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UCRL-51930 Vol. 3

**ENVIRONMENTAL EFFECTS OF ENERGY PRODUCTION
AND UTILIZATION IN THE U.S.
VOLUME 3: TECHNIQUES FOR CONTROLLING EMISSIONS**

Compiled and edited by Herbert W. Newkirk

MASTER

June 14, 1976

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**LAWRENCE
LIVERMORE
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Foreword

Historically, concern in the United States over resources has focused on whether or not there would be enough food, energy, and materials to meet current and future needs. Today, there is also concern about the ability of our land, air, and water to absorb all the effluents that energy production and utilization generates. The first annual Environmental Quality report accurately epitomizes this fact: "The conflicts between the consumption patterns that we all want, and the environmental ill effects that we all wish to avoid, is sharper for energy than perhaps any other aspect of natural resource use."

The issues being debated are complex, and while the written pieces on the subject number in the thousands, to our knowledge there is not yet available a summary of the facts related to the environmental effects of energy production and utilization. We have attempted to compile this relevant information and publish it in three volumes. It is anticipated that these handbooks will provide a data bank of environmental information that will be helpful in making the many critical cost/benefit choices that energy production and utilization demands.

Volume I deals with sources (what the emissions are and where they come from), trends (quantities of emissions and their dispersion with time), and costs of control (what it takes in time, energy, and money to meet minimum standards). Volume II concerns itself with the public health effects of energy production and utilization. Volume III summarizes the various techniques for controlling emissions, technological as well as economic, social, and political.

Each volume is divided into sections dealing with the atmosphere, water, land, and social activities - each division indicating a particular sphere of man's environment affected by energy production and use. The sources of information that were used in this study included textbooks, journal articles, technical reports, memoranda, letters, and personal communications. These are cited in the text at the end of each subsection and on the applicable tables and figures.

Good writing always benefits from both criticisms and suggestions. Comments on this edition are solicited to guide the compiler in subsequent versions of these fact files.

Finally, in a project of this magnitude many people contribute both their time and talent and deserve special recognition. To our typists, Joan Rien, Betty Irving, Virg Jaramillo, and Donna Romero, who typed the rough drafts; to Virginia Caswell of LLL's Technical Information Division who performed a superb job of literature searching in this field; to Kent Cummings for his skill in editing the volumes; and to the LLL staff members who reviewed portions of the rough drafts, Stuart Winter (Energy Planning and Analysis Group), John Tewes (K Division), Hugh Ellsaesser (G Division), David W. Dorn and Carroll Maninger (Technology Application Group) we extend our thanks.

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Section I

Air Emissions

CHEMICAL FACTORS

Carbon Monoxide

The control of carbon monoxide emissions from stationary combustion sources can be accomplished by the following methods: good operating procedures, employing alternative fuel sources, changing the waste disposal method, using afterburners on cupolas in the iron and steel industry, and by using waste heat boilers in the chemical and petroleum industry (Table 1). Some alternatives to other fuels for stationary sources include changing to gas from oil or coal; substituting nuclear or hydroelectric power; and replacing industrial, commercial, and household thermal requirements with central power.

Near-term strategies for controlling carbon monoxide emissions from automobile sources involve the following methods: modifying the internal combustion engine, using good operating practice, substituting public transportation and bicycles for private automobiles, utilizing traffic control methods to minimize stop-and-go driving, designing highways for reduced roadway concentrations, installing add-on control devices, phasing in of battery-flywheel hybrid electric cars.

Mid-term strategies for controlling carbon monoxide emissions from automobile sources involve the following methods: implementing alternative power sources for the internal combustion engine such as the gas turbine, Sterling engine, and stratified charge engine.

Long-term strategies for controlling carbon monoxide emissions from automobile sources involve implementing alternative power sources for the internal combustion engine such as the steam turbine, electric drives, free-piston engine and flywheel engine, and substituting hydrogen and methanol fuel for gasoline.

Some near-term strategies for controlling carbon monoxide emissions from aircraft include the following: development of a plan for the international regulation of aircraft emissions and fuel characteristics for planned stratospheric flight operations, the acceleration of combustion R&D programs to make stratospheric flight possible within specified nitrogen oxide emission standards, and the use of jet fuels having a sulfur content lower than that in current fuels through the application of state-of-the-art desulfurization processes.

Some mid- and long-term strategies for controlling carbon monoxide emissions from aircraft include the following: development of a global monitoring system to insure that environmental protection is being achieved, continuing research to reduce the present knowledge of the stratosphere, improvement of methods for estimating climatic change and biological consequences, implementing an atmospheric monitoring and research program for reducing uncertainties, and ascertaining whether or not atmospheric quality is being maintained.

References - Carbon Monoxide

Control Techniques for Carbon Monoxide Emissions from Stationary Sources, Department of Health, Education, and Welfare, National Air Pollution Control Administration, Washington, DC, Publ. AP-65 (1970).

Control Techniques for Carbon Monoxide, Nitrogen Oxide, and Hydrogen Emissions from Mobile Sources, Department of Health, Education, and Welfare, National Air Pollution Control Administration, Washington, DC, Publ. AP-66 (1970).

Table 1. Techniques for reducing carbon monoxide emissions from highway sources.*

Techniques for improving traffic flow	Probable effectiveness ^a
A. Freeways	
1. Reverse-lane operations	3
2. Driver advisory displays	1
3. Ramp control	2
4. Interchange design	2
B. Arterials	
1. Alinement	1
2. Widening intersections	3
3. Parking restrictions	2
4. Signal progression	2
5. Reversible lanes	3
6. Reversible one-way streets	3
7. Helicopter reports	2
C. Downtown distribution	
1. Traffic-responsive control	5
2. One-way street operations	3
3. Loading regulations	3
4. Pedestrian control	1
5. Traffic operations program to increase capacity and safety (TOPICS)	5
Techniques for reducing pollution concentration	
A. Staggered work hours	3
B. Roadway concentrations	2
C. Cross sections	2
D. Elevated, at-grade, depressed roadways	2
Techniques for reducing auto traffic	
A. Transit operations	
1. Bus lanes on city streets	1
2. Bus lanes on freeways	1
3. One-way streets with two-way buses	1
4. Park-ride-kiss-ride	3
5. Service improvements and cost reductions	2

Table 1. (continued)

Techniques for reducing auto traffic	Probable effectiveness ^a
B. Regulation	
1. Parking bans	4
2. Auto-free zones	4
3. Gasoline rationing	5
4. Idling restrictions	2
5. Four-day, forty-hour week	2
C. Pricing policy	
1. Parking policy	2
2. Road-user tax	5
3. Gasoline tax	5
4. Car pool incentives	2
D. Planned unit development	2

^aBased on traffic volume affected, pollution reduction, population exposure, and any adverse pollution impact (e.g., more or longer trips likely to be induced, or likely to cause traffic congestion). Higher numbers indicate greater levels of effectiveness.

*[Voorhees, A. M., and associates, A Guide for Reducing Automotive Air Pollution, Publ. PB 204870, USGPO, Washington, DC (1971).]

Nitrogen Oxides

The primary strategies for reducing nitrogen oxide emissions from stationary sources include staged combustion, low excess air operation, and flue gas recirculation.

Staged combustion is effective for controlling both thermal nitrogen oxides (nitric oxide fixation by high temperature) and fuel nitrogen oxide (oxidation of nitrogen chemically bound in the fuel). The method consists of initially contacting fuel with less than the amount of air (oxygen) required for complete combustion, then subsequently adding more air after a time delay in one or more steps or stages.

Low excess air operation involves minimizing oxygen availability for combination with either thermally activated or cracked fuel activated nitrogen atoms.

Flue gas recirculation lowers the concentration of nitric oxide by recirculating exhaust gases to the flame regions thereby reducing peak temperatures and oxygen availability. This method requires much greater capital investment and significantly increases operating control requirements.

Other methods include burner redesign, water/steam injection, wet scrubbing with aqueous ammonia, load reduction, remixed fuel/oxidizer, removal of nitrogen from fuels, catalytic reduction in stack processes, fuel substitution and fluidized bed combustion. (Fig. 1.)

Techniques for reducing nitrogen oxide emissions from highway vehicles include exhaust gas recirculation, adjustment of engine air/fuel ratio, catalytic reduction of exhaust nitrogen oxides, fuel modifications such as gasoline blends with methanol, substitutions such as propane and hydrogen, and engine refinements.

Techniques for reducing nitrogen oxide emissions from aircraft engines include the development of a plan for the international regulation of aircraft emissions and fuel characteristics for future stratospheric flight operations, acceleration of combustion R&D to make stratospheric flight possible within nitrogen oxide emission standards, using jet fuels having a sulfur content smaller than in current fuels, development of a global monitoring and international regulation system to insure that environmental protection is being achieved, and the development of a continuous atmospheric monitoring system and research program to further reduce remaining uncertainties and ascertain whether the atmospheric quality is being maintained.

References - Nitrogen Oxides

Cirillo, R. R., J. F. T. Schonz, and J. E. Camaione, "Aircraft Control Measures for Emission Reduction," J. Air Poll. Cont. Assoc. 26, 500 (1976).

Control Techniques for CO, NO, and Hydrocarbon Emissions from Mobile Sources, AP-66 (USGPO, Washington, DC, March 1970).

Control Techniques for Nitrogen Oxide Emissions from Stationary Sources, AP-67 (USGPO, Washington, DC, March 1970).

Fig. 1. Gas recirculation with natural gas firing - 320-MW corner fired unit (3). The exhaust gas concentration is calculated on the dry basis, i.e., with 3% excess O_2 . [Committee on Atmospheric Pollution of the Environmental Engineering Division, "NO_x Emissions from Stationary Combustion Sources," J. of the Environ. Eng. Div. (June 1974).]

Photochemical Oxidants

Control of photochemical oxidant formation has been mainly oriented toward the reduction of hydrocarbon emissions. This approach has been taken as a result of laboratory studies demonstrating that reduction of one of the major photochemical smog reactants, the hydrocarbons, besides being beneficial, would also be relatively simple to implement. Control of the major reactant, the nitrogen oxides, has not been applied as extensively yet, primarily because of the uncertainty about its merits and, secondarily, because the related technological problems for implementation are more difficult.

References - Photochemical Oxidants

Altshuller, A. P., S. L. Kopzynski, W. A. Lonneman, D. L. Wilson, and F. D. Sutterfield, "Photochemical Reactivities of Aromatic Hydrocarbon-Nitrogen Oxide and Related Systems," Environ. Sci. Technol. 4, 44 (1970).

"How Good and Useful are Air Pollution Models?" Environ. Sci. Technol. 7, 598 (1973).

Dimitriadis, B., "Effects of Hydrocarbon and Nitrogen Oxides on Photochemical Smog Formation," Environ. Sci. Technol. 6, 253 (1972).

Krier, J. E., "The Irrational National Air Quality Standards," UCLA Law Review 22, 323 (1974).

Sulfur Oxides

Tall stacks and intermittent control systems make it possible to meet ambient sulfur dioxide standards in carefully defined situations.

The desulfurization of gasoline is an attractive alternative, but to have it available nationally in conjunction with low-lead fuel would require upwards of 4 years. (Table 2.)

Two processes are currently being employed for the desulfurization of coke oven gas, the Vacuum Carbonate System, and the Strefford System. A third, the Sulfiban Process, has several plants scheduled for construction. (Table 3.)

References - Sulfur Oxides

Air/Water Pollution Report 13, 102 (March 17, 1975).

Federal Interagency Committee for Evaluation of State Air Implementation Plans, issued April, 1973.

Massey, M. J., and R. W. Dunlap, J. Air Poll. Cont. Assoc. 25, 1019 (1975).

Table 2. Inventory of desulfurization plants.*

Company	Location	Gas production (10 ⁶ ft ³ /day)	Process
<u>Plants in Operation:</u>			
Bethlehem Steel Co.	Burns Harbor, IN	120	Vacuum carbonate
	Lackawanna, NY	50	Vacuum carbonate
	Sparrows Point, MD	100	Vacuum carbonate
Donner Hanna Coke Corporation	Buffalo, NY	30	Vacuum carbonate
National Steel Co.	Weirton, WV	60	Vacuum carbonate
United States Steel Corporation	Clairton, PA	40	Vacuum carbonate
<u>Under Construction:</u>			
Inland Steel Co.	Indiana Harbor, IN	50	Vacuum carbonate
<u>Commitments For Construction:</u>			
Bethlehem Steel Co.	Bethlehem, PA	100	Sulfiban
Jones & Laughlin	Pittsburgh, PA	80	Sulfiban
Shenango Inc.	Pittsburgh, PA	32	Sulfiban

* [Adapted from Massey, M. J., and R. W. Dunlap, J. Air Poll. Cont. Assoc. 25, 1020 (1975).

Table 3. Control techniques to reduce sulfur oxide emissions.*

Methods	Advantages	Disadvantages
Dispersal of emissions and curtailment	Curtailment and tall stacks have been shown to reduce or eliminate occurrences of significant ground-level concentrations in the vicinity of large plants. Can be implemented immediately for some degree of emission control.	Curtailment interferes with plant operation. Methods are only an interim measure until reliable removal processes are available. Effective tall stacks are dependent upon meteorological and geographic conditions and do not provide a reduction in the amount of material released into the atmosphere.
Substitution of energy sources - hydroelectric and nuclear power	Causes no sulfur oxide emissions. Provides large sources of electrical energy at competitive cost.	Limited availability of suitable sites restricts expansion of hydroelectric power. Nuclear power substitution presents the possibility of introducing other emission problems.
Desulfurize high sulfur fuels		
<u>Coal</u>		
a. Coal Gasification	Sulfur oxide reduction is directly proportional to reduction of sulfur in the fuel. Readily abundant high-sulfur coal can be used as feed stock. Reduction of particulate emissions is another benefit. Sulfur removal is accomplished prior to combustion when the volume of gases to be treated is less than that of stack gases: techniques for removing the sulfur from the product gas are readily available; the clean gas permits the use	Economically feasible techniques are still in the development stage.

Table 3. (continued)

Desulfurize high
sulfur fuels

Coal (continued)

of more efficient power cycles than are presently used. Potentiality cheapest way of controlling sulfur emissions.

b. Partial Coal
Liquefaction

Obtaining a sulfur- and ash-free extract through partial liquefaction is reasonable in coal.

Complete liquefaction requires a large amount of hydrogen, which is very expensive but obtaining a sulfur- and ash-free extract through partial liquefaction is reasonable in cost.

Fuel oil

Sulfur oxide reduction is directly proportional to reduction of sulfur in the fuel. Reduction of particulate emission is another benefit. Proven refinery processes can produce a residual fuel oil with sulfur content of 0.3%.

Heavy capital investment. Interference by heavy metals in oil.

Gas

Technologically well developed. High degree of sulfur removal. Reduction of emissions is another benefit. Methods for desulfurization are readily available.

Heavy capital investment.

Sulfur oxide reduction is directly proportional to reduction of sulfur in the fuel. Reduction of particulate emissions is another benefit.

High price and unreliability of supply would require sulfur oxide abatement anyway. Exploitation of low-sulfur coal reserves in the west imposes severe environmental costs.

Table 3. (continued)

Combustion process
modification to
increase efficiency

Small improvements in the efficiency of a large power plant create large fuel savings and decrease sulfur oxide emissions.

Changes in basic techniques used to generate electricity may require a considerable R&D effort and an extensive capital investment. Long phase-in time.

Desulfurize flue gases
(Dry scrubbing, wet
scrubbing, or
attached chemical
plant)

Research to develop this technology is over 40 years old. Permits use of high-sulfur fuel feedstock. An alternative approach where a switch to low-sulfur fuel presents technical and economic problems. Processes that permit burning of high-sulfur fuels are approaching full development. Some solubled products, feasible technology.

Reliability of units 100 MW or larger has not been demonstrated. Processes considered most advanced have only been tested in a limited number of large-scale demonstrated projects. Enormous disposal problem attendant with throwaway control systems (nonregenerative alkaline and furnace injection) - products have no market value and must be disposed of in permanent impounding areas. Soluble magnesium salts will leach and contaminate water at the surface or underground. Lack of buoyancy of the plumes of all wet scrubber systems.

* [Lawrence Livermore Laboratory, staff compilation.]

Nonradioactive Particulates

Equipment for collecting particulates greater than $2\text{ }\mu\text{m}$ in diameter is readily available and uses one or more of the following techniques: absorption of particles into a liquid, withdrawal of particles onto a solid, gravity or centrifugal force field, particle charging followed by migration to a collection zone. (Figure 2 and Table 4.)

The most common liquid used to absorb particulate matter from an effluent stream is water. Devices employing this technique are called wet collectors. Their advantages include the ability to handle high humidity gases, minimal space requirements, the simultaneous collection of gases and particulates, and the cooling of high-temperature gases. Their disadvantages include stream plume problems and the disposal of the liquid and/or removal of the pollutants. This problem is usually handled in one of several ways: settling tanks and ponds, continuous filtration, liquid cyclones, continuous centrifuge, or chemical treatment.

Particulates can be withdrawn from pollutant streams and onto a solid by mechanisms using various forces, including gravitational, centrifugal, electrostatic, magnetic, thermal diffusion, Brownian diffusion, direct interception, and inertial impaction. Examples of devices using these forces are dry mechanical collectors, fabric filters, and electrostatic precipitators.

The dry mechanical collectors depend on particle inertia in a gravity or centrifugal force field. A dry collector has certain advantages compared to the wet collector. If the dust is a useful product, dry collection saves the cost of reprocessing. Handling the collected material can give rise to the cost of reprocessing. Dry, dusty material has the disadvantage of requiring ventilation and, if hygroscopic, caking can be a problem. The cleaned gas will not be cooled or completely free of fines. Without cooling, the temperature limits of equipment will have to be considered. Corrosion will be minimum unless the fumes contain corrosive mists. Equipment generally is bulky. Mechanical collectors are best suited for medium or coarse particulates. High dust-loadings can be handled at moderate pressure drops and power consumption. Simple construction of this type of collector results in lower cost and maintenance than other types.

The basic principles involved in electrostatic precipitation are: particle charging, particle migration, and rapping. Electrical precipitation requires a high-voltage discharge source, usually applied to electrodes consisting of a series of small-diameter wires. Opposite the wires are grounded electrodes which serve as the collecting elements and the terminus of the electrostatic field.

Commercially available equipment for controlling particulates less than 2 μm in diameter is not available; however, considerable development efforts are currently underway in many areas.

A recently announced scrubbing system works on the conventional venturi collection-mechanism of inertial impaction but establishes the needed particle-droplet differential velocity by consuming waste process heat rather than external energy. This system, developed by Lone Star Steel Company of Dallas, TX, called the Aerodynamic Immaculator, channels the water/steam fog from its ejector nozzle into a specially shaped aerodynamic chamber where fine particles are both encapsulated and separated from the flowing gas.

Another novel dust collector is the Pentapure Impinger which, according to the developer, Purity Corporation of Elk Grove Village, IL, enables up to 99.9% removal for most particles down to 0.1 μm in size. This is a higher efficiency than traditional abatement systems such as electrostatic precipitators, fabric filters, and venturi scrubbers. Furthermore, the new unit is reportedly both less expensive to install, operate, and maintain and more compact and reliable.

In the field of electrostatic precipitation technology, wet-precipitator manufacturers stand to benefit more than makers of dry units as standards for fine-particle emissions tighten. Though not used extensively today, wet electrostatic precipitators offer a big plus for fines by eliminating reentrainment.

One of the more innovative wet precipitators is the Hydro Precipitrol, designed by aeronautical expert Major Alexander de Seversky (Seversky Electronatom Corporation, New York, NY). The Hydro Precipitrol has upward-flow channels through one or more annular spaces within a cylindrical outer shell. Removal efficiencies for standard units reach 99.9% of all particles over 0.1 μm , and modified designs precipitate particles down to 0.01 μm . A key sidelight is that the Hydro Precipitrol comes in sizes as small as 3000 std. ft³/min, whereas other precipitators are practical only for

large-scale installations (e.g., power plants and metallurgical furnaces). Typical dusts handled include carbon black, aluminum fluoride, and oxides of titanium, zinc, aluminum, and magnesium.

Another novel device is the charged droplet scrubber, developed by TRW, Inc. (Redondo Beach, CA). Water droplets are electrostatically accelerated through an electric field. They attain the high velocities needed to capture large and even fine particles by inertial impaction, and carry them to a collecting plate. Charges up to three times those of conventional electrostatic precipitators - and thus higher collection efficiency for equivalent equipment volume - are suggested by theoretical considerations. The scrubber is suitable for particles in the 0.1 to 2-3 μm range.

The somewhat similar charged aerosol air purifier, developed by Marks Polarized Corporation, Whitestone, NY, reportedly removes stack particles all the way down to molecular size, and is equally effective on noxious gases.

At the University of Illinois, research is being conducted on the design of an electro-aerodynamic precipitator which overcomes most of the limitations of the conventional electrostatic precipitator. In such a configuration, electric wind and field have the same directions as the dusty gas flow. This, together with small passages which maintain laminar flow, eliminates reentrainment by electric wind and turbulence. The corona current also increases with dust loading, thus maintaining high operating efficiency at heavy loading. Studies, using a small-scale model, have demonstrated that such a precipitator provides consistently high efficiency (above 99%), compactness, and light weight. Highest efficiency obtained so far has been 99.98% with cigarette smoke.

The technology to remove sulfates from converters on highway vehicles is currently lacking and a mandatory sulfate standard would put automobile companies in a position where they would have to abandon catalysts completely. Officials from the large motor companies have urged the EPA to order the removal of sulfur from gasoline. However, oil industry representatives testified that although the cost of reducing the sulfur content of fuel would only mean an estimated increase of one to two cents per gallon at the pump, total expenditures and capital costs would approach \$5 billion.

In the case of stationary sources under normal climatic circumstances, the tall stack acts to lower ambient concentrations of SO_2 and suspended particles at ground level. Nonetheless, it has other undesirable features;

it ensures wider dispersion of the pollutants and a longer interval for the conversion of SO₂ to particles in the atmosphere and, following periods of inversion, leads to fumigations at ground level. It may be said to provide a lesser risk to nearby populations and a greater risk to populations of distant, wider areas.

Control strategies for fugitive dust sources which are necessary to attain national standards in each of the five air quality control regions generally indicate that unconventional air emission control techniques are required. Each of the following controls is necessary to attain primary standards: chemical stabilization, implementation of soil management control programs, paving more heavily traveled unpaved roads, speed control, and stabilization or watering of construction sites, material storage piles, and tailing piles.

References - Nonradioactive Particulates

Air & Gas Cleanup Equipment, 2nd edition (Noyes Data Corporation, Park Ridge, NJ, 1972).

Jones, H. R., Fire Dust & Particulates Removal (Noyes Data Corporation, Park Ridge, NJ, 1972).

Lilles, E. J., and D. Young, J., Air Poll. Cont. Assoc. 25, 1015 (1975).

Sitteg, M., Pollutant Removal Handbook (Noyes Data Corporation, Park Ridge, NJ, 1973).

Table 4. Advantages and disadvantages of various collection devices.*

Collector	Advantages	Disadvantages
Gravitational	Low pressure loss, simplicity of design and maintenance.	Much space required. Low collection efficiency.
Cyclone	Simplicity of design and maintenance. Little floor space required. Dry continuous disposal of collected dusts. Low-to-moderate pressure loss. Handles large particles. Handles high dust loadings. Temperature independent.	Much head room required. Low collection efficiency of small particles. Sensitive to variable dust loadings and flow rates.
Wet collectors	Simultaneous gas absorption and particle removal. Ability to cool and clean high-temperature, moisture-laden gases. Corrosive gases and mists can be recovered and neutralized. Reduced dust explosion risk. Efficiency can be varied.	Corrosion, erosion problems. Added cost of wastewater treatment and reclamation. Low efficiency on submicrometer particles. Contamination of effluent stream by liquid entrainment. Freezing problems in cold weather. Reduction in buoyancy and plume rise. Water vapor contributes to visible plume under some atmospheric conditions.
Electrostatic precipitator	99+ percent efficiency obtainable. Very small particles can be collected. Particles may be collected wet or dry. Pressure drops and power requirements are small compared to other high-efficiency collectors. Maintenance is nominal unless corrosive or adhesive materials are handled.	Relatively high initial cost. Precipitators are sensitive to variable dust loadings or flow rates. Resistivity causes some material to be economically uncollectable. Precautions are required to safeguard personnel from high voltage. Collection efficiencies can deteriorate gradually and imperceptibly.

Table 4. (continued)

	Few moving parts. Can be operated at high temperatures (550 to 850°F.)	
Fabric filtration	Dry collection possible. Decrease of performance is noticeable. Collection of small particles possible. High efficiencies possible.	Sensitivity to filtering velocity. High-temperature gases must be cooled to 200 to 550°F. Affected by relative humidity (condensation). Susceptibility of fabric to chemical attack.
Afterburner, direct flame.	High removal efficiency of submicrometer odor-causing particulate matter. Simultaneous disposal of combustible gaseous and particulate matter. Direct disposal of nontoxic gases and wastes to the atmosphere after combustion. Possible heat recovery. Relatively small space requirement. Simple construction. Low maintenance.	High operational cost. Fire hazard. Removes only combustibles.
Afterburner, catalytic.	Same as direct flame afterburner. Compared to direct flame: reduced fuel requirements, reduced temperature, insulation requirements, and fire hazard.	High initial cost. Catalysts subject to poisoning. Catalysts require reactivation.

* [Control Techniques for Particulate Air Pollutants, Department of Health, Education, and Welfare, National Air Pollution Control Administration, Washington, DC, Publ. AP-51 (1969).]

Fig. 2. Extrapolated fractional efficiency of control devices. Efficiency has been determined on a mass basis. [Shannon, L. J., Particulate Pollutant System Study, II, Fine Particle Emissions, NTIS, Springfield, VA, Publ. PB203521 (1971).]

Organic Gases

Hydrocarbon emissions from fuel combustion in stationary sources can be reduced or eliminated by essentially three techniques: improved operating practices, improved equipment design, and fuel substitution.

Good operating practice is the most practical technique for reducing hydrocarbon emissions from existing stationary combustion sources. Even the best equipment will perform poorly if improperly applied, installed, operated, or maintained. Hydrocarbon emissions are directly related to the three common combustion parameters of time, temperature, and turbulence. A high degree of fuel and air turbulence will greatly reduce hydrocarbon emissions, increase combustion efficiency, and reduce fuel consumption.

Hydrocarbon emissions may be reduced by upgrading combustion processes through improving equipment designs to reduce emissions or through redesign to reduce the quantity of fuel required for a given energy output.

Improvements in the combustion of pulverized coal and better mixing of highly turbulent secondary air into the primary combustion zone have improved combustion efficiencies and reduced emissions of hydrocarbons from steam-electric generating plants. The trend toward better steam utilization in these plants has also improved the efficiency of conversion of thermal energy from fossil fuels into electrical energy.

Continued research in the areas of magnetohydrodynamics, electrogas dynamics, and fuel cells, solar energy, etc., offers the promise of reduced fuel requirements and reduced hydrocarbon emissions.

The substitution of gas for coal or oil in any type of furnace reduces the emissions of organic gases when good combustion techniques are used. A switch from coal to oil will reduce organic emissions on smaller industrial furnaces and on commercial and domestic furnaces. This reduction in organic emissions is largely effected by the better mixing and firing characteristics of a liquid or gaseous fuel as compared to those of a solid.

The use of methane or methanol-gasoline blends offers the possibilities for health benefits and an improved environment.

Techniques for controlling hydrocarbon emissions from highway vehicles have progressed rapidly in the past few years. The first device to receive wide acceptance by the automotive industry was the positive crankcase ventilation system. The addition of this control technique in 1963 virtually eliminated all blowby emissions. It has been estimated that blowby emissions contributed from 20 to 25% of the total hydrocarbons of uncontrolled vehicles.

Emission-control systems in use on new cars nationwide include a closed positive crankcase ventilation system designed to prevent gases that blow by the piston rings from escaping into the atmosphere, exhaust-emission control systems for reducing carbon monoxide and hydrocarbon emissions in the exhaust gas, and fuel-evaporation controls to prevent the escape of gasoline vapor from fuel tank and carburetor.

An approach that appears to have the most favorable potential for reducing hydrocarbon emissions to 0.25 gal/mile, and carbon monoxide emissions to 4.7 gal/mile, involves secondary combustion of exhaust gases in an exhaust manifold reactor with exhaust recirculation.

Control of evaporative emissions from automobiles was achieved in 1971. One method of control utilizes an activated carbon trap which is connected by tubing to the fuel tank and the carburetor. When the engine is started again air is drawn through the trap and the hydrocarbons are swept into the engine. Another method uses a similar approach but stores the hydrocarbons in the crankcase rather than in an activated carbon trap. The lowering of exhaust emissions in 1968 over the 1963 value was achieved by utilizing a fuel-to-air mixture which contained less fuel.

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Trace Metals

The question of which metallic emission will be controlled, and how much and what type of control will be exercised, is largely unanswered. To date only mercury, beryllium, and lead have come under federal or state standards, and only the first two have an emission standard. Lead and nickel emitted from moving sources are currently not controlled, but the most likely control method in each case is to ban or severely limit the use of fuel additives containing these substances. Provisions for such control are given to the Administrator of EPA under the 1970 Clean Air Amendments, but have not been exercised so far.

Methods for controlling metallic emissions from stationary sources are closely related to particulate control methods (mechanical collectors, electrostatic precipitators, baghouses, and scrubbers) that are employed where coal or petroleum are used as fuels, since a large fraction of metallic emissions occur as fly ash containing metals or as metals suspended in oily droplets.

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Hydrogen Sulfide

The installation of black liquor oxidation systems and scrubbers has substantially reduced emissions. Hydrogen peroxide has been one of the most successful chemicals used in such systems.

Wet scrubbers using various absorbents and iron oxide are used in refineries, natural gas plants, and coke ovens to remove hydrogen sulfide from gas streams.

Incineration is also used to reduce emissions of the gas.

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Water Vapor

Localized ground fogs downwind from wet cooling towers can be prevented from forming by unloading the towers during those spells of weather when a fog hazard exists.

Other possible solutions include substitution of an alternative cooling method; relocation of cooling towers; heating the air to obtain adequate dilution before cooling to the dew point; increasing the height of the discharge stack; and lifting the plume over a street by mechanical jetting (use of an air curtain).

Control of water vapor injections into the stratosphere, if it turns out to be necessary, could be obtained by limiting the amount of air traffic above a given altitude and accelerating new engine development.

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RADIOLOGICAL FACTORS

Gaseous Radioactivity

Noble gas effluents from nuclear power plants and fuel reprocessing facilities can be either trapped cryogenically or absorbed at ambient temperature and removed from a contaminated gas stream, with a reported efficiency of 99.9% in pilot-plant tests.

A totally enclosed or contained facility will minimize the inputs to the atmosphere and maintain a safe environment for both workers and offsite residents. Since the dose from man-made (nonmedical) radiation is much smaller than that from the natural background, few additional controls are needed beyond those currently in effect.

Currently the release on radioactive materials to the general environment is controlled on the basis of limiting the exposure to individual and small population groups.

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Radioactive Particulates

Particulate radionuclides from power reactors (after a retention period in charcoal beds to permit the decay of isotopes of short half-life) are removed from fission and activation gases by filtration.

The volumes of gases that must be handled in nuclear reactors are small compared to those from fossil-fuel plants. Filters with an efficiency of 99.9 wt% routinely remove radioactive particles that may be suspended in potentially contaminated gas streams before venting to the atmosphere.

For fossil-fuel plants, especially coal plants, particulate radionuclides are removed along with the nonradioactive fly-ash materials through use of electrostatic precipitators or baghouse filters. The dust-collection efficiency of new units has been rising steadily over the years.

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PHYSICAL FACTORS

Thermal Inputs

There is currently no control on CO₂ production and none is contemplated. If it turns out that increased CO₂ levels appear to be inducing undesirable environmental effects, it might become necessary to regulate the rate at which fossil fuels are consumed. This could result in an acceleration in the shift to power production from other energy sources. There is no practical method of burning fossil fuels without releasing CO₂ into the air.

Heat is the one commodity that cannot be disposed of. While a small amount may be lost to outer space via radiation from heated surfaces, almost all of it remains with us for essentially all periods of interest. If the amount of heat released to the environment becomes critical, we must limit the amount generated by increasing the thermodynamic efficiency of thermal engines or turning to sources of energy that do not produce waste heat, namely, hydroelectric energy and tidal energy.

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Electromagnetic Emissions

Personnel working with radar and other rf radiators are normally protected from exposure to excessive power densities by suitable equipment location and beam orientation, by limiting of access to hazardous areas, and by using metallic screening for area shielding.

Skin and eyes can be protected from the effects of ultraviolet radiation by shielding of sources of radiation, by goggles or face shields, by clothing, and, for special purposes, by absorbing or reflecting skin creams. Protective measures include: (1) sunscreens, (2) protective clothing and barrier creams, (3) transparent material for skin and eye protection, and (4) reflection of ultraviolet radiation.

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Noise

Control techniques for the subsonic aircraft industry involve design modifications and operational restrictions. Some design modifications include: new quiet engines with high bypass ratios and low velocity jets, acoustically treated nacelles and ducts, exhaust silencers for reciprocating and turboshaft engines, noise suppression for on-board auxiliary power units, rotor and propeller aerodynamics for reduced noise, noise suppression for mechanical components such as helicopter gear boxes, vehicle aerodynamics to allow for steeper ascent and descent, and/or reduction in time required for ascent/descent. (Figure 3.)

Some operational restrictions include: power cutback on takeoff or steep climb-out depending on the situation, steep or multisegment approach depending on the situation, and preferential runway assignments avoiding noise sensitive areas.

Noise reduction for supersonic aircraft can only be accomplished through the use of supplementary jet silencers. The Concorde consortium has spent \$100 million on noise reduction and research and their technicians have been able to achieve about a 20 dB reduction when compared with the baseline configuration. The question of economic reasonableness of requiring additional noise suppression from these first generation aircraft is essentially academic since the aircraft are, in fact, range critical. This results in a situation where any trade of aircraft performance for further noise suppression would eliminate the range capability for which the aircraft was designed and eliminate any semblance of viability.

The noise footprint of the supersonic transport aircraft, however, is unique in that the high noise levels are essentially close in to the airport. This fact suggests that special airports could be designated as SST airports if sufficient land mass was contained within the airport boundary to contain the high SST noise levels within that boundary.

Techniques for controlling noise from the railroad industry include: improved suspension systems and electric motor drives, replacement of old track by welded track, application of spray-on acoustical material on the ceilings and under the platform edges, replacement of old transit cars with modern types incorporating door and window seals and vibration damping materials on the body, installation of noise barriers along the right-of-way, and acoustically effective aerial structures. (Tables 5 and 6.)

Techniques for controlling noise from highway vehicles include vehicle redesign, tire redesign, operational restrictions, vehicle and road maintenance, and route redesign. (Figures 4-6 and Table 7.)

Some vehicle redesign ideas include: new engine blocks to minimize radiation of combustion-induced noise, vibration isolation and sound damping of engine block and transmission, intake and exhaust silencers, fan noise reductions, control of ancillary equipment noise (e.g., refrigeration units, cab air-conditioning, etc.), brake system noise reduction, and body and frame redesign including insulation and acoustical enclosures.

Some tire redesigns include use of a rib-tire pattern instead of a cross bar pattern.

Some vehicle operational restrictions include: the establishment and monitoring of speed limits, limited access of certain vehicles to particular routes by time of day, controls on vehicular flows and volume, and keeping traffic flowing to avoid stopping and starting of vehicles.

Some route redesign ideas include: road surface repairs, pavement specifications, limitations on allowable grades, acceleration/deceleration ramp lengths and traffic light controls, use of depressed roadway, use of roadside barriers or berms, and route locations planned to insure maximum separation between roadway and existing noise sensitive areas and to make maximum use of shielding provided by natural barriers and provide for compatible use of land adjacent to highways.

Noise control programs for the appliance industry is a direct function of marketplace pressure so that control technology often exceeds application. Appliance manufacturers tend to maintain R&D and product engineering staffs that are capable of delivering more noise reduction than market strategy can justify.

Some companies have tried - unsuccessfully - to market quiet products, such as vacuum cleaners, blenders, and hair dryers; others have developed a number of quiet prototypes that were not put into production. Several companies keep systematic track of customer correspondence, while the industry itself maintains a Major Appliance Consumer Action Panel (MACAP) that acts as a clearinghouse for complaints. These records, all of which concern major appliances, show relatively little complaint about noise. For example, only 5% of the letters to MACAP in the first 8 months of 1971 concerned noise.

The construction industry has, until recently, been relatively uninvolved in efforts to quiet site operations. Its attitude may be attributed in part to the fact that quiet equipment has not yet been made generally available on a cost-effective basis; however, a limited capability does exist for quieting a site by relocating or rescheduling equipment.

This sector has not exercised its influence as a consumer to bring pressure to bear on the equipment manufacturers, nor has it responded to public complaints. Thus, regulatory measures may be the only solution to the problem of construction site noise, and such regulations are imminent.

Control of industrial noise involves: definition of permissible sound levels; measurement of noise and its components, including measurement of background noise, measurement of noise at the workplace, and measurement of noise at its source; reduction of noise at its source; acoustic zoning to prevent airborne propagation of noise or propagation of noise through solids; sound proofing; and the provision, where necessary, of personal protection devices.

The extent of noise control and reduction within the industries supplying small internal combustion engines has been directly related to its effect on sales and the existence of noise ordinances. With the exception of the small generator industry, buyer insistence on quiet equipment has not been sufficient to produce significant noise reduction efforts. Consequently, noise abatement programs have not been consistent. (Table 8.)

References - Noise

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Table 5. Estimated future change in noise energy for transportation system categories with three options for noise reduction.*

Source	Noise energy in kWh/d			
	1970	2000		
		Option ^a		
		1	2	3
RAIL VEHICLES				
Locomotives	1200	1200	1200	200
Existing R/T systems	6	10	6.3	0.5

^aOption 1 - No noise reduction.

2 - Estimate industry trend in noise reduction.

3 - Example of possible incremental program of noise regulation.

* [Report to the President and Congress on Noise, USGPO, Washington, DC, Doc. No. 92-63 (1972).]

Table 6. Summary of the noise reduction potential by applying current technology to existing transit vehicles.*

Existing condition	Modified condition	Estimated noise reduction, dBA	
		Car Interior	Car Exterior
Standard track, not regularly maintained	Welded track, ground	5-15	5-15
Concrete trackbed	Ballast trackbed	0-5	0
Bare concrete tunnel surfaces	Strips of absorbent material at wheel height	5-10	-
Bare concrete station surfaces	Limited absorbent material on wall surfaces and under platform overhang	-	5-10
Old type vehicles using open windows or vents for ventilation	New type cars with air conditioning	10-15	-
Standard doors and body	Improved door seals, body gasket holes plugged, etc.	0-5	-
Standard steel wheels	Steel wheels with constrained damping layer	5-15	5-15
Standard type vehicles	Installation of a 4-ft barrier alongside track	-	10-15
Standard, noisy propulsion unit	Modified unit with skewed armature slots, random blower fan blade spacing, acoustically treated fan ducts	0-5	5

Note: The values of noise reduction are estimated for the particular source alone, assuming no contributions from other sources. The values therefore cannot be added to obtain an overall noise reduction.

*[Report to the President and Congress on Noise, USGPO, Washington, DC, Doc. No. 62-93 (1972).]

Table 7. Estimated future change in noise energy for transportation system categories with three options for noise reduction.*

Source	Noise energy in kWh/d			
	1970	2000		
		Option ^a		
		1	2	3
Highway vehicles				
Medium and heavy trucks	5,000	10,000	4,000	800
Sports cars, import and compacts	1,000	2,500	1,600	250
Passenger cars (standard)	800	1,200	800	400
Light trucks and pickups	500	1,000	400	160
Motorcycles	250	800	320	80
City and school buses	20	20	8	3
Highway buses	12	12	5	1.2

^aOption 1 - No noise reduction.

2 - Estimate industry trend in noise reduction.

3 - Example of possible incremental program of noise regulation.

* [Report to the President and Congress on Noise, USGPO, Washington, DC, Doc. No. 92-63 (1972).]

Table 8. Estimated noise reduction potential for devices powered by internal combustion engines.*

Source	Noise reduction (dB) ^a		
	1975	1980	1985
Lawn care equipment	10	13	15
Chain saws	2	2	5
Generator sets	5	7	17

^aNoise reduction relative to typical current noise levels at 50 ft.

*[Report to the President and Congress on Noise, USGPO, Washington, DC, Doc. No. 92-63 (1972).]

① Lower revolutions per second	⑤ Reduced blade interaction
② More blades	⑥ Engine inlet suppression
③ Large blade area	⑦ Engine exhaust muffling
④ Modified blade tip shapes	⑧ Cabin insulation improvements

Current design approaches to helicopter noise reduction

Demonstrated noise reduction of a heavy-helicopter twin-rotor system

Fig. 3. Noise reduction for helicopters. [Report to the President and Congress on Noise, Document No. 92-63, USGPO, Washington, DC (1972).]

Fig. 4. Barrier effectiveness at varying highway distances. Community sound level as a function of way-side distance is reduced by the introduction of barriers of different heights. The same noise attenuation effect is realized when a roadway is depressed below grade, but with either the depressed roadway or on-grade roadway with barriers on both sides, reflected sound waves from the far side of roadway wall or barrier tend to counteract the amount of noise reduction. [Transportation Noise and Its Control, Department of Transportation, USGPO, Washington, DC, Publ. DOTP 5630.1 (1972).]

Fig. 5. Noise reduction with and without trees. Planting adjacent to a highway produces little physical reduction in noise level unless it is very dense and of significant depth. Trees do reduce sound levels but not enough to justify a large expenditure for this purpose alone. It has also been shown that decorative plantings, while they do not significantly reduce the sound level, have strangely enough reduced the incidents of complaints about noise. [Transportation Noise and Its Control, Department of Transportation, USGPO, Washington, DC, Publ. DOTP 5630.1 (1972).]

Fig. 6. Noise reduction produced by various highway configurations. The difference in noise levels between the on-grade and the graded configurations indicate that the noise reduction obtained with such land-contour shielding is significant. However, the use of elevated steel structures to raise a highway may result in greater noise levels adjacent to the roadway. [Transportation Noise and Its Control, Department of Transportation, USGPO, Washington, DC, Publ. DOTP 5630.1 (1972).]

Magnetic Field Emissions

Magnetic field emissions can be controlled by shielding or by avoiding the magnetic field area. The weight and size of such shields could pose difficulties, however, in transportation designs.

References - Magnetic Field Emissions

Staff report in Science Trends 32, 91 (July 29, 1974).

X Radiation

A large reduction in total human exposure to x radiation can be gained by correct use and maintenance of properly constructed equipment. As an example, the genetically significant dose from medical radiation could be reduced from 55 to 19 mrad/year, if the x-ray beams were limited to the area of the film.

While unnecessary exposures have been reduced significantly in the last two decades, there is still much reduction which can be achieved. This can occur through the more wide-spread application of collimators, sensitive film, and proper technical training. Perhaps a factor of 2 or 3 might be gained below the levels found by the 1964 X-Ray Exposure Study, without any significant technological breakthrough.

Improved training of users (including physicians, medical technicians, and industrial workers) is equally important. This must be complemented by improvements in medical and nursing education programs.

Most medical and industrial sources of x radiation in the U.S. are subject to license by the several states. Practices vary widely, ranging all the way from regular licensing and surveillance of essentially all sources to almost complete lack of regulation.

Similarly, there are wide differences in the licensing or certification of operators of x-ray equipment. Only a few states (e.g., California) have a significant program of certification for all medical x-ray workers; in California, even physicians are subject to this certification.

The licensing of individual industrial x-ray workers is practically nonexistent. This is a situation in urgent need of improvement, since a majority of large accidental exposures is due to human error rather than mechanical failure.

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Section II

Water Effluents

CHEMICAL FACTORS

Oil Spills

Practices to remove oil spills include: mechanical containment and removal, absorption, chemical dispersants, physical sinking and biological degradation.

Mechanical containment and removal by floating booms and other barrier devices, and physical removal by absorption on chopped straw, are effective means to avoid damage. Unfortunately they operate at low recovery rates and winds, waves, and currents often combine to make the methods very ineffective in open water.

Absorbents such as straw, manufactured fibers, and absorbent clays are spread on a slick, mixed with the oil, and collected. Straw is considered the most cost-effective sorbent because it holds five times its weight in oil and is less expensive than alternative absorbents.

Chemical dispersants reduce the fouling of beaches, boats, marine structures, birds and other sea life, and render the oil more susceptible to biodegradation. It may also increase the availability of the oil to the marine environment with greater resulting damage to life.

Physically sinking oil with various materials for large spills has been recommended. The possible rapid destruction of bottom fauna may lead to the destruction of the sea life dependent on the fauna for food and protection.

Biological degradation helps hydrocarbons in the sea to be naturally degraded by marine microorganisms and bacteria strains. Acceleration of biological degradation may cause additional ecological damage through oxygen depletion. Additional research is needed to develop effective and rapid acting biological methods.

Practices to minimize oil spills include: using simple and inexpensive control measures, such as load-on-top in conjunction with alarm systems, improved operating techniques, improved training for tanker crews, establishment of shipping lanes, improved navigation aids, and shorter ship turning radii.

References - Oil Spills

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Acid Mine Drainage

There are some 24 techniques, which can be used singly or in combination, for the abatement and control of acid mine drainage (Table 9). Of these, fewer than one-half have been either sufficiently tested or applied to allow an appraisal of their practicality for use in defined situations. These techniques, intended to improve the quality of surface waters affected by acid mine drainage pollution, are as follows:

- Prevent the formation of acid mine drainage at its source (e.g., mine sealing, reclamation of surface lands and waste piles, and diversion of water from pollution sources).
- Contain or isolate the polluted water or acid producing materials (e.g., deep well injection, and surface and subsurface impoundments).
- Disperse or dilute the pollutants to more acceptable levels.
- Treat polluted waters (neutralization processes).

The choice of control techniques depends on the type of mining source producing the effluents, whether it is active or inactive, the geological and hydrologic characteristics of the mine source, anticipated secondary effects, and the expected water quality improvement.

Some techniques are relatively inexpensive, such as land reclamation and drainage diversion. Since only 12% of the acid drainage comes from all surface sources, relatively little acid drainage can be reduced by using land reclamation and drainage diversion techniques, and significant results might be realized only in small areas.

Other control techniques that prevent acid formation are generally quite costly, highly dependent upon suitable geologic and hydrologic conditions, and less predictable in their effectiveness. Furthermore, they may also produce unintentional secondary effects that could cause other damages. Consequently, the practical methods available for control at many sites are usually limited in number, relatively expensive, uncertain in their predictability, and do not produce uniformly acceptable results.

An acid mine drainage abatement program should include the regulation of operating mines, the abatement of acid drainage from inactive mines, the continuation of research pertaining to acid mine drainage and the development of appropriate institutional arrangements necessary to implement an effective program.

The responsibility for regulating operating mines in order to control acid mine drainage is lodged with the individual States and embodied in State laws pertaining to water quality or mining reclamation. The scope and effectiveness of these statutes differ among the States, but all have been strengthened over the past two decades.

Of great importance in the strengthening of these statutes has been the establishment of water quality standards for interstate streams as required by the Federal Water Quality Act of 1965. Present State legislation, however, does not adequately assign the responsibility for acid mine drainage abatement from future inactive mines. Administrative regulations are the primary means of controlling acid mine drainage from mining operations on Federally owned and administered lands.

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Table 9. Mine drainage control techniques.*

Technique	Procedure	Mine type ^a	
		Surface	Underground
Surface land reclamation	The grading of earth, the construction of water ditches, and the revegetation of ground disturbed by excavation of the surface.	A I	- -
Mine entry sealing	The placement of barriers in openings from underground mines exposed to the surface to constrain the movement of air or water.	- -	- I
Drainage diversion	The channeling of surface waters or mine waters to control volume, direction, and contact time.	A I	A I
Impoundment	The physical restriction of waters within an isolated area of an underground or surface mine.	- I	- I
Refuse pile reclamation	The burial or covering and revegetation of the discarded waste rock from mining.	A I	A I
Underground grouting	The placement of a sealant on the surface or into the subsurface to constrain the movement of air and water in an underground mine, e.g., the pouring of concrete which would seal after reaching subsurface.	- -	- I
Revegetation	The planting of grasses, legumes, or trees upon the surface of areas disturbed or altered by excavation or dumping during mining.	A I	- -
Inert gas blanket	The placement and retention within an underground mine of a gas that is not reactive in the acid-mine-drainage forming process.	- -	- I

Table 9. (continued)

Technique	Procedure	Mine type ^a	
		Surface	Underground
Microbiologic iron and sulfate removal	The use of living organisms to actively reduce mine drainage contaminants.	- I	A I
Sterilization	The use of toxic materials to destroy or retard living organisms active in the acid-mine-drainage forming process.	- -	A I
Microbiological control	The use of living organisms against each other to retard the action of those which are active in the acid-mine-drainage process.	- -	- I
Internal sealing	The isolation or constraint of underground mine waters by the placement of barriers well within the depths of underground mines.	- -	A -
Resource removal	The extraction of all coal, and the burying and sealing of toxic producing strata.	A I	- -
Neutralization	The process of chemically counteracting the effects of acid mine drainage.	A I	A I
Flash distillation	The rapid evaporation of acid mine drainage and the reliquefaction of the remaining fluid, free of residual contaminants.	A I	A I
Reverse osmosis	The passage through a selective membrane of the liquid portion of acid mine drainage thereby freeing it from a major portion of the residual contaminants.	A I	A I
Ion exchange	The passage of acid mine drainage among reactive particles that selectively retain residual contaminants while the remaining liquid passes through.	A I	A I

Table 9. (continued)

Technique	Procedure	Mine type ^a	
		Surface	Underground
Desulfating	The use of living organisms that thrive on metabolic processes that destroy sulfate, which is a major residual contaminant of mine drainage.	A I	A I
Sulfide iron removal	The precipitation of iron from acid mine drainage with the addition of selectively reactive sulfide compounds.	A I	A I
Electrodialysis	The passage of acid mine drainage through an electrically charged selective membrane allowing the passage of liquid thus freeing it from residual contaminants with the appropriate electrical resistance to passage.	A I	A I
Permanganate iron removal	The precipitation of iron from acid mine drainage with the addition of an agent that oxidizes the iron.	A I	A I
Regulated pumping	The discharge of acid mine drainage at volumes, rates, times, and locations so that the contaminating effects will be minimized.	A I	A I
Stream flow regulation	The containment and release of stream waters at volumes, rates, times, and locations so that the contaminating effect will be minimized.	A I	A I
Deep well injection	The placement of acid mine drainage or its altered product into the subsurface through a vertical drilled hole.	A I	A I

^a A = Active; mines and areas in use for mining.

I = Inactive; closed or abandoned mines or portions of active mines not in use.

* [Lawrence Livermore Laboratory, staff compilation.]

Trace Metals

Methods of controlling the metal content of water discharges include self-purification removal by chemical or physical means, or controlling losses due to leakage. Industries and utilities are making headway in reducing the metal content of their discharges by such methods as chemical precipitation, electrodeposition, cementation, solvent extraction, ultrafiltration for colloidal particles, ion exchange, and activated carbon absorption. Some of these techniques simply replace one metallic impurity with another, so that the overall approach must be examined to evaluate fully the various tradeoffs.

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Putman, J. J., "Quicksilver and Slow Death," National Geographic 124 (October 1972).

RADIOLOGICAL FACTORS

Tritium

Current practice in the U.S. is to use zirconium cladding on fuel rods, rather than the former stainless steel cladding, since it resists corrosion more effectively and has more favorable properties in the nuclear radiation environment.

References - Tritium

"Tritium in the Environment from Nuclear Power Plants," in Selected Materials on Environmental Effects of Producing Electric Power, Joint Committee on Atomic Energy, 91st Congress, 1st Session, Washington, DC (1969), p. 511.

Other Radioactivity

Processes used for cleanup of liquid radioactive wastes include filtration, demineralization by ion exchangers, and various chemical precipitation techniques.

Radioactivity levels are also reduced by temporarily storing liquids to permit radioactive decay, and by dilution of effluents to reduce the concentration.

Additional stages of filtration and demineralization can be added, as in the Rancho Seco Unit (Sacramento), for recycling of all waste water for reuse in the reactor plant so that no liquid wastes are released to the environment.

References - Other Radioactivity

Hearings Before the Joint Committee on Atomic Energy on Environmental Effects of Producing Electric Power, 91st Congress, 1st Session, Washington, DC (1969), Vol. I, p. 156.

PHYSICAL FACTORS

Thermal Inputs

There is no cure for the ultimate change of all energy into heat, and in the very long run, the only possible solution of the world's thermal rejection problem would be to relocate energy systems into space.

Conforming to current standards regulation is virtually impossible without some kind of waste heat control. If the traditional, cheapest and easiest process of "once-through" river cooling should be used in a large 4000-mW power plant, 14,000 to 21,000 ft³/s would be required to keep the temperature increase under 5°F. Considering that the base flow of the Missouri River at Omaha is equal to 20,000 ft³/s (two to three times less in winter) it is very clear that only a few power plants could be built in the future without waste heat control and be in compliance with temperature standards.

Current methods of waste heat control include various impoundments and cooling towers. Artificial cooling lakes, ponds, and reservoirs may provide a pleasant solution, but natural evaporation is slow and space requirements (cost of the land) are large - at least 2, more typically 5, acres per megawatt.

Surveys of all significant U.S. utilities showed that 20% of existing and 22% of the future units will use cooling ponds and lakes. Existing reservoirs and those under construction in the U.S. could supply about 90 large fossil fueled stations above 1000 mW, 71 in the 1000- to 4000-mW range.

Another 45 fossil-fueled stations and 60 nuclear power plants with capacities above 1000 mW will have to use cooling towers during the next two decades.

Other measures that could be used to control thermal inputs to the environment include: increasing power plant efficiency, using alternative power plant techniques, finding productive uses for waste heat, and integrating with total energy systems.

A reduction in the amount of waste heat produced per unit of output can be achieved by increasing the efficiency of power plants. The outlook for increasing the efficiency of nuclear power plants by the 1990's from about 30% to the current modern fossil fuel plant efficiencies of about 40% appears good.

Research is now underway to develop more efficient methods of electric power generation. These technologies, which include magnetohydrodynamics, electrogasdynamics, and thermionic electric power generation, have considerable potential to reduce the amount of heat waste per unit of electric power generated.

Heat discharged into water may under some conditions increase types of desirable aquatic life, increase the recreational use of very cold water bodies, reduce winter ice cover on lakes and rivers to increase water-borne traffic and dissolved oxygen levels, and produce other beneficial agricultural effects. Low temperature heat from a power plant could be, and is, used for space heating of buildings, air conditioning, hot water supply, snow removal, desalting, and chemical and manufacturing processes. For most of these uses steam from the power plant would be directly utilized so that the power plant condensers could be partly or wholly eliminated.

One of the main features of total energy schemes is their integration with residential heating and cooling needs, such as the possibility of an ammonia or lithium-bromide absorption refrigeration mechanism which requires a heat supply at only 105°C for district heating and cooling.

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Section III

Land Use

CHEMICAL FACTORS

Acid Fallout

Implementation of the various techniques for limiting the emission of SO_2 in stack gases would provide adequate control of fallout to land of acidic materials. Higher stacks may or may not be beneficial and could even make the problem worse by increasing the affected area, as happened in the Cooper Basin of Tennessee and may be the case in the recent incidence of acid fallout in Sweden and Norway.

References - Acid Fallout

Likens, G. E., and F. H. Bormann, Science 184, 1176 (1974).

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Solid Effluent

Two kinds of control problems are apparent: those posed by the considerable bulk of refuse banks already in existence in the underground coal mining areas of the country, and those relating to the future disposition of solid wastes.

Some refuse banks could also be used to backfill abandoned mines or worked-out sections of mines where the backfilling would not create new problems such as those from acid mine drainage.

Some refuse banks may contain enough combustible matter to be used as fuel in generating electricity. Other refuse heaps may contain enough chemicals and minerals to make them worthwhile as commercial sources of the material.

If no other uses of the materials can be found, it may be possible to reclaim the land they occupy by grading, recontouring, and covering with topsoil that will support vegetation.

Fly ash that is stored on the power plant property can be kept from blowing away by periodic sprinkling with water from overhead pipe systems.

Acid runoff from coal refuse piles can be controlled by covering the mineral effluent with soil, establishing a vegetation cover, and providing adequate drainage to minimize erosion. Average acid formation for a restored refuse pile was estimated at 16 lb acid as calcium carbonate per acre per day, a 91% reduction over the unrestored pile. Slurry lagoons containing the fine coal rejects can be stabilized and air pollution controlled by either a vegetation cover or the application of a chemical stabilizer.

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RADIOLOGICAL FACTORS

High-Level Storage

The present state of effluent management control policy is based on requirements determined early in the development of commercial nuclear power, namely, safety beyond any reasonable doubt, reasonable cost, and accessibility of the storage facility to monitoring and control. These requirements led to the current practice of storing liquid high-level effluent in specially designed underground tanks. This is considered to be a means of interim handling but not a long-term solution.

For the long-term solution three viable options are available: Option 1 is the scheme (until recently in favor) of solidifying the effluent, including whatever actinides were present, and transporting them to a salt mine for permanent disposal. In Option 2 various effluents are separated, which ameliorates the disposal problem. A temporary visit may be made to near-surface storage facilities with full retrieval capability. Several other disposal options of possible interest can follow from the upper segments of Options 1 and 2, particularly the latter. Option 3, in situ melting, is quite different: the effluent, upon being inserted into a selected underground site or nuclear chimney, fuse themselves into a permanent glassy mass. (Table 10 and Figs. 7 and 8.)

It is too early to assess disposal in space and in the oceans for lack of adequate knowledge. For the short term, ultimate disposal in deep mines is the best-developed plan. However, the related concept of in situ melt has significant advantages and should be realistically appraised.

References - High-Level Storage

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Table 10. Summary of effluent disposal options.*

Route ^a	Option	Advantages	Disadvantages
1	Salt mine	Good shielding properties, high heat conductivity, low earthquake potential, impermeable rock isolation from aquifers, easy to excavate, adequate space for future wastes.	Corrosive media; highly susceptible to water; normally associated with other valuable minerals; difficult to monitor and retrieve wastes.
1A	Granite	Crystalline rock; low porosity if sound; comparable to salt in thermal properties; retrievable wastes.	Nonplastic media; presence of groundwater; difficult to monitor.
2	Further chemical separation; recycle actinides	Reduced long-term toxicity; technology feasible; increases future options.	Additional handling and processing; more toxic materials in fuel inventory; waste dilution due to processing; fission products remain.
2A	Further chemical separation; remove Sr and Cs; recycle actinides	Reduced long-term toxicity; reduced short-term thermal power; some reduction of fission product toxicity; increases future options.	Additional handling and processing; more toxic materials in fuel inventory; waste dilution due to processing; storage and disposal of Sr and Cs extract; fission products remain.
3	Melt <u>in situ</u>	<u>In situ</u> creation of insoluble rock-waste matrix; no transportation; reduced handling.	Highly mobile wastes during 25-year boiling phase; presence of groundwater; irretrievable wastes; proliferation of disposal sites; difficult to monitor.
3A	Melt <u>in situ</u> , central repository	<u>In situ</u> creation of insoluble rock-waste matrix; short boiling period; no proliferation of sites.	Presence of groundwater; irretrievable wastes; difficult to monitor.
2	Antarctic rocks	Immobile water	Very narrow temperature limits; not a permanent geologic feature; difficult environment.

Table 10. (continued)

Route ^a	Option	Advantages	Disadvantages
2	Continental ice sheets	Immobile water.	Cannot dispose of actinides; limited.

^aThe routes are those shown in Fig. 7.

*[Adapted from Kubo, A. S., and D. J. Rose, Science 182, 1205 (1973).]

Fig. 7. Taxonomy of nuclear effluent disposal options. [Adapted from Kubo, A. S., and D. J. Rose, *Science* 182, 1205 (1973).]

Rock salt deposits in the U.S. (after Pierce, W.G., and E.I. Rich, USGS Bull. No. 1148, 1962).

Salt deposits having thickness of at least 200 ft and lying within 2000 ft of land surface.

Fig. 8. Rock salt deposits in the U.S. At present three major disposal locations are envisaged: the AEC production facilities at Hanford, Washington, in local basalt; the commercial wastes in the salt beds of Kansas; and the salt beds of southern New Mexico, which underlie some largely mined-out potash deposits. [Schneider, K. J., et al., "Status of Solidification and Disposal of Highly Radioactive Liquid Wastes from Nuclear Power Plants in the USA," Environmental Aspects of Nuclear Power Stations, IAEA-SM-146/23, Vienna (1971).]

PHYSICAL FACTORS

Land Subsidence and Depletion

Subsidence problems have been or are being alleviated in several ways, namely: cessation of withdrawal of petroleum, gas, or water due to depletion of the supply, legal action, or replacement with substitute supply; increase or restoration of reservoir pressure due to reduction in production rate or to increase in recharge (water); repressuring by injection of water, leaving adequate pillars in place to support the overburden and, after completion of mining operations, by avoiding factors in the mine environment that cause coal pillars to spall and become weakened; and backfill the mined-out areas with rock and mine refuse.

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Strip- and Surface-Mining Activities

Reclamation Techniques

The reclamation of past disturbances falls into two major categories: abatement of undesirable conditions, and the development of restored land and water resources to more productive uses.

The first of these may be defined as "basic reclamation," or the minimum effort required to correct, at the earliest practicable moment, undesirable on-site and off-site conditions caused by past mining. This would include measures designed to alleviate or prevent erosion, acid discharge, and other physical and chemical after-effects of surface mining that generally are associated with "orphan," or derelict, lands.

The second category, the rehabilitation of mined land for specific purposes, would require more extensive treatment than for basic reclamation and the expenditure of additional funds. Development of recreational areas, for example, would require some reshaping of the land before planting, and installation of sanitary facilities to insure that streams will not be contaminated by further pollution.

For present purposes it can be assumed that two-thirds of the land disturbed to date, about 2.0 million acres, should have some type of treatment. The expanse of this acreage may be more readily grasped if it is visualized as a strip a mile wide and extending from New York to San Francisco. Of the 2.0 million acres, approximately 800,000 were mined for coal and 400,000 acres for sand and gravel.

The task of reclaiming such a large area would require the mobilization of an array of manpower and funds so vast as to make a "crash program" unfeasible. Indiscriminate reclamation without first developing comprehensive land-use plans may be wasteful and even damaging. Therefore, a time-phased program appears the most feasible approach from the standpoint of both effectiveness and efficiency.

In devising a reclamation policy for the U.S., consideration should be given to the West German experience. The West German program has been in effect for some 20 years and has been highly successful in minimizing social dislocations and environmental damage from brown-coal surface mining.

The West German program embodies four main principles that have contributed greatly to its success. First, the regulation of surface mining is incorporated within an overall regional development plan. Second, a

planning body composed of diverse public interests participates in formulating detailed requirements for mining and land restoration long before the actual mining begins. Third, the recommendations of the planning body are reviewed in public hearings. Fourth, an enforcement agency is provided with the necessary powers to enforce the approval plan.

The West German program offers visible evidence that, with detailed advance planning, striking successes can be achieved in reducing environmental damage from strip mining at a price easily borne by the consumer.

Reclamation Laws

State regulations generally require only what is called primary reclamation, in which heavy equipment is used to bury acid-containing materials and to smooth, but not grade, mine-field ridges. The major aim is to alleviate water pollution due to acidic mining wastes. Strip-mine fields that have undergone only primary reclamation still retain long furrows. Furthermore, the fertile topsoil, saved carefully in the West German mining techniques, is forever destroyed or buried in the typical American Strip-mine field. The field that has undergone primary reclamation is a wasteland on which only the hardiest vegetation can survive. Reclamation practices are somewhat better in Pennsylvania and Ohio, which have stricter standards than other Appalachian states.

References - Strip- and Surface-Mining Activities

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Power Plant Siting

One possibility for reducing the impact of power plants and transmission systems would be to reduce the demand for the energy produced and increase the efficiency of the power plants. With current growth rates, demand is doubling every 10 years.

A most likely course for reducing the visual impact of energy facilities is to put them underground. Experience with undergrounding is beginning to accumulate, and the possibilities for reducing aesthetic offense and land-use conflicts while improving real and apparent safety aspects are considerable.

Another possibility is the off-shore siting of power plants along the nation's coasts, which tend to be a concentration of load centers. Such siting, properly chosen, will reduce the land use for both the power-plant sites and the transmission facilities and should reduce aesthetic and safety concerns as well.

Another area in which land impact might be reduced is to introduce fusion reactors. If fusion reactors, which have no chemical emissions, no potential for a nuclear accident, and minimal radioactivity problems, can be sited inside big cities, substantial savings can be made in the area of land required for transmission of electricity to the load centers.

A systems solution would call for building small power plants in urban areas when the so-called waste heat could be used for space heating and cooling. This would reduce the latter demand for fuel by more complete utilization, and reduction of transmission losses would ease the emissions problem also by creating smaller sources and would require less real estate in buffer zones.

References - Power Plant Siting

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"Environmental Effects of Producing Power," Hearings before the Joint Committee on Atomic Energy, U.S. Congress (1971).

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Rogers, F. C., "Underground Nuclear Power Plants," Bull. Atomic Sci. 27, 38 (1971).

Hydroelectric Dams

Evaluations of the potential environmental impacts of new installations could result in decisions not to build, or to change the selection of the site, or to take some alternative course of action, such as building a thermal power plant instead of a hydroelectric dam.

References - Hydroelectric Dams

Joint Committee of Atomic Energy, Selected Materials on Environmental Effects of Producing Electric Power, 91st Congress, 1st Session, Washington, DC (1969), p. 160.

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Section IV Social Costs

NUCLEAR THEFT

The theft of sensitive nuclear materials could be controlled by the following techniques:

- Designing a detailed system of safeguards for each of the nuclear fuel cycles based on use of the best available technology and institutional mechanisms.
- Developing and publishing a set of procedures for the review of physical security plans submitted by industry licensees.
- Establishing a Federal Nuclear Materials Security Service with the sole responsibility of protecting nuclear materials subject to safeguards.
- Initiating discussions with the governments of other nations with substantial nuclear power programs with a view to developing a common policy in favor of effective safeguards against nuclear theft anywhere in the world.
- Requiring operators of nuclear power plants to have a physical security organization, control access to and within the reactor by using qualified and trained guards, and establish other security provisions for communications, alarm stations, liaison with local law enforcement authorities and visitor controls. Other requirements should include monitored isolation zones around such physical barriers as fences, and bullet-resistant windows and doors for power reactor control rooms.

References - Nuclear Theft

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