards (NAAQS), has established limits on some of the pollutants found in emissions from coal combustion. Standards exist for CO, NO_2, SO_2, and particulate matter. Appendix A discusses the NAAQS. Proper use of these standards could also be a reasonable starting point for evaluating stoves for the Navajo reservation.

3. Assessing the risks of using present stoves. Perhaps the most desirable approach for deciding on goals for reducing risks and improving performance of Navajo stoves would be to perform a formal risk assessment on their use. Appendix D discusses such a risk assessment. Of the four steps in formal risk assessments, one appears infeasible because of a lack of adequate data. Adequate dose-response data of sufficient quality for even an approximate risk assessment do not yet exist. As a result, formally assessing risk levels was ruled out for the present as a possible approach for decision making about improving Navajo stoves.

B. Calculation of Effects of Stove Use on Ambient Air Quality

There is a belief, widespread on the Navajo reservation, that major contributors to air pollution in the Shiprock area are the Four Corners and San Juan Power Plants, described above in Section III.D.1. This belief can be checked, and the relative contributions of the power plants and stoves can be calculated from analyses of the air in the area during inversion occasions. The calculations also require analyses of stack emissions and stove emissions. It may be assumed that the compounds sulfur dioxide and carbon monoxide effectively result only from the generating plants and area stoves if the automobile contribution of the CO is estimated and subtracted. Calculations using the ratios of these substances in the stack emissions, stove emissions, and polluted ambient air can then give the relative contributions from these two emission sources. Analyses of trace metals in the emissions and ambient air can give support to the calculations.

VII. TECHNOLOGIES AVAILABLE FOR REDUCING RISKS AND IMPROVING PERFORMANCE OF STOVES ON THE NAVAJO RESERVATION

A. The Combustion of Coal

1. Types of coal. Coal is classified by rank. The ASTM ranks coals as anthracite, bituminous coal, sub-bituminous coal, and lignite. In this order, the coals generally have decreasing carbon content and increasing amounts of volatile matter. Table 4 (next page) gives some approximate ranges of carbon content and volatile matter in different ranks of coal.

High-volatile (> 31% volatile matter on a dry, mineral-free basis) bituminous coal is further subdivided into Groups A, B, and C, with Group A having the lowest amount of volatile matter and Group C having the highest. Sub-bituminous coal is also divided into Groups A, B, and C, again with Group A having the lowest amount of volatile matter within the rank and C the highest.

Table 4

CARBON CONTENT AND VOLATILE MATTER IN DIFFERENT RANKS OF COALS[(a)(b)]

Rank of Coal	**Range of Carbon Contents, wt%**	**Range of Volatile Matter Contents, wt%**
Lignite	72.5 ± 5	51.6 ± 12.4
Sub-bituminous	76.3 ± 4.8	44.6 ± 7.7
Bituminous (high volatile)	79.7 ± 3.8	43.9 ± 11.1
Bituminous (medium to low volatile)	88.9 ± 2.8	24.3 ± 10.2
Anthracite	> 91	< 8

(a) Data from Neavel (1981).

(b) The volatile matter can contain significant amounts of carbon. The sum of the percentages in the two rows being greater than a hundred for particular ranks of coal is a reflection of this.

There are three active coal fields on or directly adjacent to the Navajo Nation land, all in Late Cretaceous strata of the Colorado Plateau, and supporting a total of six large surface mines. The Kayenta and Black Mesa surface mines are operated by Peabody Western Incorporated in the Wepo formation (Mesaverde Group) at Black Mesa, Navajo County, Arizona. Pittsburg and Midway Coal Mining Company operates the McKinley Mine in the Crevasse Canyon Formation (Mesaverde Group) northwest of Gallup, McKinley County, New Mexico. Broken Hill Proprietary (BHP) Minerals extracts coal from the Fruitland Formation at the Navajo, San Juan, and La Plata surface mines, which are located around the edge of the San Juan structural basin in western San Juan County, New Mexico.

As part of their mining leases with the Navajo Nation, Peabody Western (at Black Mesa) and BHP Minerals (at Navajo mine) are required to provide free coal for domestic use to Navajos residing within a prescribed distance from the mines. A number of these individuals collect extra coal and sell it at trading posts or flea markets elsewhere on the Navajo Nation. Free coal is not available at the McKinley mine, but some local Navajos purchase coal there.

Coals of the Fruitland Formation (Navajo and other San Juan Basin mines) are stratigraphically higher and younger than those of the Mesaverde Group [Black Mesa and McKinley mines (O'Sullivan and Beikman 1963)]. All of these Late Cretaceous coals are of relatively low rank (sub-bituminous to high-volatile bituminous), but in general, the younger Fruitland coals are lower in calorific value and higher in ash content than the Mesaverde coals (Peirce et al. 1970, Arizona Bureau of Mines 1977, Hoffman et al. 1993). Table 5 gives average analyses from studies of coals from the three major Navajo Nation fields.

Table 5

AVERAGE ANALYSES OF COALS FROM THREE MAJOR NAVAJO NATION FIELDS

	Fruitland coals	**Gallup (McKinley) coals**	**Black Mesa coals**
Equilibrium moisture, %	7.61 ± 3.18	13.39 ± 1.64	
Moisture, %	6.60 ± 1.76	13.75 ± 2.01	8.6-10.2
Ash, %	22.24 ± 7.02	10.67 ± 6.07	4.7-9.1
Volatile matter, %	35.46 ± 3.42	44.18 ± 3.37	40.0-41.2
Fixed carbon, %	42.29 ± 5.29	45.16 ±4.69	42.3-45.3
Calorific value, Btu/lb	10646 ± 1590	12420 ± 865	10910-11560
Total sulfur, %	0.97 ± 0.70	0.64 ± 0.52	0.3-0.5
Apparent rank	Subbituminous A to high-volatile B-C bituminous	high-volatile C bituminous	high-volatile B-C bituminous

Navajos are aware of the advantages of using Black Mesa (Mesaverde) coal over Navajo Mine (Fruitland) coal, owing to its higher heat content and lower ash content. Many people who live in the eastern San Juan Basin and who have ready access to free coal at the Navajo mine will nevertheless choose to purchase Black Mesa coal at local flea markets. In the winter of 1995 the going price for 100 lb of Black Mesa coal in Shiprock was approximately $10-$15.

2. Stages of coal combustion. "Coal is burned today in three ways: as lumps on a grate or in a shaft; crushed in a fluid bed; or pulverized, entrained, and burned in a dilute suspension" (Essenhigh 1981). In stoves, coal is burned in the first of these fashions: as lumps on a grate. Stoves on the Navajo reservation are intermittently-fired. Stoves fed continuously from a magazine are a rarity or nonexistent there.

"The combustion of coal ... is primarily a matter of combustion of carbon with sequential or parallel combustion of volatile matter" (Thring and Essenhigh 1963). Thus the combustion of coal occurs in two stages. The initial stage is the production and combustion of volatile matter, and the second stage is the burning of the char left by the removal of the volatile matter. An efficient coal stove must be designed to burn both the volatile matter and the char.

3. Generation and burning of volatile matter. The heating of a particle of coal generates volatile matter, much of which consists of organic substances. The composition of the volatile matter escaping from the coal particle changes as the temperature rises. The first material to escape is usually water, originally inside the coal in a liquid state or weakly bound through hydrogen bonding to sites on the internal coal surface. Next is more water, formed from hydroxyl radicals combining with hydrogen atoms either on the internal coal surface or a short distance from the surface within the coal structure. The next product is organic compounds from decomposition of the reacting structure. The first compounds are usually aliphatic. As the hydrogen in the coal becomes exhausted, the organic compounds become more olefinic. These olefinic substances can polymerize, forming tarry compounds and particulate matter. If unburned, the tarry compounds and particulate matter appear as smoke, or they condense on chimney surfaces as creosote. Also volatilized are organic compounds containing nitrogen and sulfur.

The organic compounds composing the volatile matter can in theory be burned to give a smokeless fire. This requires that the volatile matter be raised to the ignition point in the presence of sufficient oxygen for the burning. Then the principal gaseous emission contaminants are the oxides of nitrogen and sulfur. Commercial power plants burn their coal without smoke, but their combustion is a significantly different process than the burning in a coal stove. Approaches to burning the volatile matter in stoves are addressed below in Section C.

4. Burning of char. Char is the substance left when pyrolysis is complete and no further volatile matter is emitted. Carbon is its main elemental component, so the combustion of the char is essentially the burning of porous carbon particles. Once the particle reaches the char ignition temperature in the presence of free oxygen, burning takes place. Because the oxygen-carbon reaction is a heterogeneous one, the burning occurs on surfaces. The reaction surface can be the exterior surface of the particle, or the interior surface of the pores inside the coal particle. The reaction can also occur by oxygen diffusing into the carbon lattice and attacking the carbon atoms. The products of the carbon oxidation are carbon monoxide and carbon dioxide. If the combustion is carried out properly, there is little of the monoxide; the product is mostly CO_2.

After burning of the char, ash remains. Section IV.B.2 describes ash, and the trace elements it contains. The hazards presented by trace elements in the ash are largely unknown, as discussed above in Section IV.C.3.

B. The Development of Stoves

1. Wood stoves and coal stoves. There has been an upsurge in interest in stove design and performance over the last 15 years. A majority of the interest has been directed toward wood stoves, however. The indexes of *Chemical Abstracts* from 1977 through 1995 list 119 articles treating wood stoves, and only 16 treating of coal stoves. The current *Books in Print* lists 11 books under the heading "stoves, wood," and none under "stoves, coal."

Wood stoves and coal stoves are designed differently. A coal fire is much hotter than a wood fire. Materials of construction must be chosen accordingly. Coal fires can burn much longer unattended than a wood fire, so coal stoves can be designed for the possibility of continuous burning. This means a coal stove must provide a means for removing ash from the combustion region while burning is continuing.

Coal should not be burned in a wood stove. Wood should not be burned in a coal stove, except as a means to ignite a coal fire. Most wood stoves are not designed to handle the temperatures of a coal fire, and their secondary air flow for burning volatile matter is quite different from that of a coal stove. The primary air flow in a wood stove is also different from that in a coal stove, since the characteristics of a wood fire are much different from those of a coal fire. Burning coal in a wood stove is very likely to warp metal components and ruin the stove. In a coal stove, primary and secondary air flows are not designed for wood fires, and the result is a very smoky fire with resulting pollution (Husted 1996). The deposition of creosote from the smoke adds a chimney-fire hazard to the burning of wood in a coal stove.

Most coal stoves are designed for burning anthracite coal (Vivian 1993). However, as mentioned above, the Navajos burn subbituminous and bituminous coals from the nearby mines. Using subbituminous or bituminous coal in a stove designed to burn anthracite coal can produce a significant increase in pollutant emissions. For example, Butcher and Ellenbecker (1981) found that burning bituminous and anthracite coal in a stove designed for the latter produced 10.4 and 0.05 g particulate matter/kg coal, respectively, a difference of about 200. The CO emissions were 116 and 21 g/kg of coal burned, respectively, a difference by a factor of about 5. Sanborn (1982) found that the average rates of particulate emissions from 3 residential coal stoves were 1.7 and 21.2 g/kg for burning an anthracite and a bituminous coal, respectively, a difference of an approximate factor of 12. Sulfur dioxide emissions in the latter study were 21.2-114.6 and 12-162 ppm for the anthracite and bituminous coals, respectively, for no significant differences. The SO_2 emissions were primarily dependent on the burn rate and the firebox temperature.

Jaasma et al. (1991) compared the field performances in Crested Butte, Colorado, of various wood stoves and a hand-fired coal stove. They found that the coal stove effectively matched the particulate-matter emissions of both EPA-certified catalytic and noncatalytic wood stoves. This adds justification to the EPA's exemption of coal stoves from their regulations. The coal stove emitted about 50% more CO than the EPA-certified wood stoves. The coal in the Crested Butte region is a high-grade bituminous coal verging on anthracite quality, raising the question of what would have happened had the coal stove used low-grade bituminous or subbituminous coal.

Stoves are usually used for cooking or space heating or both. The survey on stove use conducted at Navajo Community College (Appendix B) indicated that a significant number of stoves were used for cooking. Any proposed program needs to consider this aspect of stove use on the reservation.

2. Evolution of wood stoves, 1950-1996. The evolution of wood stoves in the last half century has taken two paths. In developing countries, the emphasis has been on improving efficiency to reduce the effort required for gathering wood and to reduce the rate of deforestation. Stix (1995) and Kammen (1995) describe this evolution. One of the requirements for these stoves is that they be inexpensive, so people inhabiting the impoverished areas of the world can afford them. Minimizing pollution has not been one of the major design criteria for these stoves.

In the United States, wood-stove evolution has followed a different path. An upsurge in popularity of wood stoves began about the same time as the energy crisis of the 1970's, and the large numbers of stoves began to pollute some areas' atmospheres. In response to this problem, the EPA mandated a two-phase program to limit smoke emitted by stoves manufactured or sold in the U.S. The second phase restricted heating stoves manufactured after July 1, 1990 or sold after July 1, 1991. Section VI.A.1 above gives these standards.

The stoves meet the EPA limits via two approaches. One approach uses a catalytic converter to burn smoke using secondary air. The other approach contacts a mixture of secondary air and smoke with heated metal surfaces which ignite the smoke and burn it. Salespeople at local wood-stove outlets claim that some present stoves emit pollutants at levels well under the EPA standards.

Although the stoves may pass the EPA-specified tests, this does not mean their pollutant emissions are negligible. A piece of anecdotal evidence says that burning approximately three cords of wood over a three-year period in a late model wood stove in mountain cabin gave a chimney that upon cleaning yielded about 10 lbs of very hard creosote (Vanderborgh 1996). This works out to about 1 g creosote/kg of wood fuel. This places the stove as performing well within EPA standards, even though the stove emitted a significant amount of smoke during the three years.

Wood stoves continue their development. A recent appearance is a downdraft stove that produces clean gas and charcoal from wood (LaFontaine and Reed 1991). The gas burns and drives more combustible volatiles out of the wood, converting the latter to charcoal. Some similar biomass stoves have also been created (e.g., Beedie et al. 1993).

Investigators are evaluating design performance (Prasad 1993) and optimizing design parameters (Rajpal and Maheshwari 1992). Emission tests on different stove designs continue (Kandpal et al. 1994). Design principles for wood and biomass stoves are being published (Baldwin 1987, Mukunda et al. 1993). Some numerical modeling of the combustion process and associated fluid dynamics behavior has been attempted (e.g., Beedie et al. 1993), but it appears that more sophisticated and larger capacity computers are needed for this very complex task.

3. Evolution of coal stoves, 1940-1996. From 1940 to 1950, engineers at Battelle Memorial Institute in Columbus, Ohio, worked at creating a stove that would burn bituminous coal without emitting smoke. They succeeded (Landry and Sherman 1950). "... new design principles based on the newly recognized elementary types of fuel beds, led to the development of practical operating heaters [burning bituminous coal] ... that were essentially smokeless, had improved combustion efficiency, and permitted much longer periods between firings" (Sherman and Landry 1963). However, during the years immediately following World War II, pipelines snaked across the U.S., bringing the convenience of oil and gas to almost the entire country. Sales of coal-burning heaters plummeted, and "commercial exploitation [of the smokeless bituminous-burning stoves] has not followed" (Sherman and Landry op. cit.).

In contrast to the forced evolution of wood stoves by the EPA edict, the decision to exempt coal stoves from regulation combined with the low demand for coal stoves has discouraged progress in this area. Nevertheless, the principles developed by Landry and Sherman have been and are being used in coal-stove design. Toynbee (1982) mentions a South African coal-fired "Frifire" heater, implying that it has low emission of pollutants due to properly designed air flows and baffling. He also describes research aimed at developing an intermittently fed, coal-fired heater with low emission of pollutants. A 1990 model coal stove by a reputable U.S. manufacturer (Buck Model 24 stove) upon visual inspection has obvious baffling and directed air flows for the apparent purpose of reducing emission of pollutants. An expensive (ca. $1300) Irish coal stove currently states in its advertising literature that "metered primary air passes up through the rugged shaker grates while controlled secondary air enters over the coal bed ensuring complete combustion of coal tars, hydrocarbons, and gases for optimum efficiency and output" (Waterford, 1990).

Not all coal stoves exhibit such attributes, however. Without EPA standards, coal stoves of widely varying quality are available. Since no regulations exist, anybody with a welding torch and some heavygauge sheet metal can put together a device and call it a coal stove. Thus coal stoves range from simple home-made stoves constructed from welded sheet metal up to the Waterford variety. The lack of demand for high-quality coal stoves has also discouraged development. The New Buck Corporation of Spruce Pine, North Carolina, a manufacturer of high-quality wood and gas stoves, ceased manufacturing coal stoves around 1990 (Dean, 1996).

C. Emissions from Coal Stoves

Section IV.B.1 states that the gaseous emissions from the combustion of coal contain SO_2, NO_x, CO, PAHs, and particulate matter probably containing significant amounts of trace metals. A poorly designed coal stove will emit all of these pollutants. A well designed "smokeless" coal stove, based either on the Landry-Sherman principles or later developments for burning volatile matter, will consume the PAHs and particulate matter and most of the CO. This cleanup leaves the oxides of sulfur and nitrogen, and trace metals volatilized from the combustion of particulate matter. Thus even a well designed coal stove may emit significant amounts of pollutants. Any action plan must consider these emissions.

VIII. TECHNOLOGIES NEEDED

A. Necessity of Coordinating New Technologies with Indigenous Culture

Kammen (1995) points out the necessity of coordinating new technologies with indigenous cultures. The new technologies must be employable by the intended users with a level of training appropriate to the culture. The new technologies must work in the field under less-than-ideal conditions. The new technologies must be reparable by local artisans and with locally available materials. The new technologies must be compatible with practices that the intended users will employ. If any of these conditions are not fulfilled, implementation of a new technology will likely fail.

B. Cultural Aspects of Navajo Use of Stoves

The results of the survey carried out at NCC had a clear message. Irrespective of any instructions, the Navajos are going to burn both wood and coal in their stoves. This result was unexpected, but knowing this will help prevent failure of the project.

Other messages in the survey results were more predictable. For widespread use, economical stoves are almost certainly a necessity. The majority of stoves on the reservation are probably used for heating rather than for cooking, although the fraction used for cooking is not insignificant. Instructions supplied with the stoves by the sellers vary widely in quality and veracity.

Anecdotal evidence supplies other cautions. If the Navajos do not understand the necessity for particular facets of the stove, they may remove them for other uses. As an example, walkways composed of firebrick have been observed combined with stoves lacking firebrick.

These aspects must be considered for any project designed to lower the rate of pollutant emission from stoves in the Navajo Nation.

C. Technologies Needed to Satisfy both Cultural Aspects and Need to Reduce Harmful Stove Emissions

As pointed out earlier, wood and coal stoves have followed different evolutionary paths, and present stoves are suited for either one fuel or the other, but not both. Yet Navajos burn both in their stoves. Thus any new technology must be able to accommodate both fuels, and perhaps other biomass materials as well. If the new technology is to be applicable to developing nations outside the U.S., then the ability to use other biomass materials is a necessity.

Other needs of any new technologies are perhaps obvious. Any new stoves must be affordable by the people who will use them. They must be simple to operate. Proper training, appropriate to the indigenous culture, must be given.

Finally, the level of emissions from the new stoves must be minuscule.

IX. PROPOSED ACTIVITIES

A. Final Project Goals

The ultimate goals of this project are

- Reduction of outdoor air pollution in the Shiprock area to meet EPA NAAQS levels.
- Reduction of indoor air pollution on the Navajo reservation to everywhere meet EPA NAAQS levels.
- Creation of a pollution-free coal and biomass stove that is affordable by residents of the Navajo Nation and residents of industrializing nations.

B. Intermediate Project Goals

Meeting the ultimate goals requires fulfillment of the following series of intermediate goals:

- Quantitative determination of the relative contributions of power plants and stoves to outdoor air pollution in the Shiprock area.

- Quantitative determination of the extent of stove emissions in contaminating indoor air on the Navajo reservation.
- Design of an economical, pollution-free coal and biomass stove for space heating and cooking.

C. Actions Needed to Achieve Goals

1. Listing of the actions. A large number of actions are planned to achieve the goals of this project. The number of actions is ambitious, but the goals are worthwhile. The actions are listed in the following paragraphs.

2. Gathering samples of stack gas from power plants. Gathering of samples of stack gas from Four Corners and San Juan Power Plants during winter months.

3. Determining extent of coal-stove usage in Shiprock area. Surveying the Shiprock area to determine quantitatively the extent and characteristics of stove usage.

4. Gathering and analysis of chimney gas samples in Shiprock area. Extensive gathering of gas samples of residential chimneys while stoves are in operation in the Shiprock area. Analysis of these samples is a necessary precursor to divining the source of poor air quality in the area.

5. Gathering and analysis of outdoor air samples in Shiprock area during high-pollution occurrences. Gathering of air samples in Shiprock area during occurrences of inversion-caused polluted ambient air. Analysis of these samples will tell the source of the pollution.

6. Gathering and analysis of indoor air samples around the Navajo nation. Obtaining an extensive set of indoor air samples from different regions in the Navajo Nation during the winter months.

7. Purchase and testing of a low-quality stove. Purchase of a low-quality coal stove, followed by testing of the stove for emissions under various burning conditions using the coals used by the Navajos.

8. Purchase and testing of a high-quality stove. Purchase of a high-quality coal stove followed by testing of the stove for emissions under various burning conditions using the coals used by the Navajos.

9. Development of an economical, low-emission coal and biomass stove. Design, construction, and testing of more economical low-emission stoves. Much work has been done in this area, but much remains to be done. The capabilities of Los Alamos and NCC can combine to accomplish this task. As noted earlier, numerical modeling of the complex processes occurring in stoves undoubtedly requires large computers with both high speed and extensive memories. Los Alamos has the world's best in this area.

Physical models, designed using proper engineering principles, can reduce the cost of testing full-size stoves. Combining these approaches can yield the desired results.

10. Development of devices for removal of noxious oxides in residential stoves. Design, construction, and testing of devices for removal of oxides of nitrogen and sulfur and removal of trace metals from stove off gases.

11. Relative time requirements. The last two actions could consume more time than the others combined.

X. DISCUSSION

The series of actions listed above is ambitious, but the goals are worthwhile. This report presents no time schedule, because such a schedule depends entirely on funding of the project. Funding sources have not yet been identified, so amounts available are at present unknown.

The extension of the results of the proposed project to areas beyond the Navajo reservation are obvious. Pollution problems in industrializing nations are becoming apparent. Successful completion of the project will be a major boon for a world increasingly beset by serious pollution.

XI. CONCLUSIONS

There is a need for action dealing with air pollution problems on the Navajo reservation. Some of these problems are symptomatic of those in developing nations, and solution of these problems could have worldwide implications.

Stoves are probably a significant contributing factor to the air pollution problems on the Navajo reservation.

Quantification of the relative contributions of air-polluting factors on the Navajo reservation is desirable.

Improvement in coal-stove technology, especially in control of emissions, economy of manufacture, and flexibility of fuel use, is desirable.

XII. ACKNOWLEDGMENTS

This work was carried out under the auspices of the U.S. Department of Energy. The extensive help of research librarians at the Los Alamos National Laboratory technical library is gratefully acknowledged. Conversations with two knowledgeable salespeople at stove outlets—Lloyd Husted of Farmington's Raindrops, Inc., and Earl Dean of Albuquerque's Out West—yielded many insights into stove operation and behaviors of stove users.

APPENDIX A

STANDARDS FOR AND EFFECTS OF POLLUTANTS EMITTED BY COMBUSTION OF COAL

A-1. Hazards Associated with Substances Appearing in Products of Coal Combustion

a. Acronyms used in this section. This section uses the following acronyms:

ACGIH	American Conference of Governmental Industrial Hygienists.
AIHA	American Industrial Hygiene Association.
CL	Ceiling value.
ERPG	Emergency Response Planning Guideline (for air contaminants).
lel	Lower explosion limit.
OSHA	Occupational Safety and Health Administration.
PEL	Permissible exposure limit.
STEL	Short-term exposure limit.
TLV	Threshold limit value.
TWA	Time-weighted average.
uel	Upper explosion limit.

The Glossary defines the limits dealing with exposure.

b. Dangerous properties and exposure limits. The paragraphs below list recent exposure limits and other safety aspects associated with the principal pollutants in the emissions from the combustion of coal. Unless otherwise stated, the values are taken from Lewis (1992). While the sections below cover the principal hazards associated with these materials, Lewis (op. cit.) presents more detailed information on the materials' hazardous properties.

For exposure limits of toxic materials, AIHA's ERPGs are the most thoroughly reviewed standards (CCPS 1989). The standards of OSHA and ACGIH also have wide use, and the tables below give these. The notation "(skin)" after an exposure limit indicates that the substance can be absorbed by the skin and cause morbidity.

c. Carbon monoxide. Recent limits are

OSHA PEL:	TWA 35 ppm	CL 200 ppm (skin)	
ACGIH TLV:	TWA 50 ppm	ACGIH STEL:	400 ppm
lel:	12.5%	uel:	74.2%
autoignition temp.:	1128°F (609°C, 882 K)		

d. Carbon dioxide. Recent limits are

OSHA PEL:	TWA 10,000 ppm	OSHA STEL	30,000 ppm
ACGIH TLV:	TWA 5000 ppm	ACGIH STEL:	30,000 ppm

e. Nitric oxide. Recent limits are

OSHA PEL:	TWA 25 ppm	CL 200 ppm (skin)	
ACGIH TLV:	TWA 25 ppm	ACGIH PEL:	25 ppm

f. Nitrogen dioxide. Recent limits are

OSHA PEL:	CL 5 ppm	CL 5 ppm	
ACGIH TLV:	TWA 3 ppm	ACGIH STEL:	5 ppm

g. Sulfur dioxide. Recent limits are

OSHA PEL:	TWA 2 ppm	STEL 5 ppm (skin)
ACGIH TLV:	TWA 2 ppm	STEL 5 ppm

A-2. Morbidity Effects of Toxic Trace Elements

Finkelman (1995) lists morbidity effects of various toxic trace elements in coal. Ingestion of relatively large amounts of these substances cause the effects. Dose-response relationships for ingestion of small amounts of these substances are not yet available.

Trace Element	**Morbidity Effect**
Antimony (Sb)	NA*
Arsenic (As)	anemia, gastric disturbances, renal symptoms, ulceration; skin and lung carcinogen in humans; a suspected teratogen
Boron (B)	respiratory disease and lymphatic, liver, spleen and kidney effects; an animal and probable human carcinogen
Cadmium (Cd)	emphysema and fibrosis of the lung, renal injury, possible cardiovascular effects; and animal and possible human carcinogen; testicular toxicity in mice and rats; teratogenic in rodents
Cobalt (Co)	NA
Chromium (Cr)	NA
Lead (Pb)	anemia, cardiovascular, neurological, growth retarding, and gastrointestinal effects;' some compounds are animal and possible human carcinogens; foetotoxic and probably teratogenic to humans
Manganese (Mn)	respiratory and other effects
Mercury (Hg)	neural and renal damage, cardiovascular disease; methylmercury is teratogenic in humans
Nickel (Ni)	dermatitis, intestinal disorders; nickel and nickel oxide dusts are carcinogenic to guinea pigs and rats; nickel refining is associated causally with cancer in humans

Trace Element	**Morbidity Effect**
Selenium (Se)	gastrointestinal disturbances, liver and spleen damage, anemia; a possible carcinogen, a suspected teratogen
Uranium (U)	NA

* Not Available

A-3. National Ambient Air Quality Standards

a. Primary and secondary air quality standards. "National primary ambient air quality standards define levels of air quality which the Administrator judges are necessary, with an adequate margin of safety, to protect the public health. National secondary ambient air quality standards define levels of air quality which the Administrator judges necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant" (*Federal Register* 40 CFR 50.2).

b. Carbon monoxide. The national primary air quality standard for CO is 9 ppm (10 mg/m^3) for an 8-hr average concentration not to be exceeded more than once per year, and 35 ppm (40 mg/m^3) for a 1-hr average concentration not to be exceeded more than once per year (*Federal Register* 40 CFR 50.8).

c. Nitrogen Dioxide. The national primary air quality standard for NO_2 is 0.053 ppm (100 μg/m^3). The national secondary ambient air quality standard for NO_2 is also 0.053 ppm (100 μg/m^3) (*Federal Register* 40 CFR 50.11).

d. Sulfur oxides (sulfur dioxide). The national primary air quality standards for sulfur oxides measured as sulfur dioxide are 80 μg/m^3 (0.03 ppm) annual arithmetic mean and 365 μg/m^3 (0.14 ppm) maximum 24-hr concentration not be exceeded more than once per year (*Federal Register* 40 CFR 50.4).

e. Particulate matter. The national primary and secondary 24-hr ambient air quality standards for particulate matter are both 150 μg/m^3 24-hr average concentration. The national primary and secondary annual standards for particulate matter are 50 μg/m^3 annual arithmetic mean. The particulate matter measured are those particles with aerodynamic diameters less than or equal to a nominal 10 μm (*Federal Register* 40 CFR 50.6). The EPA is currently considering a new standard that regulates particulate matter with aerodynamic diameters less than or equal to a nominal 2.5 μm, and specifying maximum concentration levels ranging from 12.5 to 20 μg/m^3 averaged annually and 18 to 65 μg/m^3 averaged daily (Anon. 1996).

APPENDIX B

Domestic Coal Combustion: A Typical Stove Study for Shiprock and the surrounding Area---an invasive survey report

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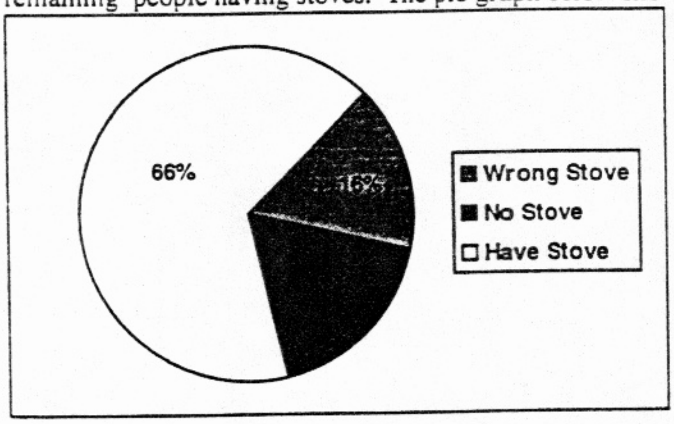
Objective
To obtain an idea of the coal stove situation for Shiprock and the surrounding area.

Narrative
An invasive survey was conducted to obtain information of the coal stove situation for Shiprock and the surrounding area. The survey was conducted at Navajo Community College since the student body consists of people from this area of study. Fifty surveys were filled out over a course of two days. It contained twelve questions ranging from owning a stove to where fuel (coal, wood and other) were obtained and friend/relative stove owning. (see page two for sample survey)

Data
The collected data was transferred into a Microsoft Excel spreadsheet. See the following pages for the full data.

Interpretations
Of the fifty people, 8 inferred the study was kitchen cooking stoves. This error was due to miscommunication on our part. Therefore, that data obtained should be excluded. Of the 50 people 9 stated that they had no stove, with 33 remaining people having stoves. The pie graph below shows that pictorially most people in this area have stoves.



The stoves are generally used for heating. We found that the popular stoves were wood/coal stoves purchased from border towns of the reservation, such as Farmington, NM and Gallup, NM. Most of the survey participants did not know the cost of their stoves, as for the ones who did, the average cost of the stove is $411.00. In some cases the stoves were free, passed from one generation to another or made by family members. The predominant stoves are made of steel and iron. The type of fuel used is a mixture of coal and wood. It was not surprising that most of the people obtained their coal from Black Mesa, Arizona and their wood from the mountains. Most people surveyed burned mostly during the winter all week and throughout the night. For the people who purchased their stoves most said that the retailer did not specify the specific fuel to use only in the stove. What is interesting to see is that almost all of the people surveyed said they have friends and relatives who have stoves. The survey showed that most people were from Shiprock, NM.

Conclusion
Shiprock cannot represent the entire reservation. As a border town, there are more people with jobs, hence more costly and higher quality of stoves. This small scale survey is very small and should give an idea as to where improvements can be made. From the survey, we can still see that there are many people whom own stoves. Where they obtain their fuel is especially important. Given more time, this survey would have been more thorough. A greater sample size would be needed to fully represent the Navajo Nation. For further studies, the samples should be gathered from various points on the reservation.

Domestic Coal Combustion:
A Typical Stove Study in Shiprock and Surrounding Areas
-- a survey report

The four corners which encompasses parts of the Navajo Nation is a focal point of coal mining and coal generation plants. This directly impacts the environment and the economics of the Navajo Nation. In addition, these plants have mad it convient for locals to obtain coal to burn in homes for heat and possibly cooking. Our interest lies within the domestic level of coal combustion. This project is a collaborative effort with Los Alamos National Laboratory. Given a time constraint, this survey study was localized to Shiprock, New Mexico and the surrounding area. The goal of the project is to develop improvements to stoves on the Navajo reservation that will diminish adverse health effects caused by using coal in these stoves and will better the stoves' performance.

1. Do you have a stove? [Y/N]

2. What do you use it for?
   - ◊ heating
   - ◊ cooking
   - ◊ other

3. What type of stove is it?
   - ◊ wood
   - ◊ coal
   - ◊ other

4. Where did you get your stove from?

5. How much did it cost?

6. What is it made of?

7. What do you burn in it?
   - ◊ only coal
   - ◊ only wood
   - ◊ mixed

8. How long do you burn?

9. How often during the week do you burn?

10. Where does your fuel (coal, wood, other) come frcm?

11. During your purchase, was it specified what fuel to use only in stove?

12. Do you have any friends or relatives who have stoves?

Thank you for your time and input. The data you gave is beneficial and important to this research.

Stove Survey Data

# of surveys	Do you have stove?	What do you use it for?	What type of stove is it?	Where did you get your stove from?	How much did it cost?
1	N				
2	N				
3	Y	heating	wood	have no idea	?
4	Y	heating	wood	?	?
5	Y	heating	wood and coal	Farmington, NM	$ 300.00
6	Y	cooking	wood and coal	I don't know	I don't know
7	Y	heating	wood and coal	Gallup Store	don't know
8	Y	heating	wood and coal	In Farmington @ stove store near SJRMC, Orley's Manfacturing Co. Stove	about $800
9	Y	heating in winter	wood and coal	Farmington (has electric blower)	$1,200
10	Y	heating and cooking	wood and coal	Farmington-Gambles	$400.00
11	Y	heating	don't know	weild by cousin	free
12	N(but my mother does)	she uses it for heating and cooking	coal	Gallup, NM	$600.00
13	N	just for cooking	other		
14	Y	heating	wood and coal		over 2 or 3 hundred
15	Y	heating	wood and coal	Farmington	$300
16	Y	heating	wood	?	?
17	Y	heating	wood and coal	I have no idea	I don't know
18	N	cooking	other-used for cooking	came with mobile home	
19	N				
20	Y	heating	wood and coal	don't know	don't know
21	Y	heating	wood	from my husband mother. Its an old stove. I don't know what is it.	
22	Y	cooking	other	was already in house	N/A
23	N				
24	Y	heating	passed down?	n/a	steel
25	N				
26	Y	heating	wood	wasn't there during the purchase	i don't know how much it cost
27	N	cooking	other	already in home	no idea
28	Y	heating	wood and coal	it was already been bought by someone else	I have noe idea
29	Y	heating	coal	I don't know. Gallup I think	$200
30	Y	heating	wood and coal	have no idea	?
31	Y	heating	wood and coal	Huston Lumber	$300.00
32	Y	heating and cooking-sometimes	both wood and coal	don't know it was already there	don't know (maybe free)
33	Y	heating	wood and coal	from grandmother	N/A
34	Y	heating	wood and coal	a friend	free
35	Y	heating	wood and coal	unknown	unknown
36	N				
37	Y	heating	wood and coal	Farmington	$400
38	Y	heating and cooking	wood stove	store	$120
39	Y	heating	coal		
40	Y	heating and cooking	wood and coal	don't know	don't know
41	Y	heating	wood and coal	Alb., NM	$300.00
42	Y	heating	wood	friend	
43	Y	heating	wood and coal	father brought it home	about $600 and other around $350
44	N				
45	Y	heating cooking and other	wood and other	It came with the house we bought	I have no idea
46	N				
47	Y	heating	wood	Gambles-Farmington, NM	$400.00
48	Y	heating	wood and coal	came with the purchase of the house	about $380.00
49	Y	cooking	other	was there when we move in the housing of Protit	nothing
50	Y	cooking	other	NHA housing	don't know how much it cost

Stove Survey Data

What is it made of?	What do you burn in it?	How long do you burn?	How often during the week do you burn?
?	mixed-wood and coal	evening-through the night	winter-7
?	mixed-wood and coal	10-12 hrs	maybe 5 day a week
steel, wood burning stove	mixed-wood and coal	all day mainly in the winter	All week
I don't know	mixed-wood and coal	during winter	7days a week, maybe twice a day
don't know	mixed-wood and coal	about 5 hrs at night	still new...we'll see at winter
steel or iron	mixed-wood and coal	from 5pm to 11am the next morning	depends on weather. usually eveyday during the fall/winter season to heat home
cast iron with viewing window	mixed-wood and coal	depends on weather	all week at night if cold
cast iron	mixed-wood and coal	depends on weather, each day	entire week
metal	coal and wood	winter-24 hrs/day, 7days a week, mostly evening and morning	all week when cold
metal, has high resistance to heat. It needs to be lined with bricks when burning coal.	mixed-coal and wood	depends on weather or six hours then we switch on electric heaters	seven days a week depending on weather
metal and rock layer inside	mixed-wood and coal	all night	7days a week
metal	mixed-coal and wood	all night	7 days a week
I don't know metal-iron	mixed-coal and wood	1 day @ winter=9hrs	more
metal	mostly coal	all day and night if necessary	in winter-7 days / wk.
		1 hr for cooking	3 times a day
metal	mixed-wood and coal	hours	just in the winter, everyday
Iron cast	only wood	45 min to one hour	one cold dy, every day or all night
N/A		don't cook	don't know
			3
steel	mixed	2 hours	
made of steel	mixed-wood and coal	just for winter	7 days a week during the winter
steel	mixed	only during the winter	once a day
steel	mixed-wood and coal	only when it's very cold	every other day
cast iron and steel	only coal	10 hrs	3 times
steel and metal	mixed	fall/winter	morning/evening
steel	mixed	only during the winter	7days a week during the winter
steel	mixed-wood and coal	During the winter only and @ night only	everynight during the winter and not summer
cast iron	mixed	early morning 15 hrs	practically all day throughout the night
iron	mixed-wood and coal	4 hrs a day	
cast iron	mixed	all night until morning only in the winter time	7days
steal	mixed wood and coal	all night, 1/2 day and heater	
cast iron	mixed wood and coal	not during the summer, winter times (all day)	mostly all the time when it is cold
	only coal	4- 6 hours	5 days a week
Aluminum, bricks, steel	mixed	8-10 hours if needed longer	7days a week
steel	only wood	6 hours during the winter	7 days a week
cass iron	only wood	4 or 5 hour	in the evening
it's black steel of some sort	only wood and mixed	about all night when it's cold and all day if necessary when its cold	
steel	mixed	1 hour	once a week
steel	only wood	evenings only (about 5 hours)	4-5 times a week
steel	mixed	all night and day during the winter	4-5 days
don't know	nothing	match	everyday to cook
don't know	mixed		n/a

Stove Survey Data

Where do you get your fuel from?	During your purchas, was it specified what fuel to use only in stove?	Do you have friends or relatives that have stoves?
		yes
		no
coal-Black Mesa, AZ	yes	yes
different places	i don't think so	yes
coal-Peabody Mine, Kayenta, AZ: wood-San Juan County, LaPlata	yes, only wood and coal	yes
coal and wood	don't know	yes
coal-Gallup	don't know	yes
Coal-BHP, Wood-mountains in area	yes, coal and wood	yes
wood-Chuska mountain, and coal-P&N coal, blackmesa	yes	yes
wood-Lukachukai Mountain, coal-Peabody, Blackmesa	no	yes
wood-mountains, coal-APS	yes, just wood and coal	yes
wood-local area, coal-vendors or coal company	yes	most of them
wood-mountains: coal-area 3 (aps)		yes
Peabody Coal Company (Blackmesa)	no	yes
wood-mtns (?), coal-Navajo Mine	no, but probably just wood	yes
coal-Black Mesa	i don't know	yes
other-propane	proane	grandmother
		yes
Black Mesa, AZ and Cortez, CO	No	yes
a man bring the woods and i paid him for it	yes, cedars and cotton wood mix	some
don't know	no	yes
		yes
here and there	no	yes
		yes
wood and coal	i wasn't there during the purchase	yes
buy it in land ourselves	no	yes
we buy them or get them ourselves	no	yes
Black Mesa	yes	yes
Peabody Coal Mine/Mtn. wood	no	yes
We usually get our wood from the mountain and our coal from Black Mountain or sometime we buy it	no, they did not specified what fuel to use	yes
from the mountain, dry up woods and coal from Blk mountain coal co. and or APS	no	yes
coal-hesperus, co. wood-purchase from people	no	yes, my sister
		yes
BhP, Area 3	yes	yes
our fuel comes from Black Mesa mine	yes	yes
mtn. and Blackmesa	yes, mixture	yes
mountain wood	wood and coal	yes
wood	yes	yes
wood bring back home, coal from Black Mesa	no	yes
		yes
from APS	no	yes
		yes!
buy it from flea Market	no	yes
coal and wood	no	yes
gas	nothing	yes
		dad and sister

Stove Survey Data

Place of Residence (was optional
Erica Harvey, Box 523, Shiprock, NM 87420
Loretta Gray, NCC librarian
Michelle Charley, Box 3031, Shiprock, NM 87420
Deanna Benally, Box 2393, Shiprock, NM 87420
Valerie Weaver, Box 1223, TeecNosPos, AZ 86514-1223
Ursula Bedah, P.O. Box 331, Sanostee, NM 87461
Erik Yazzie, Box 279, Chamber AZ 86502
Eva Martin, Box 2494, Shiprock, NM 87420
J.R. Hunt, Box 3043, Shiprock, NM 87420
James Hunt, Box 901, Shiprock, NM 87420
Nathaniel Begay, Box 335, Sanostie, NM 87461
Abel Joe, Box 841, Teec Nos Pos, AZ 86514
Shiprock
Red Valley, AZ
Teecnospos, AZ
Mexican Water, AZ
Shiprock, NM
Shiprock, NM
Red Mesa, AZ
Shiprock, NM
Shiprock, NM
Shiprock, NM
Shiprock, NM
Little Water, NM
Little Water, NM
Phillip A. Harrison, P.O. Box 622, Shiprock, NM
Mark Henderson, Box313 Sanostee, NM 87461
Leroy Begay, P.O. Box 2892, Shiprock, NM 87420 (505)368-3547
Cheryl L. Rodriguez, P.O. Box 884, Shiprock, NM 87420 (505)368-5928
in Shiprock Area
Shiprock, NM
Shiprock in Non-Profit Housing
Shiprock, NM

APPENDIX C

ANALYTICAL DATA

(All analysis amounts are in ppm)

To ensure that the analyses were correct, the tests analyzed standard samples of shale and fly ash. The "target values" are the accepted amounts in the materials, the other listed values are the local analyses. Agreement was generally excellent. Differences give a "feel" for the uncertainty in the analyses. Thus the SGR-1 and NBS1633a samples are for verification purposes; the analyses are not used in the report.

Sample #	Description	Date	Al	As	Ba	Be	Br	Ca	Cd	Cl
SGR-1*	SRM Shale, Target Values	2/96	34507	57	290	1.06	?	59892	0.93	32
SGR-1	SRM Shale	2/96	35646	54	266	0.99	<4	59657	1.48	86
NBS1633a*	SRM Fly Ash Target Values	2/96	143003	145	1500	12	2.3	11078	1	?
NBS1633a	SRM Fly Ash	2/96	144412	160	1166	13.7	<5	10799	2.14	29
SJ-Coal	Grnd Coal, San Juan Generating Plant	2/9/96	13887	2.1	167	1.19	<5	8515	<0.8	67
SJ-Coal	Grnd Coal, San Juan Generating Plant	2/9/96	20556	1.0	170	0.94	---	9241	0.94	---
SJ-Fly Ash	Fly Ash, San Juan Generating Plant	2/6/96	118818	12.7	437	4.62	<5	32035	3.78	55
SJ-Fly Ash	Fly Ash, San Juan Generating Plant	2/6/96	118542	12.1	442	4.42	---	30741	2.65	---

Sample #	Co	Cr	Cu	F	Fe	Hg	K	Li	Mg	Mn	Mo	Na
SGR-1*	11.8	30	66	1960	21193	1.39	13780	147	26778	263	35.1	22184
SGR-1	14.8	29.6	72.0	1449	22038	1.87	14051	138	27412	261	33.5	25243
NBS1633a*	46	196	118	84	94004	0.16	18761	170	4523	178	29	1706
NBS1633a	63.0	187	123	20	101560	2.31	20483	197	4585	189	<20	1800
SJ-Coal	3.6	7.6	18.3	41	5531	0.60	2173	20	1779	44	<4	2101
SJ-Coal	5.7	4.7	20.7	---	5563	0.33	2588	24	2169	45	<5	2126
SJ-Fly Ash	23.1	28.5	68.0	19	35225	0.34	10370	80	6382	265	<4	9531
SJ-Fly Ash	20.3	23.9	62.4	---	35032	<0.2	10085	80	5927	275	<4	9156

Sample #	Ni	Pb	P_2O_5	Sb	Se	S	Sr	Ti	V	Zn
SGR-1*	29	38	3280	3.4	3.5	15300	420	1583	128	74
SGR-1	31.1	48.3	1560	2.7	3.0	12883	419	1612	134	76
NBS1633a*	127	72.4	3800	6.80	10.3	1800	830	7973	297	220
NBS1633a	134	45.9	3329	4.5	8.6	1562	853	9085	321	220
SJ-Coal	1.2	15.9	272	0.4	0.8	4165	95.5	1476	25.9	19
SJ-Coal	2.8	17.9	---	---	1.4	---	308	1438	25.0	16
SJ-Fly Ash	16.4	52.5	1076	1.6	0.8	914	424	6046	114	64
SJ-Fly Ash	14.2	57.9	---	---	0.9	---	438	6104	116	61

Description	Sample #	Date	O2, %	CO, ppm	CO2, %	NO, ppm	NO2, ppm	NOx, ppm	SO2, ppm
6" above flame	4	1/19/96	17.9	1341	2.6	32	7	39	17
Inlet of volcano probe in flame	5	1/19/96	8	5552	11.3	148	0	148	1006
Fresh coal - Fire stoked. 18" above flame	8	1/19/96	19.4	620	1.3	10	2	12	28
Fresh coal. Fire stoked. 18" above flame. Door closed	9	1/19/96	19.7	493	1	6	1	7	19
Room Air	10	1/19/96	20.4	0	0.4	0	0	0	6
Stack 2 San Juan Plant		2/8/96	6.3	86	12.8	388	2	390	91
Stack 2 San Juan Plant		2/8/96	6.2	71	12.9	411	2	413	119
Stack 2 San Juan Plant		2/8/92	6.1	178	13	416	2	418	119
Stack 2 San Juan Plant		2/8/96	6.1	108	13	424	2	426	125
Stack 2 San Juan Plant		2/8/96	6.2	48	12.9	418	2	420	127
Stack 2 San Juan Plant		2/8/96	6.1	75	13	417	2	419	115
Stack 2 San Juan Plant		2/8/96	6.2	64	12.9	428	1	429	122
Stack 3 San Juan Plant		2/8/96	7.3	347	11.9	236	1	237	157
Stack 3 San Juan Plant		2/8/96	7.1	441	12.1	235	1	236	159
Stack 3 San Juan Plant		2/8/96	7.2	542	12	237	1	238	154
Stack 3 San Juan Plant		2/8/96	7.3	318	11.9	237	1	238	159
Stack 3 San Juan Plant		2/8/96	7.1	531	12.1	245	1	246	157
Stack 3 San Juan Coal		2/8/96	7.2	300	12	243	1	244	174
Stack 3 San Juan Plant		2/8/96	7.1	346	12.1	237	1	237	178
Ambient Air San Juan Plant		2/8/96	20.2	1	0.6	2	0	2	3
Coal Stove	1	3/21/96	5.5	17052	13.5	37	2	39	0
Coal Stove	2	3/21/96	15.6	4876	4.7	6	0	6	741
CoAl Stove	3	3/21/96	18.3	1604	2.2	8	0	8	16
Coal Stove	4	3/21/96	18.6	1415	2	7	0	7	15
Coal Stove	5	21-Mar	18.4	1552	2.2	9	0	9	18
Coal Stove	7	3/21/96	14.8	4856	5.3	128	0	128	158
Coal Stove	8	3/21/96	16.6	3642	3.7	65	0	65	124
Coal Stove	9	3/21/96	18.8	1250	1.8	27	0	27	36
Coal Stove	10	3/21/96	20.2	694	0.6	0	0	0	11
Coal Stove	13	3/21/96	16.6	830	3.7	93	2	95	39
Coal Stove	14	3/21/96	17.9	551	2.6	50	1	51	21
Coal Stove	15	3/21/96	17.7	372	2.8	52	1	53	30
Coal Stove	17	3/21/96	18.1	367	2.4	47	1	48	22
Coal Stove	19	3/21/96	18.2	452	2.4	44	1	45	16
	20	3/21/96	18.8	780	1.8	29	1	30	0
	21	3/21/96	18.8	839	1.8	25	1	26	0
	23	3/21/96	16.8	3528	3.5	19	0	19	154
	24	3/21/96	16.5	1531	3.8	11	0	11	295
	25	3/21/96	16.8	505	3.5	14	0	14	260
	27	3/21/96	16.9	321	3.5	17	0	17	299
	28	3/21/96	12.1	1286	7.7	96	0	96	112
	29	3/21/96	12.5	709	7.4	101	1	102	111
	33	3/21/96	16.4	242	3.9	34	0	34	23
	34	3/21/96	16.5	383	3.8	30	0	30	17
	35	3/21/96	15.9	389	4.4	32	0	32	24
	36	3/21/96	16.7	223	3.7	25	0	25	19
	37	3/21/96	9.6	11815	9.9	128	1	129	143
	38	3/21/96	4	28505	14.8	128	0	128	0
	39	3/21/96	3.3	28612	15.5	110	0	110	0
	40	3/21/96	6.3	14303	12.8	120	0	120	0
	41	3/21/96	5.8	3813	13.2	148	0	148	155
	42	3/21/96	10.9	82	8.7	91	0	91	105
	44	3/21/96	10.7	417	8.9	133	1	134	118
	45	3/21/96	16.5	96	3.8	58	0	58	34
	46	3/21/96	17	162	3.4	45	0	45	24
	47	3/21/96	16.8	195	3.6	50	0	50	20
	48	3/21/96	17.5	389	2.9	31	0	31	13
	49	3/21/96	17.9	478	2.6	12	0	12	9
	51	3/21/96	15.6	518	4.6	44	1	45	7
	52	3/21/96	17.4	776	3	43	0	43	0
	53	3/21/96	13	1449	6.9	100	1	101	41
	54	3/21/96	16	700	4.3	52	0	52	27
	55	3/21/96	16.2	1210	4.1	43	0	43	2
	56	3/21/96	17	1148	3.4	37	0	37	0
	59	3/21/96	8.5	3995	10.9	162	0	162	75
	60	3/21/96	6.3	5879	12.8	165	0	165	53
	61	3/21/96	6.3	5215	12.8	157	0	157	48
	62	3/21/96	14	914	6.1	63	0	63	58
	63	3/21/96	8	3018	11.3	115	0	115	54

Description	Sample #	Press, mb	Eff %, N	Xair, %	Ambient, C	Flue, C	Nett, C
6" above flame	4	0.07	25.7	606	16.5	301.6	285.1
Inlet of volcano probe in flame	5	0.25	96.2	63	17.7	32.2	14.5
Fresh coal - Fire stoked. 18" above flame	8	0.6	19.1	1312	20.8	176.9	156.1
Fresh coal. Fire stoked. 18" above flame. Door closed	9	0.66	28.1	1782	21.3	124.6	103.3
Room Air	10	0.71	92.2	> 20%	21.8	27.1	5.3
Stack 2 San Juan Plant		0.1	98.3	43	13.7	48	34.2
Stack 2 San Juan Plant		0.09	98.3	42	13.6	48	34.4
Stack 2 San Juan Plant		0.11	98.3	41	13.7	48.2	34.5
Stack 2 San Juan Plant		0.12	98.3	41	13.7	48.2	34.5
Stack 2 San Juan Plant		0.13	98.3	42	13.7	48.2	34.5
Stack 2 San Juan Plant		0.17	98.3	41	13.7	48.1	34.4
Stack 2 San Juan Plant		0.18	98.3	42	13.7	47.9	34.2
Stack 3 San Juan Plant		0.13	97.9	54	13.6	49.7	36.1
Stack 3 San Juan Plant		0.13	97.6	52	13.6	55.2	41.6
Stack 3 San Juan Plant		0.12	97.3	53	13.7	59.9	46.2
Stack 3 San Juan Plant		0.18	97.3	54	13.9	62.9	49
Stack 3 San Juan Plant		0.18	97.2	52	13.9	62.4	48.5
Stack 3 San Juan Coal		0.23	97.5	53	14.3	59.5	45.2
Stack 3 San Juan Plant		0.26	97.4	51	14.5	61.3	46.8
Ambient Air San Juan Plant		0.38	100	100	15.3	11.1	-4.2
Coal Stove	1	0.09	92.6	35	22.1	25.4	3.3
Coal Stove	2	0.47	93.3	295	24.8	29.6	4.8
CoAl Stove	3	0.64	91.3	732	26	40.8	14.8
Coal Stove	4	0.66	91	816	26.3	40.9	14.6
Coal Stove	5	0.69	91.7	746	26.5	40.5	14
Coal Stove	7	0.7	93.5	244	27.5	36.4	8.9
Coal Stove	8	0.11	94.1	396	27.8	27.7	-0.1
Coal Stove	9	0.17	96.1	900	28	27.3	-0.7
Coal Stove	10	0.22	94.5	28.3	na	27.1	-1.2
Coal Stove	13	0.34	97.8	391	29.1	34.8	5.7
Coal Stove	14	0.33	97	618	29.2	36.2	7
Coal Stove	15	0.31	97.3	561	29.3	37.8	8.5
Coal Stove	17	0.29	97.8	657	29.4	34.3	4.9
Coal Stove	19	0.27	97.6	674	29.4	33.8	4.4
	20	0.28	94.9	904	29.6	36.6	7
	21	0.28	94.7	934	29.7	36	6.3
	23	0.31	93.5	419	30.1	33.4	3.3
	24	0.33	97.1	379	30.2	32.6	2.4
	25	0.32	98.7	421	30.2	32.5	2.3
	27	0.34	99	423	30.3	3.5	2.2
	28	0.39	97.6	138	30.6	48.7	18.1
	29	0.4	97.8	150	30.6	50.4	19.8
	33	0.47	96	373	31.6	53.2	21.6
	34	0.48	95.9	379	31.9	52.7	20.8
	35	0.49	96.6	318	32.2	52.3	20.1
	36	0.54	96.3	397	32.6	52.3	19.7
	37	0.63	92.9	85	33.9	49.8	15.9
	38	0.61	88.1	23	34	53	19
	39	0.64	89	18	34	54.3	20.3
	40	0.65	92.6	43	34.1	54.6	20.5
	41	0.65	97.3	39	34.2	55.2	21
	42	0.66	98.5	110	34.4	54.6	20.2
	44	0.7	98.2	105	34.6	56.1	21.5
	45	0.71	96.3	381	34.8	56.4	21.6
	46	0.72	95.8	440	34.8	55.5	20.7
	47	0.72	96.2	417	34.9	54.4	19.5
	48	0.72	95.4	527	34.9	52.9	18
	49	0.72	97.4	618	35	40.9	5.9
	51	0.75	98.8	297	35.3	40.6	5.3
	52	0.77	95.5	511	35.6	49.1	13.5
	53	0.8	97.4	166	35.7	51.1	15.4
	54	0.77	96.8	329	35.7	49.6	13.9
	55	0.81	96.4	353	35.7	49.1	13.4
	56	0.82	95.4	448	35.8	49.1	13.3
	59	0.82	97	68	35.6	51.4	15.8
	60	0.81	95.9	43	35.5	57.9	22.4
	61	0.81	96.4	43	35.5	58	22.5
	62	0.77	96.7	202	35.4	58.2	22.8
	63	0.8	97.1	62	35.4	58.7	23.3

APPENDIX D

ASSESSING THE RISKS OF USING THE PRESENT STOVES ON THE NAVAJO RESERVATION

D-1 Components of a Risk Assessment

Paustenbach (1989) identifies four components of assessing the risk associated with a process or facility. These are hazard identification, exposure assessment, dose-response assessment, and risk characterization. Hazard identification is "the process of determining whether human exposure to an agent could cause an increase in the incidence of a health condition (cancer, birth defect, etc.) or whether exposure by a nonhuman receptor, for example fish, birds, or other wildlife, might adversely be affected" (Paustenbach op. cit.). It may also be defined as "the analysis of the significance of hazardous situations associated with a process or activity" (CCPS 1992). Exposure assessment is "the process of measuring or estimating the intensity, frequency, and duration of human or animal exposure to an agent currently present in the environment or of estimating hypothetical exposure that might arise from the release of new chemicals into the environment." The dose-response assessment is "the process of characterizing the relation between the dose of an agent administered or received and the incidence of an adverse health effect in exposed populations and estimating the incidence of the effect as a function of exposure to the agent." Risk characterization is "the process of estimating the incidence of a health effect under the various conditions of human or animal exposure described in the exposure assessment" (Paustenbach op. cit.)

D-2 Identifying Hazards Connected with Using the Present Stoves on the Navajo Reservation

A hazard is the possibility of harm or loss. (This distinguishes it from risk, which is the probability of harm or loss.) Many formal procedures have been developed for identifying hazards in a facility or process, and these are described in the risk-analysis literature (e.g., CCPS 1992). If the risk assessment approach had appeared feasible, this step would have involved first investigating the coal-combustion literature to find the possible pollutants that result from coal combustion. This would be followed by studies of the literature to find what contaminants are present in gaseous emissions and in the ash from the use of stoves. Emissions and ash from both normal operations and upsets would be considered.

D-3 Estimating the Human Exposure to Contaminants Produced by Using the Present Stoves on the Navajo Reservation

a. Stages in estimating human exposure. This step of the risk assessment procedure would consider two types of exposure—indoor and outdoor. Both types of exposure are estimated in three stages:

quantification of the contaminants in the source term, quantification of the transport of contaminants from source to receptors, and calculation of exposure.

b. Quantification of contaminants in source term. Quantification of the contaminants in the source term requires analysis of the source term or calculation of the components in the source term from appropriate models.

c. Quantification of transport of contaminants from source to receptor. Quantification of the transport of contaminants from the source to the receptor requires models for the modes of transport and rate of transport within the modes.

d. Calculating the human exposure to contaminants. Once the rates of contaminant transport have been calculated, the extent of human exposure to the contaminants must be calculated. Again, models are used here, giving the population exposed and the extent of exposure.

D-4 Dose-Response Assessments of Contaminants Produced by Using the Present Stoves on the Navajo Reservation

Reliable and quantitative dose-response data are very difficult to obtain. As mentioned in the text (Section IV.A.2), what Gehrs said in 1981 remains true today, "The current understanding of trace metal toxicity is not adequate to permit assessment of the long-term effects..." The same can be said generally of dose-response assessments of pollutants resulting from the burning of coal. An example of the controversy surrounding this area can be seen for the case of cadmium exposure, related in the Wall Street Journal in August of 1992 (Davis, 1992).

Since the current understanding of the dose-response effects of pollutants resulting from the combustion of coal is so poor, this dooms the prospect of carrying out a reliable quantitative risk assessment in this area.

D-5 Calculation of Risks Associated with Using the Present Stoves on the Navajo Reservation

The final step in the risk assessment procedure combines the results of the exposure calculations with dose-response data to give an estimate of the risk. Risk may be expressed as fatalities per person-year of exposure, years of life lost per person-year of exposure, illnesses contracted per person-year of exposure, etc. Unfortunately, this step could not be carried out because of the lack of acceptable dose-response data. Thus the risk-assessment approach was not used to define goals for the proposed project.

REFERENCES

[Citations ending with the Chemical Abstracts (*CA*) reference indicate that the information presented in the report was taken from the abstract, not from the complete publication.]

Anon., "Revision of Ozone and Particulate Matter Standards Linked by EPA," *Chem. Eng. Prog.*, **92**(8), 25 (August 1996).

Arizona Bureau of Mines, "Chemical Analyses of Coal Samples from the Black Mesa field, Arizona." Arizona Bureau of Mines Circular 18 (14 pp.), 1977.

Baldwin, S. F., Biomass Stoves—Engineering Design, Development, and Dissemination. Volunteers in Technical Assistance, Arlington, VA, 1987.

Beck, G. D., and J. D. Brain, "Prediction of the Pulmonary Toxicity of Respirable Combustion Products from Residential Wood and Coal Stoves," *Resid. Wood Coal Combust., Spec. Conf., Proc.*, 264-80, 1982 (*CA* **100**, 204633).

Beedie, D., T. O'Doherty and N. Syred, "CFD Modeling of a 200-kW Biomass Stove," *Proc. 5th IMechE Conf. Engineering Applications of Computational Fluid Dynamics*, pp. 151-160. Inst. Mech. Eng., 1993 (*CA* **120**, 195763).

Butcher, S. S., and M. J. Ellenbecker, "Particulate Emission Factors for Small Wood and Coal Stoves," *Proc. Int. Conf. Resid. Solid Fuels: Environ. Impacts Solutions* 1981 (*CA* **99**, 110026).

Ceely, F. J., and E. L. Daman, "Combustion Process Technology," Chapter 20 in Chemistry of Coal Utilization—Second Supplementary Volume (M. A. Elliott, ed.), pp. 1313-1387. Wiley, New York, 1981.

Center for Chemical Process Safety (CCPS), Guidelines for Hazard Evaluation Procedures (2nd ed. w/ worked examples). Am. Inst. Chem. Engrs., New York, 1992.

Center for Chemical Process Safety (CCPS), Guidelines for Chemical Process Quantitative Risk Analysis. American Institute of Chemical Engineers, New York, 1989.

Davis, B., "Risk Analysis Measures Need for Regulation, but It's No Science." *Wall Street Journal*, Thursday, Aug. 6, 1992, pp. A1 & A7.

DOE (U.S. Department of Energy), Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, "Electric Power Monthly," Reports # DOE/EIA-0226(96/4 through 96/7), April 1996 through July 1996.

DOE (U.S. Department of Energy), Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, "Inventory of Power Plants in the United States 1993," Report # DOE/EIA-0095(93), December 1994.

Dean, E., personal communication, September, 1996.

Elliott, M. A., and G. R. Yohe, "The Coal Industry and Coal Research and Development in Perspective," Chapter 1 in Chemistry of Coal Utilization—Second Supplementary Volume (M. A. Elliott, ed.), pp. 1-54. Wiley, New York, 1981.

Essenhigh, R. H., "Fundamentals of Coal Combustion," Chapter 19 in Chemistry of Coal Utilization—Second Supplementary Volume (M. A. Elliott, ed.), pp. 1153-1312. Wiley, New York, 1981.

Finkelman, R. B., "Environmental Consequences of Coal Utilization," notes from a short course presented at Navajo Community College, Shiprock, NM, June 1, 1995.

Gehrs, C. W., D. S. Shriner, S. E. Herbes, E. J. Salmon and H. Perry, "Environmental, Health and Safety Implications of Increased Coal Utilization," Chapter 31 in Chemistry of Coal Utilization—Second Supplementary Volume (M. A. Elliott, ed.), pp. 2159-2223. Wiley, New York, 1981.

Gluskoter, H. J., N. F. Shimp, and R. R. Ruch, "Coal Analyses, Trace Elements, and Mineral Matter," Chapter 7 in Chemistry of Coal Utilization—Second Supplementary Volume (M. A. Elliott, ed.), pp. 369-424. Wiley, New York, 1981.

Hoffman, G. K., F. W. Campbell, and E. C. Beaumont, "Quality Assessment of Strippable Coals in Northwestern New Mexico: Fruitland, Menefee, and Crevasse Canyon Formation Coals in San Juan Basin, and Moreno Hill Formation Coals in Salt Lake Field," New Mexico Bureau of Mines and Mineral Resources Bulletin 141 (84 pp.), 1993.

Husted, Lloyd E., personal communication (September, 1996).

Jaasma, D. R., M. R. Champion, and M Gundappa, "Field Performance of Woodburning and Coalburning Appliances in Crested Butte during the 1989-90 Heating Season," Report EPA/600/7-91/005. Avail. NTIS (1991) (*CA* **123,** 218644).

Kammen, D. M., "Cookstoves for the Developing World," *Sci. Am.*, **273**, 72-75 (July 1995).

Kandpal, J. B., R. Maheshwari and T. C. Kandpal, "Comparison of CO, NO2 and HCHO emissions from biomass combustion in Traditional and Improved Cookstoves," Energy (Oxford), 19, 1151-1155 (1994) (*CA* **122**, 37618).

Kukrety, N., V. M. Pattarkine, S. Saksena, V. Joshi and P. V. Sridharan, "Performance of Coal Based Fuels in Domestic Cooking Stoves," *Fuel Sci. Technol.*, **13**, 71-82 (1993) (*CA* **122**, 13468).

LaFontaine, H., and T. B. Reed, "An Inverted Downdraft Wood-Gas-Stove and Charcoal Producer," *Energy Biomass Wastes*, **15**, 1023-1049 (1991) (*CA* **117**, 93584).

Landry, B. A., and R. A. Sherman, "The Development of a Design of Smokeless Stove for Bituminous Coal," *Trans. ASME*, **72**, 9-17 (1950).

Lewis, R. J., Sr., Sax's Dangerous Properties of Industrial Materials, 8th ed., vol. **1**, p. xxvi, vol. **2**, pp. 697, 700, vol. **3**, pp. 1898-1899, 2213, 2251-2252. Van Nostrand Reinhold, New York, 1992.

Mayers, M. A., "Combustion in Fuel Beds," in Chemistry of Coal Utilization (H. H. Lowry, ed.), vol. 2, pp. 1482-1521. Wiley, New York, 1945.

Mukunda, H. S., S. Dasappa, B. Swati and U. Shrinivasa, "Studies on a Stove for Powdery Biomass" *Int. J. Energy Res.*, **17**, 281-291 (1993).(*CA* **120**, 139141).

Neavel, R. C., "Origin, Petrography, and Classification of Coal," Chapter 3 in Chemistry of Coal Utilization—Second Supplementary Volume (M. A. Elliott, ed.), pp. 91-158. Wiley, New York, 1981.

O'Sullivan, R. B., and H. M. Beikman, "Geology, Structure, and Uranium Deposits of the Shiprock Quadrangle, New Mexico and Arizona," U.S. Geological Survey Miscellaneous Geologic Investigations Map I-345 (1963).

Paustenbach, D. J., "Introduction: A Primer for Conducting Human or Environmental Health Risk Assessments," in The Risk Assessment of Environmental Hazards; A Textbook of Case Studies (D. J. Paustenbach, ed.), pp. 1-24. Wiley, New York, 1989.

Peirce, H. W., S. B. Keith, and J. C. Wilt, "Coal, Oil, Natural Gas, Helium, and Uranium in Arizona," Arizona Bureau of Mines Bulletin 182, pp. 11-42 (1970).

Prasad, K. K., "Off-Design Performance of Wood Burning Cook Stoves," *J. Energy, Heat Mass Transfer*, **15**, 21-44 (1993) (*CA* **120**, 168612).

Rajpal, P. S., and R. C. Maheshwari, "Optimization Studies of Portable Metallic Stoves for Energy Conservation," *Fuel Sci. Technol. Int.*, **10**, 109-116 (1992) (*CA* **116**, 109995).

Sanborn, C. R., "Characterization of Emissions from Residential Coal Stoves," *Resid. Wood Coal Combust. Spec. Conf., Proc.*, 151-60 (1982). (*CA* **100**, 179472)

Sherman, R. A., and B. A. Landry, "Combustion Processes," in Chemistry of Coal Utilization—Supplementary Volume (H. H. Lowry, ed.), pp. 773-819. Wiley, New York, 1963.

Slack, A. V., "Control of Pollution from Combustion Processes," Chapter 22 in Chemistry of Coal Utilization—Second Supplementary Volume (M. A. Elliott, ed.), pp. 1447-1490. Wiley, New York, 1981.

Stix, G., "Simply, the Best," *Sci. Am.*, **272**, 36 (April 1995)

Thring, M. W., and R. H. Essenhigh, "Thermodynamics and Kinetics of Solid Combustion," in Chemistry of Coal Utilization—Supplementary Volume (H. H. Lowry, ed.), pp. 754-772. Wiley, New York, 1963.

Toynbee, P. A., "Domestic Coal Firing in Smokeless Zones," *Proc. Int'l Conf. Residential Solid Fuels—Environmental Impacts and Solutions*, Portland, OR, June 1-4, 1981, pp. 892-911. Oregon Graduate Center, Beaverton, OR, 1982.

Vanderborgh, N. E., personal communication, November 1996.

Vivian, J., "Mother's 1993 Wood and Coal Stove Advisory," *The Mother Earth News*, **135**, 30-37, 78, 82, 95 (December, 1992/January, 1993).

Waterford, "The Erin Coal Stove," advertising literature describing this stove. Waterford Irish Stoves, Inc., West Lebanon NH, 1990.

Yohe, G. R., and E. O. Blodgett, "Reaction of Coal with Oxygen in the Presence of Aqueous Sodium Hydroxide. Effect of Methylation with Dimethyl Sulfate," *J. Am. Chem. Soc.*, **69**, 2644-2648 (1947).