ENVIRONMENTAL EFFECTS OF ENERGY PRODUCTION AND UTILIZATION IN THE U.S. VOLUME I: SOURCES, TRENDS, AND COSTS OF CONTROL

Compiled and edited by Herbert W. Newkirk

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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 Jaramille, 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.

Contents

List of Illustrations	ix
List of Tables	xvii ⁴
Acronym Glossary	xxviii
I. Environmental Quality	1
Sources	1
Trends	1
Effects on the Atmosphere	1
Effects on Rivers and Lakes	2
Effects on the World Oceans	2
Land Use	3
Costs of Control	3
References - Environmental Quality	5
II. Effects on the Atmosphere	10
Summary	10
Sources	10
Trends in the United States, 1973	11
Costs of Control, 1973	12
References - Effects on the Atmosphere (Summary)	13
Chemical Factors	32
Carbon Monoxide	32
References - Carbon Monoxide	33
Nitrogen Oxides	42
References - Nitrogen Oxide	44
Photochemical Oxidants	55
References - Photochemical Oxidants	57
Sulfur Oxides	62
References - Sulfur Oxides	67
Nonradioactive Particulates	87
References - Nonradioactive Particulates	96
Organic Gases	135
References - Organic Gases	136
Trace Metals	144
References - Trace Metals	146

Hydrogen Sulfide	161
References - Hydrogen Sulfide	163
Water Vapor	169
References - Water Vapor	170
Radiological Factors	173
Gaseous Radioactivity	173
References - Gaseous Radioactivity	178
Radioactive Particulates	197
References - Radioactive Particulates	203
Physical Factors	
Thermal Inputs	214
References - Thermal Inputs	219
Electromagnetic Emissions	226
References - Electromagnetic Emissions	230
Noise	234
References - Noise	237
Magnetic Field Emissions	241
X Radiation	242
References - X Radiation	243
III. Effects on Water Quality	253
Summary.	253
Sources	253
Trends	253
Costs of Control	254
Chemical Factors	255
Oil Spills	255
References - Oil Spills	258
Acid Mine Drainage	272
References - Acid Mine Drainage	273
Trace Metals	275
References - Trace Metals	277
Radiological Factors	280
Tritium	280
References - Tritium	282
Other Radioactivity in Liquid Effluents	289

Physical Factors	290
Thermal Inputs	290
References - Thermal Inputs	292
Depletion of Water Reserves	310
IV. Land Use	318
Summary	318
Sources	318
Trends	319
Costs of Control	319
References - Land Use (Summary)	320
Chemical Factors	324
Acid Fallout	324
References - Acid Fallout	325
Solid Effluent	329
References - Solid Effluent	331
Radiological Factors	340
High-Level Storage	340
References - High-Level Storage	342
Natural Background Radiation	350
References - Natural Background Radiation	353
Resource Use	358
Land Subsidence	358
References - Land Subsidence	359
Strip- and Surface-Mining Activities	363
References - Strip- and Surface-Mining Activities	366
Power Plant Siting	377
References - Power Plant Siting	382
Hydroelectric Dams	387
References - Hydroelectric Dams	387
Fuel Mineral Depletion	388
Energy-Related Minerals Depletion	396
References - Energy-Related Minerals Depletion	397
V. Social Costs	401
Benefit vs Ecological Risk	401
Mining Accidents	406
Transportation Accidents	414

Automobiles and Trucking	414
Railroads	414
Aviation	415
References - Transportation Accidents	415
Oil and Gas Occupational Accidents	420
Nuclear Accidents	424
Fission Power	424
Fusion Power	425
References - Nuclear Accidents	425
Nuclear Theft	431
Source	431
Trends	431
Costs of Safeguards	433
Inflation and Balance of Payments Deficits	438
Manpower Availability	443
Capital Availability	444
Industrialization	448
References - Industrialization	448
Basic Human Needs	452
References - Basic Human Needs	452

List of Illustrations

Figure	Title	Page
1.	Total environmental expenditures in the petroleum industry, 1966-1973.	9
2.	Emissions to the atmosphere from fossil fuels in the U.S. during 1971, percentage by weight.	30
3.	Emissions to the atmosphere from fossil fuels in the U.S. during 1971, percentage by effect.	31
4.	Global carbon monoxide emission sources, 1971.	38
5.	Nationwide sources of carbon monoxide emissions, 1972.	39
6.	Status of carbon monoxide levels, 1973. Note that in many cases an excess of one station near a roadway or power plant is sufficient to categorize the whole area.	40
7.	Trends in carbon monoxide concentrations, 1961-1972, CAMP cities. (a) Trend lines for annual averages in five CAMP cities. (b) Trend lines for annual 99th percentiles in five CAMP cities. .	41
8.	Sources of global man-made emissions of nitrogen oxide, 1971. . .	51
9.	Global quantities of nitrogen oxide emissions for 1968.	52
10.	Sources of nationwide emissions of nitrogen oxide, 1972.	53
11.	Trends in nitrogen dioxide concentrations for some selected cities in New Jersey.	54
12.	Interaction of hydrocarbons with atmospheric nitrogen dioxide photolytic cycle.	58
13.	Status of oxidant/ozone levels, 1972.	59
14.	Trend in oxidant results by year at CAMP sites.	60
15.	Smoothed deviations from monthly means of total ozone from 17 stations in the period 1957-1970, and the intensity and timetable of nuclear explosions in this period.	61
16.	Nationwide sources of sulfur oxides emissions, 1972.	77
17.	Estimated historical global sulfur dioxide emissions.	78
18.	Status of sulfur dioxide levels, 1973.	79
19.	Trends in sulfur dioxide concentrations, 1964-1972, NASN stations.	80
20.	National and regional trends in sulfur dioxide, 1970-1973. . . .	81

Figure	Title	Page
21.	Downward trends of annual sulfur dioxide averages at downtown CAMP stations.	82
22.	Comparison of sulfur dioxide trends in Chicago with regulations governing percent sulfur content in fuel. Note that the trend was for decreasing sulfur dioxide emissions even before regulations were introduced.	83
23.	Comparison of sulfur dioxide trends in Philadelphia with regulations governing percent of sulfur content in fuel. Note that the trend was toward decreasing sulfur dioxide emissions even before regulations were introduced.	84
24.	Comparison of sulfur dioxide trends at Bayonne, New Jersey, with regulations governing percent sulfur content in fuel.	85
25.	Sulfur dioxide concentrations vs time in years for New York City..	86
26.	A marine aerosol.	109
27.	Nationwide sources of particulate emissions, 1972.	110
28.	Chemical elements in polluted atmospheres. The inner ring encloses elements present in the natural background (soil dust and marine aerosols). The second ring encloses primary particulate matter introduced by man. The outer ring encloses secondary material formed in the atmosphere.	111
29.	Status of suspended particulate levels, 1973.	112
30.	Nonurban average sulfate concentration.	113
31.	Urban sulfate concentrations, 1970. Within approximately the eastern half of the continental U.S., levels of sulfate were higher at urban sampling sites than at nonurban site.	114
32.	National and regional trends in total suspended particulate, 1970-1973. A general decline in total suspended particulate levels occurred throughout the nation. This trend occurred in all five geographic areas, as indicated by the regional and national composite averages.	115
33.	Trends in total suspended particulate concentrations, 1960-1972, at NASN stations. (a) Composite annual averages at urban and nonurban stations. (b) Composite averages and 90th percentiles of annual maximum daily concentrations at 95 urban stations.	116
34.	Dustfall data for six cities: Pittsburgh, Cincinnati, Chicago, New York, Detroit, and Philadelphia.	117
35.	Trends in particulate matter for Montana, Salt Lake Basin, New York City, and the Chicago area.	118

Figure	Title	Page
36.	Total suspended particulate vs time, Chicago, 1950-1970.	119
37.	Dustfall particulate vs time, Chicago, 1950-1970.	119
38.	Trends in BSO and BSO percent of TSP at 32 urban and 19 nonurban NASN stations.	120
39.	Composite annual average of BaP concentrations for 32 urban and 19 nonurban NASN stations.	121
40.	Trends in national coal consumption, BSO and BaP annual averages..	122
41.	Dustfall concentration vs time in years for New York City. . . .	123
42.	Coefficient of haze (COH) vs time in years for New York City. . .	124
43.	Total suspended particulate concentration vs time in years for New York City.	125
44.	Estimated chronology of worldwide atmospheric particulate loading by volcanic activity and by human activity, 1850-1970. Average of volcanic loading added for comparison (thin solid line). Rough calibration of volcanic loading in terms of planetary average temperature effect is shown outside margin at right.	126
45.	Atmospheric extinction at Lowell Observatory, Flagstaff, Arizona. (V. L.) Mitchell's estimate. (Q) Mean vertical extinction in the blue. (K) Blue-yellow color index.	127
46.	Chronology of mid-Atlantic aerosol data.	128
47.	Smithsonian aerosol extinction data at 0.391 and 0.395 μm for Mount Montezuma, Chile.	129
48.	Urban and nonurban long-term sulfate trends at NASN monitoring stations.	129
49.	Nationwide distribution of average sulfate (a) concentrations, 1968-1970, and (b) fractions expressed as percent of total particulates, 1968-1970.	130
50.	Average daily noontime visibilities in Los Angeles. The trend is of deteriorating visibility.	131
51.	Smithsonian aerosol extinction data at 0.391 μm for Table Mountain, California. There has been no detectable change in the global atmosphere transmission from remote, high-altitude sites in the last half century.	132
52.	Trend of deteriorating visibility of turbidity, Lick Observatory..	133

Figure	Title	Page
53.	Long-term trend of atmospheric transmittance for solar radiation at Phoenix, Arizona. The trend is of deteriorating transmittance. Note that transmittance is best in winter when surface concentration of particulates is highest.	134
54.	Nationwide sources of man-made hydrocarbons, 1972.	141
55.	Global sources of man-made hydrocarbon emissions, 1971.	142
56.	Emissions of hydrocarbons from fossil-fuel combustion (10^6 tons/y).	143
57.	Dispersion of lead in the environment.	154
58.	Mercury in feathers of birds of prey. Moving up the food chain: concentrations of mercury in Swedish birds of prey moved up as they ate birds that in turn had eaten seeds treated against mold with mercury dressings.	155
59.	Arsenic in tobacco, fish, and shellfish. Arsenic trioxide levels found in U.S. tobacco reflected the use of lead arsenate sprays (blue area). A few spot measurements indicate high and now lower levels of arsenic in shellfish.	156
60.	Mercury in humans, fish, and fish-eating birds. Mercury in tuna (and probably in oceans as a whole) has been fairly constant. But fish in many local areas have been badly polluted along with fish-eating birds. Cyntent in humans may have declined.	157
61.	Trends of lead in glaciers and plants. Lead levels in glaciers, moss, and elm trees have been growing at similar rates, although the actual concentrations vary. Elm trees are graphed above in parts per 100 million, Poland glacier in parts per billion. Moss is shown in parts per million, Greenland glacier in parts per trillion.	158
62.	Trends of heavy metals in moss and trees. Information is sparse for the other toxic heavy metals, but these five are known to be on the increase in two environmental indicators (moss and tree rings). Zinc is shown in parts per 100,000.	159
63.	Lead concentrations in surface air as a function of time.	160
64.	Consumption of mercury and estimated discharge of mercury from the combustion of coal and oil. Estimates of mercury discharge by the combustion of coal and oil are based on 1 ppm mercury in oil and 2 ppm mercury in coal.	160
65.	Approximate cost of gas desulfurization plants in 1967 (amine or other types).	167
66.	Sulfur recovery plant irvestment.	168

Figure	Title	Page
67.	Deleted	172
68.	Total gaseous effluents for BWR, PWR, and HTGCR plants, 1967-1972.	190
69.	Gaseous effluents for BWR plants, 1967-1972.	191
70.	Gaseous effluents for PWR plants, 1967-1972.	192
71.	Estimated world inventory of tritium in the atmosphere and in surface waters.	193
72.	Estimated production of krypton-85 and tritium from the nuclear power industry of the Free World.	194
73.	Thermonuclear tritium in precipitation at continental and marine stations.	195
74.	Tritium injection following the 1962 thermonuclear detonations, corrected for decay to 1963.	196
75.	Natural radioactivity in soil and fly ash at Turkey Point and Widows Creek, 1967-1969.	208
76.	Ground level inventory of strontium-90 in late 1959.	209
77.	Total halogens and particulates for BWR, PWR, and HTGCR plants, 1967-1972.	210
78.	Halogens and particulates in BWR and PWR plants, 1967-1972.	211
79.	The variation with time of total stratospheric inventory of strontium-90 and carbon-14, with periods and yields (in Mtons) of nuclear explosives.	212
80.	Concentration of radioactive substances in the air mainly from nuclear weapons tests.	213
81.	Primary radiation processes contributing to the global heat budget.	220
82.	Earth heat balance.	221
83.	Sources and sinks of the global carbon monoxide cycle.	222
84.	Carbon dioxide produced by fossil-fuel combustion, 1950-1967.	223

Figure	Title	Page
85.	Carbon dioxide concentration in the atmosphere. Atmospheric concentration of carbon dioxide, observed since 1958 at Mauna Loa, Hawaii, has increased steadily. At present the increase averages about 1.5 ppm each year.	224
86.	Average temperature changes observed in the northern hemisphere together with estimates of heating effects due to carbon dioxide increase, and cooling effects due to volcanic dust.	225
87.	Global atmosphere thermal pollution effects. Thermal waste energy and carbon dioxide tend to increase global temperature. Particulates tend to decrease it. The net result is uncertain at this time.	225
88.	The uv, visible, and near ir spectrum.	233
89.	U.S. industry sales of home microwave ovens.	233
90.	Typical noise levels. Approximate relation between EPNdB scale and dB(A) scale is shown.	238
91.	Comparison of five surveys of outdoor noise levels in residential areas in the U.S. between 1937 and 1971.	239
92.	Sideline noise.	240
93.	Aircraft noise comparison.	240
94.	Estimated percent distribution of medical x-ray procedures by type of facility and supervision, U.S., 1964. The total number of procedures represented is 119 million.	247
95.	Estimated mean exposure per film for radiographic examinations of the abdomen by type of facility, U.S., 1964.	248
96.	Summary of estimated average whole-body radiation doses in the U.S.	249
97.	Estimated percentage distribution of genetically significant dose by type of medical roentgenologic examination, U.S., 1964. . . .	250
98.	Estimated annual x-ray experience of the population by number of persons, visits, examinations and procedures, and films or exposures, U.S., 1964.	251
99.	Estimated percentage distribution of genetically significant dose from diagnostic medical roentgenology by age and sex, U.S., 1964..	252
100.	Sources of oil spills in the ocean.	270
101.	Type, number, and percentage of the 269 tanker casualties. . . .	271

Figure	Title	Page
102.	Mercury cycle in the environment.	279
103.	Total tritium in liquid effluents for PWR, HTGCR, and BWR plants, 1967-1972.	284
104.	Tritium in liquid effluents for PWR plants, 1967-1972.	285
105.	Tritium in liquid effluents for BWR plants, 1967-1972.	286
106.	Estimates of future tritium concentration in Lake Michigan from nuclear reactor operation. These values are in addition to tritium from fallout and natural sources.	287
107.	Environmental tritium in surface waters.	288
108.	Mixed fission and corrosion products in liquid effluents, 1967-1972.	299
109.	Schematics of power plant operation. (a) Fossil Fuel. (b) Boiling water reactor. (c) Pressurized water reactor. . . .	300
110.	Light-water nuclear plant, waste-heat rejection by once-through cooling, 100% capacity factor.	301
111.	Light-water nuclear plant, waste-heat rejection by evaporative cooling, 100% capacity factor.	302
112.	Light-water nuclear plant, waste-heat rejection by cooling pond, 100% capacity factor.	303
113.	Light-water nuclear plant, waste-heat rejection by dry cooling, 100% capacity factor.	304
114.	Coal-fired power plant, waste-heat rejection by once-through cooling, 100% capacity factor.	305
115.	Coal-fired power plant, waste-heat rejection by evaporative cooling, 100% capacity factor.	306
116.	Coal-fired power plant, waste-heat rejection by cooling pond, 100% capacity factor.	307
117.	Coal-fired power plant, waste-heat rejection by dry cooling, 100% capacity factor.	308
118.	River cooling capacity vs projected requirements and utilization. Once-through cooling from rivers on a year-around basis falls far short of meeting the projected cooling requirements.	309
119.	Projected exponential growth in our use of water.	317

Figure	Title	Page
120.	The acidity of rain in the Finger Lakes Region of New York State and at the Hubbard Brook Experimental Forest in New Hampshire is illustrated by low pH values during 1970-1971 at three sites. Annual averages, weighted to take into account the amount of precipitation that fell, were as follows: Hubbard Brook (June to June): 4.03; Aurora (August to August): 3.91; Ithaca (August to August): 3.98. Values of pH below 5 indicate unusually strong acids in rain. Low values have been found in rain in Massachusetts and Connecticut, as well as in New York and New Hampshire. . . .	326
121.	Acidity of rainfall in the U.S. between March 15 and March 3, 1973. Heavy acidity occurs in substantially all rain that falls east of the Mississippi.	327
122.	Weighted annual concentrations of (a) NO_3^- and NH_4^+ and (b) SO_4^{2-} and the pH of precipitation at the Hubbard Experimental Forest in New Hampshire.	328
123.	The sources and disposition of high-level effluent in the nuclear fuel cycle for fission reactors.	346
124.	Savannah River high-level waste inventory.	347
125.	Idaho high-level waste inventory.	348
126.	High-level nuclear effluent.	349
127.	Average strontium-90 intake in New York City (pCi/d).	357
128.	Collapse of underground mines causes subsidence at the surface. .	360
129.	Subsidence from 1928 to August 1962 and location of selected bench marks at Long Beach Harbor area, California. (Lines of equal subsidence from Long Beach Harbor Department.)	361
130.	Areas of land subsidence in California. Major subsidence due to fluid withdrawal shown in black; subsidence in Delta caused by oxidation of peat.	362
131.	Trend in area disturbed annually by coal stripping.	375
132.	Land disturbed by surface mining by commodity, to 1965.	376
133.	Benefit-risk pattern for involuntary exposure.	404
134.	Risk comparison. Benefit-risk pattern for involuntary exposure. .	405
135.	Total U.S. coal mine deaths from accidents, 1907-1973.	412
136.	Total nonfatal injuries, U.S. coal mines, 1930-1973.	413

Figure	Title	Page
137.	Motor vehicle accidents, 1973. Between 1912 and 1973, motor vehicle deaths per 10,000 registered vehicles were reduced 85%, from 33 to about 5. (Mileage data were not available in 1912.) In 1912, there were 3100 fatalities when the number of registered vehicles totaled only 950,000. In 1973, there were 55,800 fatalities, but registrations soared to nearly 129 million. . . .	419
138.	Frequency of fatalities due to man-caused events.	428
139.	Frequency of fatalities due to natural events.	429
140.	Frequency of property damages due to natural and man-caused events.	430
141.	Vulnerable points of the nuclear fission fuel cycle. Stages of nuclear fuel cycle where routine radiation releases occur and where nonroutine releases or incidents could occur. Arrows indicate transportation links. U-uranium, UO_2 -uranium dioxide, U_3O_8 -uranium oxide, Pu-plutonium.	437
142.	Resources. The dollar is buying fewer goods and services because it is paying for more environmental control equipment, tankers, oil rigs, engineers, and pipelines to get the resources to make the goods and services.	441
143.	Declining net resources may be one of the principal forces driving world inflation.	442
144.	Projected capital investment in the U.S.	447
145.	Energy consumption per capita.	449
146.	Growth of U.S. energy consumption.	450
147.	Energy consumption vs growth patterns in the U.S.	451

List of Tables

Table	Title	Page
1.	Capital expenditures by the U.S. energy industries for the abatement of air and water emissions and other activities (new plant and equipment, 10^6 dollars).	6
2.	Capital expenditures by the U.S. energy industries for the abatement of air and water emissions and other activities (changes in production process, 10^5 dollars).	7
3.	Estimated total emission control expenditures by all U.S. industries (10^9 1973 dollars)	8
4.	Emissions to the atmosphere from various sources in the U.S. during 1971 (10^6 tons).	14
5.	Annual airborne releases from a coal gasification electricity system: 1000-MW(e) power plant, 3% sulfur coal, 75% load factor	15
6.	Annual airborne releases from an uncontrolled geothermal electricity system: 1000-MW power plant, 75% load factor . . .	16
7.	Annual airborne releases from a solar electricity system: 1000-MW power plant, 75% load factor	17
8.	Annual airborne releases from a fusion reactor electricity system: 1000-MW power plant, 75% load factor	17
9.	Annual airborne releases from a conventional nuclear reactor electricity system: 1000-MW light water power plant, 75% load factor	18
10.	Annual airborne releases from an uncontrolled coal-fired electricity system: 1000-MW power plant, 75% load factor . . .	19
11.	Annual airborne releases from an uncontrolled oil-fired electricity system: 1000-MW power plant, 75% load factor . . .	20
12.	Annual airborne releases from an uncontrolled gas-fired electricity system: 1000-MW power plant, 75% load factor . . .	21
13.	U.S. emission trends, total emissions to the atmosphere, 1940-1970 (10^6 tons/y)	22
14.	U.S. emission trends, rates of change (%)	23
15.	Annual airborne releases control costs from a coal-fired electricity system: 1000-MW power plant, 75% load factor . . .	24
16.	Annual airborne releases control costs from an oil-fired electricity system: 1000-MW power plant, 75% load factor . . .	25

Table	Title	Page
17.	Annual airborne releases control costs from a gas-fired electricity system: 1000-MW power plant, 75% load factor . . .	26
18.	Annual airborne releases control costs from a nuclear reactor electricity system: 1000-MW light water power plant, 75% load factor	27
19.	Capital expenditures by the U.S. industries for control of air emissions	28
20.	Capital expenditures by the U.S. industries for control of air emissions	29
21.	Estimated global carbon monoxide production by man-made and natural activities (10^8 tons/y)	34
22.	Nationwide quantity of carbon monoxide emissions from various sources, 1972.	35
23.	Costs of control, light-duty vehicles	36
24.	Costs of control, heavy-duty vehicles	37
25.	Nationwide emissions of nitrogen oxide, 1972 (10^6 tons).	45
26.	Estimated nitrogen oxide production from nuclear tests	46
27.	Nationwide estimates of nitrogen oxides emissions, 1940-1972 (10^6 tons/y)	47
28.	Combustion modification control costs in public utility boilers.	48
29.	Estimated control costs and reduction of NO_x emissions, for a 1000-MW boiler used 6120 h/y by selected methods and by ton	49
30.	Estimated costs of catalytic reduction for three control systems	50
31.	Main reservoirs of sulfur	68
32.	Global sulfur dioxide pollutant emissions (10^6 tons)	68
33.	Quantity of nationwide sulfur oxides emissions, 1972	69
34.	Sulfur oxides: rates of change in estimated weight of total nationwide emissions for selected stationary source categories (%/y)	69
35.	Sulfur dioxide: estimated total nationwide emissions (10^6 tons)	69

Table	Title	Page
36.	Costs of long-term options	70
37.	Estimated costs of flue-gas treatment	71
38.	Summary of sulfur dioxide control process systems	72
39.	Estimated capital and annual cost of meeting ambient sulfur dioxide standards at TVA coal-fired plants	73
40.	Estimated capital and annual cost of adding SO ₂ removal systems on all TVA coal-fired plants	74
41.	Costs of near-term options	75
42.	Cost of alternative sulfur dioxide control strategies (NERA Study)	76
43.	Nationwide particulate emissions, 1972 (10 ⁶ tons)	98
44.	Summary of estimates of man-made emissions of primary particulates (10 ⁶ metric tons/y)	99
45.	Typical composition of particulate matter in Los Angeles smog. .	100
46.	Source contributions to Pasadena aerosol, September 3, 1969. . .	102
47.	Estimated benzo(a) pyrene emissions in the U.S., 1968	103
48.	Total suspended particulates: estimated total nationwide emissions (10 ⁶ tons/y)	104
49.	Percent frequencies of visibilities in the range 0-6 mi after excluding hours with rain and hours with relative humidities exceeding 69% for the periods June-September 1962-1965 and June-September 1966-1969. The trend is of deteriorating visibility	105
50.	Costs of specific disposal systems	106
51.	Total installation cost for various types of control devices expressed as a percentage of purchase costs	107
52.	Installed costs of control equipment	108
53.	Sources of Atmospheric methane	138
54.	Nationwide emissions of man-made hydrocarbons, 1972 (10 ⁶ tons/y)	139
55.	Methane concentration in geothermal fluids	139
56.	Hydrocarbon emissions from industrial process losses, 1940-1970 (10 ³ tons/y)	140

Table	Title	Page
57.	Trace metals most abundantly found in the atmosphere primarily from the production or consumption of energy	147
58.	Impact and emission tabulation for the coal fuel cycle data and estimates for the year 1970	148
59.	Amounts of elements mobilized into the atmosphere as a result of weathering processes and the combustion of fossil fuels (ppm)	150
60.	Emission sources of lead	151
61.	Trace metals in soils and plant materials around a power plant	152
62.	Total mercury concentrations in four Greenland glacial ices. . .	153
63.	Sources of hydrogen sulfide emissions in coke plants	164
64.	Deleted	165
65.	Hydrogen sulfide content of coke-oven gas	165
66.	Total hemispheric hydrogen sulfide emissions (10^6 tons)	166
67.	Amount of water vapor associated with geothermal systems (vol%)	171
68.	Natural tritium distribution	179
69.	Gaseous radioactive wastes from U.S. atomic energy plants . . .	179
70.	Gaseous emissions from the uranium fuel cycle	180
71.	Radioiodine releases for 1000-MW(e) plant extrapolated from 1971 reported releases	181
72.	Volume of air required to meet concentration standards and average site boundary concentrations for yearly emission from a 1000-MW(e) power station (operated as a base-load plant, with an 80% availability)	182
73.	Principal radionuclides induced in air by a nuclear explosion	183
74.	Initial radioactivity from some radionuclides of greatest environmental concern (in kCi) for various sizes and types of detonations. A, fission-product activity; B, induced activity in igneous rock	184

Table	Title	Page
75.	Relative percentage of total estimated dose from man-made radionuclides in nuclear-stimulated natural gas	185
76.	Comparison of radioactivity in Gasbuggy and Rulison	185
77.	Radiological aspects of copper production using nuclear mining techniques	186
78.	Field gamma radiometry of hot-spring areas in northern Nevada and northern California	187
79.	Production of fission-product tritium in the free-world nuclear power economy	188
80.	Nuclear weapons yield in energy released and tritium production in kg from 1945 to 1962	189
81.	Plutonium aerosol airborne under stated conditions at Battelle Northwest laboratories	204
82.	Rocky Flats plutonium releases	205
83.	Radium and thorium radionuclides in residual fuel oil ash	205
84.	Relative volatilities in steam of potentially volatile gamma emitters produced by a total of 1 Mton of fission explosives in igneous rock, after 180 d	206
85.	Potentially volatile radioactive nuclides present 180 d after a 1000-kton nuclear explosion in igneous rock	207
86.	Number of workers exposed to ultraviolet radiation (estimate from Chicago Metropolitan Survey extrapolated to U.S. population)	231
87.	Laser characteristics	232
88.	Estimated mean exposure per film by type of radiographic examination, U.S., 1964	245
89.	Estimated mean exposure per dental film by type of examination, U.S., 1964	246
90.	Annual water effluent from a conventional nuclear electricity system: 1000-MW LWR reactor, 75% load factor	259
91.	Annual water effluents from an uncontrolled coal-fired electricity system: 1000-MW power plant, 75% load factor	260
92.	Annual water effluent from an uncontrolled oil-fired electricity system: 1000-MW power plant, 75% load factor	261

Table	Title	Page
93.	Annual water effluent from an uncontrolled gas-fired electricity system: 1000-MW power plant, 75% load factor. . . .	262
94.	Annual water effluents from a geothermal steam electric plant: 1000-MW(e) power plant, 75% load factor	263
95.	Annual water effluent from a solar electricity system: 1000-MW power plant, 75% load factor	263
96.	Annual water effluent from a coal gasification electricity system: 1000-MW power plant, 3% sulfur coal, 75% load factor. .	264
97.	Annual water effluent from a fusion reactor electricity system: 1000-MW power plant, 75% load factor	265
98.	Capital expenditures by U.S. industries for control of water quality	266
99.	Capital expenditures by U.S. industries for control of water quality	267
100.	Estimated annual oil discharges into the oceans, all sources . .	268
101.	Oil spill statistics (bbl)	268
102.	Oil spill incidents by general area, 1970 and 1971	269
103.	Cost and effectiveness of some techniques for controlling acid mine drainage	274
104.	Trace metals in water from various energy sources that may pose health hazards to man	278
105.	Annual tritium release in liquid effluents from various nuclear electricity systems: 1000-MW delivery system, 100% capacity factor	283
106.	Annual radioactivity release in liquid effluents from various nuclear electricity delivery systems: 1: 70-MW(e) delivery system, 100% capacity factor	295
107.	River cooling capacity vs projected requirements and utilization	296
108.	Cost of cooling systems for 800-MW power stations burning fossil and nuclear fuel (10^6 1970 dollars)	297
109.	Types of cooling systems and estimated cooling costs (1970 dollars)	298
110.	Typical water consumption for recovering oil from oil shale by various recovery methods (10^6 bbl/d)	311

Table	Title	Page
111.	Typical water consumption for a 50,000 bbl/d oil-shale plant	312
112.	Water requirements for coal conversion processes	313
113.	Water use by cooling towers serving 1000 MW(e) fossil and nuclear plants, based on heat rejection rates of 4500 Btu/kWh and 6750 Btu/kWh, respectively	315
114.	Annual water use by various 1000-MW electrical energy delivery systems (gal): 100% load factor	316
115.	Land use in the U.S. for energy activities	321
116.	Annual land use by various 1000-MW electrical energy delivery systems (acres): 100% load factor	322
117.	Land use requirements for oil-shale processing	323
118.	Annual solid effluent from an oil-fired electricity system: 1000-MW power plant, 75% load factor	332
119.	Annual solid effluent from a coal-fired electricity system: 1000-MW power plant, 75% load factor	333
120.	Annual solid effluent from a gas-fired electricity system: 1000-MW power plant, 75% load factor	334
121.	Annual solid effluents from a coal gasification electricity system: 1000-MW(e) power plant, 3% sulfur coal, 75% load factor	335
122.	Annual solid effluent from a solar electricity system: 1000-MW power plant, 75% load factor	336
123.	Annual solid effluent from a fusion reactor electricity system: 1000-MW power plant, 75% load factor.	336
124.	Annual solid effluent from a conventional nuclear electricity system: 1000-MW light water reactor, 75% load factor	337
125.	Annual gaseous effluents from a geothermal steam electric plant: 1000-MW(e) power plant, 75% load factor	338
126.	Estimated schedule of oil-shale development and spent shale ash produced for disposal.	339
127.	Cost of separating and recycling actinides in effluent from a light water reactor. The three cost categories represent 1.1, 1.5, and 2.0 times the current light water reactors reprocessing costs	343

Table	Title	Page
128.	Cost of separating strontium, cesium, and actinides and recycling actinides. The cost of recycling actinides is the light-water-reactor estimate	343
129.	Cost range for management of high-level effluent from LWR fuels	344
130.	Summary of effluent disposal costs	345
131.	The overall average U.S. doses from natural radiation	355
132.	Estimated average U.S. doses from fallout (mrem/capita/y)	356
133.	Projected disturbed acreage of the surface mining of coal in the year 2000 (10^6 tons)	368
134.	Cumulative land required to provide fuels for electrical generation	369
135.	Typical solid waste disposal represented by various methods of recovery oil from oil shale (10^6 bbl/d)	370
136.	Summary of estimated acreage and cost data for a basic reclamation program	371
137.	Summary of estimated acreage and cost data for a limited basic reclamation program	372
138.	Summary of estimated acreage and cost data, by land use, for a rehabilitation program	373
139.	1964 costs attributable to reclamation of surface-mined land in the U.S.	374
140.	Land requirements for power-plant sites	383
141.	Potential sites off New Jersey and California for shallow-water concepts	384
142.	Overall acceptability	385
143.	Bus-bar costs	386
144.	Some fuel resources and consumption rates (measured in 10^{12} GJ = 10^{21} J = 0.948×10^{18} Btu ≈ 0.95 Q)	389
145.	Resource requirements for a hydroelectric system: 1000 MW(e) delivered energy	390
146.	Resource requirements for a light water nuclear reactor system: 1000 MW(e) delivered energy	391

Table	Title	Page
147.	Resource requirements for a geothermal steam electric system: 1000 MW(e) delivered energy	392
148.	Resource requirements for a coal gasification electric system: 1000 MW(e) delivered energy	393
149.	Resource requirements for an oil shale electric system: 1000 MW(e) delivered energy	394
150.	Resource requirements for a coal-fired electric system: 1000 MW(e) delivered energy	395
151.	Ore requirements to produce 1974 U.S. electricity by various processes [200,000 MW(e)-y at assumed 40% efficiency, that is, 500,000 MW(t)-y]	398
152.	Materials requirements for 10^6 MW(e) of fusion generating capacity	399
153.	Nonfuel ore requirement for projected CTR's from 2000 to 2020	400
154.	Estimated health effects in 1975 associated with production of electric power	403
155.	Annual social costs from a conventional coal-fired electricity system: 1000-MW power plant, 75% load factor	408
156.	Comparison of coal and uranium mining accident rates	409
157.	Uranium mining accident data	410
158.	Annual social costs from a conventional nuclear electricity system: 1000-MW power plant, 75% load factor	411
159.	Selected railroad statistics for 1970	416
160.	Fatality, injury, and severity rates for freight trains	417
161.	Civil aviation accident deaths and death rates, 1933 to 1973 . .	418
162.	Occupational injury rates in the oil and natural gas industries.	421
163.	Annual social costs from a conventional oil-fired electricity system: 1000-MW power plant, 75% load factor	422
164.	Annual social costs from a conventional gas-fired electricity system: 1000-MW power plant, 75% load factor	423
165.	Typical reactor problems in the past decade	426

Table	Title	Page
166.	Magnitude of latent health effects expected in a 20-y period for an accident that produces 100 fatalities	427
167.	Total masses of material that contain one fast critical mass of material, if separated from other materials and converted to metal (total mass in kg)	434
168.	Damage radii for various effects of nuclear explosions as functions of yield	435
169.	Fuel-cycle materials rank ordered by increasing weights required to yield one critical mass of fission explosive material, in metallic form, without uranium enrichment	436
170.	Financial requirements of importing metals to supply projected CTR capacity in the period 2000-2020	440
171.	Estimated capital requirements for the energy industry	445
172.	Net benefit of breeder reactor to nation	446

Acronym Glossary

AQCR	Air Quality Control Region
AQS	Air quality standards
BaP	Benzo(a) pyrene
BOD	Biological oxygen demand
BSO	Benzene-soluble organics
BWR	Boiling water reactor
CAMP	Continuous Air Monitoring Program
CIPP	Changes in production processes
CTR	Controlled thermonuclear reactors
DOB	Depth of burial
GSD	Genetically significant dose
HTGR	High-temperature gas-cooled reactor
LASL	Los Alamos Scientific Laboratory
LMFBR	Liquid-metal fast-breeder reactor
LWR	Light-water reactor
(MPC) _a	Maximum permissible concentration, air
(MPC) _w	Maximum permissible concentration, water
NAAQS	National Ambient Air Quality Standards
NADB	National Aerometer Data Bank
NASN	National Air Sampling Network
NTS	Nevada Test Site
OCS	Outer continental shelf
PAN	Peroxacetyl nitrate
PWR	Pressurized water reactor
SDOB	Scaled depth of burial
SNAP	Space Nuclear Auxiliary Power
TEL	Tetraethyl lead
TSP	Total suspended particulate

ENVIRONMENTAL EFFECTS OF ENERGY PRODUCTION AND UTILIZATION IN THE U.S. VOLUME I: SOURCES, TRENDS, AND COSTS OF CONTROL

Section I Environmental Quality

SOURCES

Scientific attempts to measure the effect of our energy activities on the natural environment are only very recent. We are certainly not able, at this time, to come to any final conclusion about the earth's capacity to absorb energy-generated environmental effects.

We can, however, make four basic points that illustrate how difficult it will be to understand and control the future state of our ecological system .

1. We have almost no knowledge about where the upper limits might be to emission growth curves.
2. The presence of natural delays in ecological processes increases the probability of underestimating the control measures necessary and therefore increases the probability of inadvertently reaching those upper limits.
3. Many energy-generated emissions are globally distributed; their effects may appear long distances from their points of generation.
4. Difficult tradeoffs will have to be made between energy generation, consumption, and emissions cleanup because of the earth's finiteness.

TRENDS

Effects on the Atmosphere

During 1974, as a result of the Arab oil boycott, the primary concern in this country became the interrelationship between the pursuit of clean air and the provision of energy. In some respects the energy crisis was supportive of improved air quality; in other cases the two goals conflicted.

For the longer term, the Arab boycott made clear that the U.S. must move towards the capability of self-sufficiency in energy. This capability, in turn, would require greater future use of coal with both low and high sulfur content. The policy problem was to permit increased use of coal without violating ambient-air-quality standards.

The adequacy of flue-gas desulfurization systems, known as stack-gas scrubbers, is one point of controversy. This technology permits high- or medium-sulfur fuels to be burned, with removal of the sulfur after combustion but before emission to the atmosphere. A large fraction of the U.S. utility industry, however, holds that scrubber technology is not sufficiently developed and is resisting a commitment to this technology.

Tests of prototype vehicles indicate that 1975 cars can be expected to have better fuel economy than 1974 models because of the use of catalytic converters as a means of controlling hydrocarbon and carbon monoxide emissions.

Improvements in the nation's urban air quality have been achieved in recent years. Occurrences of poor air quality are still commonly observed, however, and worsening trends have been noted in some areas.

Effects on Rivers and Lakes

An analysis of the individual discharges in Region IV (Atlanta) shows not only that the major portion of the industrial water pollution problem is concentrated in a few industries, but also that it is concentrated in a few large plants.

Effects on the World Oceans

The oceans, in contrast to the land masses of our globe, are truly international. No nation exercises sovereignty over them, and no nation, acting alone, can protect them from environmental insults.

As early as 1962 the international community set an ultimate goal of eliminating all intentional discharges of oil into the oceans. But approximately 1.5×10^6 metric tons of oil continues to enter the oceans from bilge pumping, tank cleaning, and ballast discharges. About 250,000 metric tons enter the oceans from vessel accidents.

As nations develop stronger controls on energy-generated air and water discharges, there is concern that wastes formerly discharged into the air and

water might be dumped into the ocean. The U.N. General Assembly in 1970 called for a Law of the Sea conference to stabilize international rules governing national rights in the ocean and, particularly, to establish a regime for mineral exploration and exploitation of the seabeds. Substantive negotiations began in Santiago, Chile, in the spring of 1974.

Land Use

Besides reclamation of land use in mining, the major challenges in land use continue to be associated with the care of wastes from conversion operations. These vary widely and include the disposal of radioactive wastes from fuel reprocessing plants, wastes from sulfur dioxide removal systems, refuse from coal cleaning at mines, and brine from geothermal resources.

At present the requirement for land by energy activities can be reasonably well met from existing land resources. The increase in demand for land by a specific user is usually satisfied by buying land from users who value it less or from buying surplus land. By the year 2000, however, it is expected that there may be a deficit for certain land uses that cannot be made up from surplus land, and there will be a decrease in uses that place a lower value on land.

COSTS OF CONTROL

Environmental expenditures by the U.S. petroleum industry during the period 1966-1973 amounted to \$5.5 billion (Fig. 1). The funds expended on air, water, land, and other conservation programs rose from \$271 million in 1966 to \$1.2 billion in 1973 -- better than a fourfold increase. The \$1.2-billion expenditure represents an outlay of more than \$5 for every man, woman, and child in the U.S.

Of the 1973 total, \$737 million was expended on air conservation, \$402 million on water conservation, and \$100 million on land and other conservation programs. Capital expenditures for conservation during 1973 amounted to \$682 million. This represented some 12.7% of the petroleum industry's total domestic capital outlays in 1973.

The nation's funding for control and abatement of radiation and noise is summarized below:

Emission	1973 actual	1974 estimate	1975 estimate
Radiation	\$181 million	\$192 million	\$236 million
Noise	\$ 66 million	\$ 88 million	\$62 million

Overall, the nation's energy industries invested an estimated \$2.7 billion in 1973 for plant and equipment to abate air and water pollution. Two industries, electric utilities and petroleum, accounted for \$2.0 billion, or 74% of the total. (Table 1.)

Energy industries were planning to spend \$3.5 billion for air and water pollution in 1974 with most of the expenditures borne by the following industries: electric utilities, \$1.651 billion; petroleum, \$926 million. The amount spent in 1973 by the nation's energy industries for changes in production processes (CIPP) that result in air and water emission reduction was an estimated \$737 million. Two industries, electric utilities and petroleum, accounted for \$523 million, or 71% of the total. Of the \$3.5 billion in environmental control expenditures planned for 1974, \$797 million, or 23% are for CIPP. (Table 2.)

Projected outlays for environmental control in 1980 total \$45.7 billion in 1969 dollars, 55% related to energy activities. The electric utility industry is expected to increase investments in air and water emission control from \$1.6 billion in 1974 to \$2.9 billion in 1975, \$2.4 billion in 1976, and \$1.6 billion in 1977. The petroleum industry investment in emission control is estimated at \$302 million by 1976, with an additional \$218 million in 1977 and an additional \$109 million in 1978. (Table 3.)

The U.S. oil industry spent \$100 million on land and other conservation programs during 1973 and \$352 million during the period 1966-1973. The nation's total federal funding for emissions control of land during the period 1973-1975 was:

1973 \$61 million (actual)
1974 \$62 million (estimated)
1975 \$66 million (estimated)

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Table 1. Capital expenditures by the U.S. energy industries for the abatement of air and water emissions and other activities (new plant and equipment, 10⁶ dollars).*

Industry	1973				1974 (estimated)			
	Total	Emission abatement			Total	Emission abatement		
		Total	Air	Water		Total	Air	Water
All Industries	100,076	4,938	3,176	1,762	112,114	6,542	4,346	2,196
All energy industries	76,918	2,719	1,671	1,048	85,322	3,513	2,268	1,245
<u>Manufacturing</u>	14,845	934	544	390	17,612	1,414	849	565
<u>Durable goods</u>								
Electrical machinery	2,895	129	44	85	3,179	175	53	122
Machinery, except electrical	3,478	80	52	28	3,975	118	74	44
Transportation equipment								
Motor vehicles	2,244	143	81	62	2,687	178	103	75
Aircraft	531	21	11	10	580	13	7	6
Other	288	6	4	2	308	4	2	2
<u>Nondurable goods</u>								
Petroleum	5,409	555	352	203	6,888	926	610	316
<u>Nonmanufacturing</u>	62,073	1,785	1,127	658	67,710	2,095	1,419	680
Mining	2,759	91	41	50	3,143	100	53	47
Railroad	1,939	16	5	11	2,272	19	3	16
Air transportation	2,413	16	12	4	2,160	9	4	5
Other transportation	1,605	11	6	5	1,617	17	10	7
Public utilities								
Electric	16,250	1,409	906	503	18,808	1,651	1,160	491
Gas and other	2,837	42	15	27	3,355	46	19	27
Communication, finance, service, construction and other	34,270	200	142	58	36,355	257	170	87

*[Data abstracted from U.S. Department of Commerce, Bureau of Economic Analysis; see also Council on Environmental Quality, Environmental Quality, 5th Annual Report, USGPO, Washington DC (1974).]

Table 2. Capital expenditures by the U.S. energy industries for the abatement of air and water emissions and other activities (changes in production process, 10⁶ dollars).*

Industry	1973			1974 (planned)		
	Total	Air	Water	Total	Air	Water
All Industries	1169	724	444	1465	1003	462
All energy industries	737	452	285	797	514	283
<u>Manufacturing</u>	279	172	107	373	230	143
<u>Durable goods</u>						
Electrical machinery	35	14	21	46	16	30
Machinery, except electrical	36	24	12	42	27	15
Transportation equipment						
Motor vehicles	35	19	16	29	17	12
Aircraft	0	0	0	0	0	0
Other	2	1	1	0	0	0
<u>Nondurable goods</u>						
Petroleum	151	94	57	239	153	86
<u>Nonmanufacturing</u>	458	280	178	424	284	140
Mining	20	15	5	28	22	6
Railroad	5	3	2	4	2	2
Air transportation	2	2	0	0	0	0
Other transportation	4	3	1	5	3	2
Public utilities						
Electric	372	223	149	296	198	98
Gas and other	14	3	11	11	2	9
Communication, finance, service, construction and other	41	31	10	80	57	23

*[Data abstracted from U.S. Department of Commerce, Bureau of Economic Analysis; see also Council on Environmental Quality, Environmental Quality, 5th Annual Report, USGPO, Washington, DC (1974).]

Table 3. Estimated total emission control expenditures by all U.S. industries (10⁹ 1973 dollars).*

Pollutant/medium	1973			1982			Cumulative, 1973-1982		
	O&M ^a	Capital costs ^b	Total annual costs ^c	O&M ^a	Capital costs ^b	Total annual costs ^c	Capital investment	O&M ^a	Total annual costs ^c
Air pollution									
Public	0.1	0.1	0.2	0.5	0.2	0.7	1.7	3.8	5.4
Private									
Mobile	1.2	0.2	1.4	8.4	4.9	13.3	31.3	49.9	74.4
Stationary	1.1	1.1	2.2	4.7	3.1	7.9	21.4	35.3	62.6
Total	2.4	1.4	3.8	13.6	8.2	21.9	54.4	89.0	142.4
Water pollution									
Public									
Federal	0.2	NA	NA	0.2	NA	NA	1.8	NA	NA
State and local	1.4	4.1	5.4	4.2	8.3	12.5	50.6	27.4	88.5
Private									
Industrial	0.9	1.1	2.0	2.8	2.2	5.0	16.5	21.6	40.4
Utilities	NA	NA	0.01	0.4	0.3	0.7	4.4	2.2	3.5
Total	2.5	5.2	7.4	7.6	10.8	18.2	73.3	51.2	132.4
Noise	NA	0.1	NA	NA	1.0-1.4	NA	6.0-8.7	NA	NA
Radiation									
Nuclear power plants	NA	NA	NA	<0.05	0.05	0.07	0.3	0.08	0.3
Solid waste									
Public	1.1	0.3	1.4	1.9	0.5	2.4	4.2	15.5	19.3
Private	1.9	<0.05	1.9	3.0	0.1	3.1	0.4	25.2	25.6
Total	3.0	0.3	3.3	4.9	0.6	5.5	4.6	40.7	44.9
Land reclamation									
Surface mining ^d	0.3	0	0.3	0.6	0	0.6	0	5.0	5.0
Grand total ^e	8.2	6.9	14.8	26.7	19.7	46.3	132.6	185.9	325.0

^aOperating and maintenance costs.

^bInterest and depreciation.

^cO&M plus capital costs.

^dIncludes only coal mining.

^eDoes not include noise control.

*[J. Air Poll. Cont. Assoc. 25, 190 (1975).]

Fig. 1. Total environmental expenditures in the petroleum industry, 1966-1973. [J. Air Poll. Cont. Assoc. 25, 52 (1975).]

Section II

Effects on the Atmosphere

SUMMARY

Sources

The major air contaminant for most large urban areas in the U.S. continues to be photochemical oxidants caused by atmospheric reactions of hydrocarbons and oxides of nitrogen in sunlight. Carbon monoxide and suspended particulate matter also continues to cause concern. Problems caused by other emissions such as lead, nitrogen dioxide, and sulfur dioxide are not as severe.

Emissions from motor vehicles account for the greatest portions of hydrocarbon, oxides of nitrogen, and carbon monoxide emissions. Industry and agriculture are responsible for most of the man-made particulate matter in the atmosphere.

1971 and 1972 data from air monitoring sites show that the trend in air quality improvement noted in 1970, and as far back as data can be found, has continued. Although emissions are undesirable anywhere, emission control does not appear, today, to be essential in large areas of the nation on the basis of either essentially aesthetic or health considerations.

Transportation emissions showed a drop in hydrocarbons (from 15.2 to 14.7×10^6 tons) and carbon monoxide (from 78.1 to 77.5×10^6 tons) in 1973. Overall, natural production of hydrocarbons, carbon monoxide, and perhaps nitrogen oxides, far exceeds that from man-made sources. In view of the costs to the nation, in dollars or in fuel consumption, of early implementation of the 1975-1976 standards, attention seems warranted to the possibilities of temporarily enforcing the established emissions standards only in those specific urban areas where air quality is known to be adversely affected by automotive emissions, reserving national implementation for the day when they are available reliable, relatively inexpensive emission-control systems that exact no fuel penalty.

Of the 10 largest cities in the U.S., 6 have shown a general trend toward improved levels of particulates and 7 have shown a similar improving trend for sulfur dioxide in 1973. (Tables 4-12 and Figs. 2-3.)

TRENDS, 1973

The general picture of nationwide trends in emission concentrations is downward, corresponding to improved air quality for most regions in 1973. This has been a continuing trend traced as far back as data can be found.

The primary annual suspended particulate standard was exceeded by only about 25% (341 of 1300) of the high-volume stations reporting a full year's data in 1973. These 341 stations represent well over 50% (99 out of 172) of the Air Quality Control Regions (AQCR's) reporting any yearly particulate data.

The 24-h suspended particulate standard was exceeded by less than 10% of the total stations reporting as little as one quarter's data (303 out of 3380). But those 303 stations are distributed among almost 50% of the nation's AQCR's (115 out of 247).

The annual sulfur dioxide standard was exceeded by only 3% of the stations reporting annual means (14 out of 457), representing 10 of the 100 AQCR's contributing such data. Similarly, the 24-h sulfur dioxide standard was exceeded at approximately 3% of the total stations reporting as little as one quarter's data (59 out of 1623), representing 20 AQCR's. The sulfur dioxide downward trend appears to be leveling off, which is not surprising considering that most reporting stations are now below the standards.

Carbon monoxide was reported from 212 stations in 60 AQCR's: 24 stations representing 10 AQCR's exceeded the 1-h standard, and 153 stations representing 53 AQCR's exceeded the 8-h standard. Carbon monoxide data are quite limited, but the declining percentage of 8-h averages exceeding the 8-h standard indicates an improvement.

The 1-h total oxidant/ozone standard was exceeded at 163 of the 187 stations reporting at least one quarter's data, covering 52 of the 57 AQCR's submitting such data. The majority of oxidant data is supplied by California, and it exhibits a downward trend in evident response to reduced automotive emissions.

Analyses of the benzene-soluble organic fraction of suspended particulate samples and of the specific organic constituent benzo(a) pyrene show distinct decreases in their concentrations over the period 1960-1970. Both are considered to originate chiefly from human activities. A steady shift in coal use from relatively inefficient residential space-heating units to large, more efficient power plants is suggested as a possible major factor contributing to these observed decreases. (Tables 13 and 14.)

Many factors can influence year-to-year fluctuations in trend lines. Weather changes are an important factor. Other factors are population growth, the addition of new sources of emissions, the effect of changes in air pollution control programs, changes in methods of measurement, and changes in the location and number of air monitoring stations.

COSTS OF CONTROL, 1973

In 1973 the U.S. petroleum industry spent \$737 million on air conservation, or 61% of the total budget on environmental expenditures. Overall, the nation's energy industries invested an estimated \$1.7 billion in 1973 for plant and equipment to abate air emissions. Two industries, electric utilities and petroleum, accounted for \$1.3 billion, 76% of the total.

The energy industries are planning to spend \$2.3 billion for environmental controls in 1974 with most of the expenditures borne by the following industries: electric utilities, \$1.2 billion; petroleum, \$610 million.

The amount spent in 1973 by the nation's energy industries for CIPP that results in air emission reduction was an estimated \$452 million. Two industries, electric utilities and petroleum, accounted for \$317 million, or 70% of the total.

Of the \$2.3 billion in control expenditures planned for 1974, \$514 million, or 22%, were for CIPP.

New car owners will be paying \$300 per car for required emission-control equipment by 1976-1977. Because automobile contractors assume a substantial increase in imports of sub-subcompact cars, the U.S. balance of payments is expected to be adversely affected by the increased automobile costs associated with control equipment. The annual net exports of goods and services of the U.S. are expected to be reduced by a maximum of \$700 million in 1980.

While some effort has been made to balance control costs vs damage costs, estimates indicate that in 1977 mobile sources will account for 68% of the control costs but only 10% of the reduced damages. This data may reflect haste in conceiving present control standards.

Energy-related research and development will account for nearly half the emission control and abatement research and development spending, or about 19.5% of the 1975 total. In 1974 energy-related programs accounted for only 3.1% of the total environmental research and development spending. (Tables 15-18.)

Projected outlays for environmental control in 1980 are estimated to be \$11.6 billion, or 25% of the total, with 55% related to energy activities. It has been estimated that environmental measures will increase U.S. petroleum imports in 1975 by some 4×10^6 bbl/d. Assuming an average value of \$11/bbl, this increase in imports would reduce our trade balance by some \$16 billion in 1975. The 4×10^6 bbl figure includes 2.2×10^6 bbl of increased oil demand resulting from automotive emission controls (0.6×10^6), delay in obtaining natural gas from Alaska (0.7×10^6), and replacement of coal with oil to meet sulfur emission standards (0.9×10^6). The other 1.8×10^6 bbl/d increase in oil imports results from a reduction in domestic oil supply, stemming primarily from the Alaskan delay (1.4×10^6) and offshore drilling delays (0.4×10^6). (Tables 19 and 20.)

References - Effects on the Atmosphere (Summary)

Air/Water Pollution Report 12, 463 (1973).

Air/Water Pollution Report 12, 493 (1974).

Environmental Protection Agency, The Economics of Clean Air, Senate Document No. 92-67, USGPO, Washington, DC (1972), pp. 1-14.

1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974).

Table 4. Emissions to the atmosphere from various sources in the U.S. during 1971 (10⁶ tons).*

Source	CO	Partic- ulates	SO _x	HC	NO _x	Totals
Transportation	77.4	0.8	0.6	16.2	8.6	103.6
Stationary fuel combustion	0.3	3.7	18.4	0.2	6.3	28.9
Industrial processes	17.5	9.3	6.8	6.5	2.9	43.0
Solid waste disposal	11.2	1.9	0.2	4.5	0.4	18.2
Miscellaneous combustion	0.9	4.1	7.2	0.4	6.4	19.0
Total	107.3	19.8	33.2	27.8	24.6	212.7

*[1972 National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Table 5. Annual airborne releases from a coal gasification electricity system: 1000-MW(e) power plant, 32 sulfur coal, 75% load factor.*

System process	Effluent type																	
	CO (tons)	CO ₂ (tons)	CH ₄ (tons)	H ₂ (tons)	H ₂ O ₂ (tons)	H ₂ S (tons)	N ₂ (tons)	Ar (tons)	Fly ash (tons)	MgO+CaCO ₃ MgO+CaS (tons)	SO ₂ (tons)	Humidified air		Drift		Flow gas (10 ³)	SO ₂ (tons)	Remarks
												H ₂ O (tons)	Waste heat (kWh)	gal/min	Dissolved solids (tons)			
Extraction	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Same as coal-elec. system
Process	416	10.1	4.1	14.6	4.1	8.7	651	11.2	38	1610	510	--	--	--	--	--	--	--
Transport	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Same as coal-elec. system
Conversion	--	--	--	--	--	--	--	--	--	--	10	$1.01 \cdot 10^7$	$1.0 \cdot 10^{10}$	216	215	$2.4 \cdot 10^{12}$	$9.9 \cdot 10^1$	--
Transmission	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	416	10.1	4.1	14.6	4.1	8.7	651	11.2	38	1610	510	$1.01 \cdot 10^7$	$1.0 \cdot 10^{10}$	216	215	$2.4 \cdot 10^{12}$	$9.9 \cdot 10^1$	--

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley CA, Rept. No. EEED 103 (December 1974), p. 161.]

Table 6. Annual airborne releases from an uncontrolled geothermal electricity system: 1000-MW power plant, 75% load factor.*

System process	Environmental impact (tons)		
	Total airborne release (tons)	Effluent type	
		H ₂ S	Other
Exploration	NA	NA	NA
Extraction	18×10^6	17.7	0.3
Processing	Nil	0	
Transport	Nil	0	
Conversion	Nil	0	
Transmission	0	0	
Total	18×10^6	17.7	0.3

*[Council of Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973); Environmental Quality, 4th Annual Report, USGPO, Washington, DC (1973).]

Table 7. Annual airborne releases from a solar electricity system: 1000-MW power plant, 75% load factor.*

System process	Effluent heat			
	Drift		Humidified air (tons of H ₂ O)	Waste heat (kWh)
	gal/min	Tons		
Extraction	0	0	0	0
Processing	0	0	0	0
Transport	0	0	0	0
Conversion	2070	2063	9.86×10^8	79.9×10^9
Transmission	0	0	0	0
Total	2070	2063	9.86×10^8	79.9×10^9

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley CA, Rept. No. EEED 103 (December 1974), p. 207.]

Table 8. Annual airborne releases from a fusion reactor electricity system: 1000-MW power plant, 75% load factor.*

System process	Effluent type					
	H ₂ S (tons)	Tritium (Ci)	Drift		Humidified air (tons of H ₂ O)	Waste heat (kWh)
			gal/min	tons		
Extraction	0	0	0	0	0	0
Processing	3	2100	0	0	0	0
Transport	0	0	0	0	0	0
Conversion	0	0	158	159	7.58×10^6	6.11×10^9
Transmission	0	0	0	0	0	0
Total	3	2100	158	159	7.58×10^6	6.11×10^9

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley CA, Rept. No. EEED 103 (December 1974), p. 45.]

Table 9. Annual airborne releases from a conventional nuclear reactor electricity system. 1000-MW light water power plant, 75% load factor.*

System process	Environmental impact	
	Total airborne releases	
	Tons	Ci
Exploration	NA	NA
Extraction	Nil	69.9
Processing	6192	3.49×10^5
Transport	Nil	0
Conversion	0	140×10^5
Transmission	0	0
Total	6192	4.89×10^5

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973); Environmental Quality, 4th Annual Report, USGPO, Washington, DC (1973).]

Table 10. Annual airborne releases from an uncontrolled coal-fired electricity system: 1000-MW power plant, 75% load factor.*

System process	Total airborne release (tons)	Environmental impact						
		Type (tons)						
		Part	SO _x	CO	HC	NO _x	Aldehydes	Other
Exploration	NA	---	---	---	---	---	---	---
Extraction	NA	---	---	---	---	---	---	---
Deep	NA	---	---	---	---	---	---	---
Surface	NA	---	---	---	---	---	---	---
Processing								
Deep	4,714	4,714	---	---	---	---	---	---
Surface	4,714	4,714	---	---	---	---	---	---
Transport								
Deep	26,270	25,748	125	135	96	145	8	1.3 tons (organic acids)
Surface	26,270	25,748	125	135	96	145	8	1.3 tons (organic acids)
Conversion								
Deep	352,217	203,200	124,500	1,270	381	22,860	6	2.2 Ci (radioactive)
Surface	352,217	203,200	124,500	1,270	381	22,860	6	2.2 Ci (radioactive)
Transmission	0	0	0	0	0	0	0	0
Total								
Deep	383,201	233,662	124,625	1,405	477	23,005	14	1.3 tons (organic acids)
Surface	383,201	233,662	124,625	1,405	477	23,005	14	2.2 Ci (radioactive)

*Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973); Environmental Quality, 4th Annual Report, USGPO, Washington, DC (1973).]

Table 11. Annual airborne releases from an uncontrolled oil-fired electricity system: 1000-MW power plant, 75% load factor.*

System process	Total airborne release (tons)	Environmental impact						
		Type (tons)						
		Part	SO _x	CO	HC	NO _x	Aldehydes	Other
Exploration	NA	NA	NA	NA	NA	NA	NA	NA
Extraction								
Onshore	0	0	0	0	0	0	0	0
Offshore	0	0	0	0	0	0	0	0
Processing								
Onshore	87,524	419	3,290	71,290	11,027	1,108	109	281 (ammonia)
Offshore	87,524	419	3,290	71,290	11,027	1,108	109	281 (ammonia)
Transport								
Onshore	1,507	334	260	313	165	422	13	0
Offshore	1,507	334	260	313	165	422	13	0
Import	1,326	34	885	17	17	386	4	0
Conversion								
Onshore	69,321	1,578	46,438	8	395	20,705	197	0
Offshore	69,321	1,578	46,438	8	395	20,705	197	0
Import	69,321	1,578	46,438	8	395	20,705	197	0
Transmission	0	6	0	0	0	0	0	0
Total								
Onshore	158,352	2,331	49,988	71,611	11,587	22,235	319	281 (ammonia)
Offshore	158,352	2,331	49,988	71,611	11,587	22,235	319	281 (ammonia)
Import	70,664	1,612	47,323	25	412	21,091	201	0

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973); Environmental Quality, 4th Annual Report, USGPO, Washington, DC (1973).]

Table 12. Annual airborne releases from an uncontrolled gas-fired electricity system: 1000-MW power plant, 75% load factor.*

System process	Environmental impact							
	Total airborne release (tons)	Type (tons)						
		Part	SO _x	CO	HC	NO _x	Aldehydes	Other
Exploration	NA	NA	NA	NA	NA	NA	NA	NA
Extraction	0	0	0	0	0	0	0	0
Processing	4,230	0	0	0	0	4,230	0	0
Transport	6,962	0	0	0	0	6,962	0	0
Conversion	12,865	426	17	11	1,136	11,076	85	114 (organics)
Transmission	0	0	0	0	0	0	0	0
Total	24,057	426	17	11	1,136	22,268	85	114 (organics)

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973); Environmental Quality, 4th Annual Report, USGPO, Washington, DC (1973).]

Table 13. U.S. emission trends, total emissions to the atmosphere, 1940-1970 (10⁶ tons/y).*

Year	Sulfur dioxide	Particulates	Carbon monoxide	Hydrocarbons	Nitrogen oxides
1940					
Controllable	22.2	19.2	42.5	10.1	5.5
Miscellaneous (uncontrollable) ^a	0.6	25.7	30.5	6.5	1.0
Total	22.8	44.9	72.5	16.6	6.5
1950					
Controllable	24.3	20.8	62.3	15.6	8.2
Miscellaneous (uncontrollable)	0.6	12.4	20.6	6.2	0.6
Total	24.9	33.2	82.9	21.8	8.8
1960					
Controllable	22.6	21.0	79.3	18.8	10.9
Miscellaneous (uncontrollable)	0.6	8.9	19.3	7.0	0.5
Total	23.2	29.9	98.6	25.8	11.4
1968					
Controllable	30.5	22.5	93.4	22.1	19.1
Miscellaneous (uncontrollable)	0.6	5.9	18.0	7.6	0.4
Total	31.1	28.4	111.4	29.7	19.5
1969					
Controllable	31.9	22.8	97.6	21.9	20.6
Miscellaneous (uncontrollable)	0.2	12.2	17.5	6.3	0.5
Total	32.1	35.0	115.1	28.7	21.1
1970					
Controllable	33.3	22.3	96.0	22.5	22.0
Miscellaneous (uncontrollable)	0.1	3.2	4.7	4.8	0.1
Total	33.4	25.5	100.7	27.3	22.1

^aUncontrollable sources include forest fires, structural fires, coal refuse banks, some agricultural burning, and some solvent evaporation.

*[1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974.)]

Table 14. U.S. emission trends, rates of change (%).*

Emissions	1940-1970	1940-1960	1940-1970
Carbon monoxide			
Total	1.1	1.5	0.2
Road vehicles	4.0	4.3	3.4
Hydrocarbons			
Total	1.7	2.2	0.6
Road vehicles	3.3	4.3	1.0
Nitrogen oxides			
Total	4.2	2.9	6.8
Road vehicles	4.8	4.9	4.6
Fuel combustion	3.7	2.0	7.3
Steam-electric utilities	6.6	6.5	6.7
Sulfur oxides			
Total	1.3	0.6	2.6
Fuel combustion	1.5	0.2	4.2
Steam-electric utilities	6.6	6.5	6.7
Industrial process	1.9	1.3	3.0
Particulates			
Total	-1.9	-2.0	-1.6
Industrial process	1.4	1.5	1.1
Fuel combustion	-1.1	-1.1	-1.1
Steam-electric utilities	2.1	4.1	-1.8
Population -- U.S. total	1.45	1.53	1.27

*[1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974).]

Table 15. Annual airborne releases control costs from a coal-fired electricity system: 1000-MW power plant, 75% load factor.*

System process	Total airborne release (tons)	Change (%)	Environmental impact		
			Costs (10 ³ dollars)		
			Investment	Annual total	Mills/kWh
Exploration	NA	NA	NA	NA	NA
Extraction					
Deep	NA	NA	NA	NA	NA
Surface	0	0	0	0	9
Processing					
Deep	59	-98.7	NA	14	0.002
Surface	59	-98.7	NA	14	0.002
Transport					
Deep	26,270	0	0	0	0
Surface	26,270	0	0	0	0
Conversion					
Deep	45,175	-87.2	40,000	11,826	1.80
Surface	45,175	-87.2	40,000	11,826	1.80
Transmission	0	0	0	0	0
Total					
Deep	71,504	81	40,000	11,840	1.802
Surface	71,504	81	40,000	11,840	1.802

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973); Environmental Quality, 4th Annual Report, USGPO, Washington, DC (1973).]

Table 16. Annual airborne releases control costs from an oil-fired electricity system: 1000-MW power plant, 75% load factor.*

System process	Environmental impact				
	Total airborne release (tons)	Change (%)	Costs (10 ³ dollars)		
			Investment	Annual total	Mills/kWh
Exploration	NA	NA	NA	NA	NA
Extraction					
Onshore	0	0	0	0	0
Offshore	0	0	0	0	0
Processing					
Onshore	3,210	-96.3	1,415	229	0.067
Offshore	3,210	-96.3	1,415	229	0.067
Transport					
Onshore	1,507	0	0	0	0
Offshore	1,507	0	0	0	0
Import	1,326	0	0	0	0
Conversion					
Onshore	38,362	-44.7	0	14,242	2,168
Offshore	38,362	-44.7	0	14,242	2,168
Import	38,362	-44.7	0	14,242	2,168
Transmission	0	0	0	0	0
Total					
Onshore	43,079	-73.0	1,415	14,471	2,168.07
Offshore	43,079	-73.0	1,415	14,471	2,168.07
Import	39,688	-45.0	0	14,242	2,168

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973); Environmental Quality, 4th Annual Report, USGPO, Washington, DC (1973).]

Table 17. Annual airborne releases control costs from a gas-fired electricity system: 1000-MW power plant, 75% load factor.*

System process	Environmental impact				
	Total airborne release (tons)	Change (%)	Costs (10 ³ dollars)		
			Investment	Annual total	Mills/kWh
Exploration	NA	NA	NA	NA	NA
Extraction	0	0	0	0	0
Processing	4,230	0	NA	NA	NA
Transport	6,962	0	NA	NA	NA
Conversion	12,865	0	NA	NA	NA
Transmission	0	0	0	0	0
Total	24,057	0	0	0	0

*[Council on the Environment, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973); Environmental Quality, 4th Annual Report, USGPO, Washington, DC (1973).]

Table 18. Annual airborne releases control costs from a nuclear reactor electricity system: 1000-MW light water power plant, 75% load factor.*

System process	Environmental impact						
	Total airborne release		Change (%)		Costs (10 ³ dollars)		
	Tons	Ci	Tons	Ci	Investment	Annual total	Mills/kWh
Exploration	NA	NA	NA	NA	NA	NA	NA
Extraction	Nil	69.9	0	0	0	0	0
Processing	6192	3.49×10^5	0	0	0	0	0
Transport	Nil	0	Nil	0	0	0	0
Conversion	0	1.40×10^3	0	-99	4000	614	0.093
Transmission	0	0	0	0	0	0	0
Total	6192	3.50×10^5	0	-29.3	4000	614	0.093

*[Council on the Environment, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973); Environmental Quality, 4th Annual Report, USGPO, Washington, DC (1973).]

Table 19. Capital expenditures by the U.S. industries for control of air emissions.*

Industry	Expenditures for new plant and equipment (10 ⁶ dollars)	
	1973 air	1974 (estimated) air
All industries	3176	4346
All energy industries	1671	2268
<u>Manufacturing</u>	544	849
<u>Durable goods</u>		
Electrical machinery	44	53
Machinery, except electrical	52	74
Transportation equipment		
Motor vehicles	81	103
Aircraft	11	7
Other	4	2
<u>Nondurable goods</u>		
Petroleum	352	610
<u>Nonmanufacturing</u>	1127	1419
Mining	41	53
Railroad	5	3
Air transportation	12	4
Other transportation	6	10
Public utilities		
Electric	906	1160
Gas and other	15	19
Communication, finance, service, construction, and other	142	170

*[Data abstracted from U.S. Department of Commerce, Bureau of Economic Analysis; see also Council on Environmental Quality, Environmental Quality, 5th Annual Report, USGPO, Washington, DC (1974).]

Table 20. Capital expenditures by the U.S. industries for control of air emissions.*

Industry	Changes in production process (10 ⁶ dollars)	
	1973 air	1974 (estimated) air
All industries	724	1003
All energy industries	452	514
<u>Manufacturing</u>	172	230
<u>Durable goods</u>		
Electrical machinery	14	16
Machinery, except electrical	24	27
Transportation equipment		
Motor vehicles	19	17
Aircraft	0	0
Other	1	0
<u>Nondurable goods</u>		
Petroleum	94	153
<u>Nonmanufacturing</u>	280	284
Mining	15	22
Railroad	3	2
Air transportation	2	0
Other transportation	3	3
Public utilities		
Electric	223	198
Gas and other	3	2
Communication, finance, service, construction, and other	31	57

*[Data abstracted from U.S. Department of Commerce, Bureau of Economic Analysis; see also Council on Environmental Quality, Environmental Quality, 5th Annual Report, USGPO, Washington, DC (1974).]

What they are

Where they come from

Fig. 2. Emissions to the atmosphere from fossil fuels in the U.S. during 1971, percentage by weight. [Compiled from data in Babcock, L. R., and N. L. Nagda, J. Air Poll. Cont. Assoc. 22, 727 (1972).]

What they are

Where they come from

Fig. 3. Emissions to the atmosphere from fossil fuels in the U.S. during 1971, percentage by effect. [Compiled from data in Babcock, L. R., and N. L. Negda, J. Air Poll. Cont. Assoc. 22, 727 (1972).]

CHEMICAL FACTORS

Carbon Monoxide

Sources

Man-Made - Carbon monoxide sources are widespread and occur whenever fossil fuels are incompletely combusted. For the individual, cigarette smoking is probably the most important source, followed by motor vehicle exhaust, occupational sources, and some beauty and kitchen cooking devices. Industrial processes, solid waste burning, and miscellaneous fires contribute smaller amounts.

The majority of carbon monoxide sources are located in the highly industrialized northern hemisphere. (Tables 21 and 22 and Figs. 4 - 6.)

Natural - The largest natural source of carbon monoxide results from the oxidation of methane emitted by decaying organic matter. Other natural sources are associated with all biological activity in sea water: the growth and decay of chlorophyll, carbon-monoxide-producing colonies of plankton in the warmer regions of the oceans, the photochemical oxidation of methane and marsh gas, forest fires, volcanoes, and coal mines. (Table 2.)

Trends

Most major cities in the U.S. have continued to show declining concentrations of carbon monoxide since 1964, reflecting improved air quality. Collected carbon monoxide measurements made in New York City back to 1922 were found to have far higher values in the earlier measurements. It is very possible that the concentration of carbon monoxide in the air we breathe is now lower than at any time since man first learned to use fire.

Figure 7 shows the trends in carbon monoxide concentrations during the period 1961-1972 for Continuous Air Monitoring Program (CAMP) cities. Automobile controls began in 1968 and most trend lines indicate decreasing levels of pollution.

Costs of Control

Mobile Sources - Estimated investment costs for mobile-source emission controls on automobiles and light-duty trucks varies from \$0 in 1967 to a maximum additional cost per new vehicle of \$215.00 in 1975 and \$410.00-\$435.00

in 1977. Costs in the period 1975-1977 will be \$201 for new gasoline trucks and \$1000 for new diesel trucks and buses.

Monitoring for the effects of stratospheric pollution costs (in 1971 dollars) approximately \$5 million/y for the 1975-1980 period, and about \$22 million/y past 1980. These costs represent insurance against unwarranted overexpenditure for either adverse impacts or abatement measures.

These estimates must be used with discretion because the costs do not reflect what it would cost to control carbon monoxide alone but, rather, carbon dioxide and nitrogen oxides. Controlling only carbon monoxide would be much cheaper. Also, there are much better arguments for controlling automobile emissions of carbon monoxide than nitrogen oxides. (Tables 23 and 24.)

Stationary Sources - Limiting carbon monoxide from cupolas to low emission levels would cost \$12 million/y. Reducing carbon monoxide emission levels to 1% of present emissions would cost \$150,000/y for small refining companies and \$720,000/y for large integrated firms. Total control costs for all refinery sources would be \$58 million/y.

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Table 21. Estimated global carbon monoxide production by man-made and natural activities (10^8 tons/y).*

Activity	Total	Northern hemisphere	Southern hemisphere
<u>Sources</u>			
Man-made	7.1	6.0	1.1
Oceans	1.1	0.4	0.7
Rain water	-	Negligible	-
Bush and forest-fires, burning of agricultural waste	0.7	0.4	0.3
Oxidation of hydrocarbons	0.7	0.4	0.3
Total	9.6	7.2	2.4
Oxidation of methane	17-44	-	-

*[Compiled from Seller, W., Tellus 26, 116 (1974).]

Table 22. Nationwide quantity of carbon monoxide emissions from various sources, 1972.*

Source	Quantity (10 ⁶ tons)
Stationary fuel combustion	0.3
Miscellaneous	0.9
Industrial processes	17.5
Solid waste disposal	11.2
Transportation	77.4
Total	107.3

*[1972 National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Table 23. Costs of control, light-duty vehicles.*

Model year	Typical changes or controls added	Additional cost per new vehicle (dollars)	Total cost per vehicle (cumulative, dollars)
<u>Autos and light-duty trucks</u>			
1968-1969	Closed PCV system, carburetor changes, ignition timing changes, inlet air temperature control	5.40	5.40
1970	Additional carburetor changes, idle control solenoid, ignition timing changes	7.40	12.80
1971	Evaporative emission control, improved idle control solenoid with overheat protection, low compression ratios, additional carburetor changes	19.70 ^a	32.50 ^a
1972	Valve and valve seat changes for unleaded gasoline	2.00	34.50
1973-1974	Exhaust gas recirculation for NO _x control, speed controlled spark timing	48.00	82.50
1975	Catalytic oxidation of HC and CO unitized ignition systems for 50,000 mile service-free performance, air injection for catalytic unit	163.50	246.00
1976-1977	Dual catalyst units for HC, CO, and NO _x ; or tandem NO _x and CO-HC catalytic units; modified manifold reactors to reduce catalyst load	105.00 ^a	351.00 ^a

^aAbove the cost of controls or simpler system replaced.

*[Lawrence Livermore Laboratory, staff compilation.]

Table 24. Costs of control, heavy-duty vehicles.*

Model year	Changes or controls added	Additional cost per new vehicle (dollars)	Total cost per vehicle (cumulative, dollars)
<u>Gasoline trucks and buses</u>			
1970- 1972	Lean operating carburetion, ignition timing changes	9	9
1973- 1974	Evaporative emission controls	32	41
1975- 1977	Exhaust gas recirculation for NO _x , plus air injection for HC, CO, 15-25% increased displacement	201	242
<u>Diesel trucks and buses</u>			
1970- 1974	Improved fuel injectors and careful operation to prevent excess smoke	0	0
1975- 1977	Extensive derating of operational horsepower range; larger engines required for some applications compared to previous engines; injection system design modifications	1000	1000

*[Lawrence Livermore Laboratory, staff compilation.]

Fig. 4. Global carbon monoxide emission sources, 1971. [Lawrence Livermore Laboratory, staff compilation.]

Fig. 5. Nationwide sources of carbon monoxide emissions, 1972. [National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012. (1974).]

Fig. 6. Status of carbon monoxide levels, 1973. Note that in many cases an excess of one station near a roadway or power plant is sufficient to categorize the whole area. [National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Fig. 7. Trends in carbon monoxide concentrations, 1961-1972, CAMP cities. (a) Trend lines for annual averages in five CAMP cities. (b) Trend lines for annual 99th percentiles in five CAMP cities. 1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974).

Nitrogen Oxides

Sources

Any process that heats air above 2300 K will produce significant quantities of nitrogen oxide as an equilibrium constituent. Examples of such heating include the shock waves from nuclear explosives and the operation of the combustion chambers of aircraft jet engines, automobiles engines, and stationary power plants. (Table 25 and Figure 8.)

Nitrogen is 79% of the atmosphere, but because it is a relatively inert gas it cannot be used directly by the large majority of living things. It must first be "fixed" or incorporated in a chemical compound by specialized organisms or industrial processes. Only then can it be used by plants and animals.

The largest, single, natural source of fixed nitrogen is probably terrestrial micro-organisms and associations between such micro-organisms and plants. However, the majority of nitrogen compounds in the air are due to natural reactions. Even with respect to nitrogen oxides considered harmful (nitrogen oxide and nitrogen dioxide) nature contributes much more than man. (Figure 9.)

Nitrogen oxide production from nuclear tests is greater than 20 kton. Table 26 gives the quantity of nitrogen oxide production per year from 1952 to 1972 and compares it by year to the number of fully operational Concorde aircraft required to produce an equal amount. Amounts of nitrogen oxide at least comparable with those expected from large fleets of Concorde aircraft have already been directly injected into the stratosphere.

Trends

United States, 1972 - As a result of new and special monitoring methods at 200 sites across the country, the EPA now believes that nitrogen dioxide is not a widespread air emissions problem in the U.S. Most air quality control regions are meeting the ambient standard. (Table 27 and Fig. 10.)

Regions where the standard is believed to be exceeded are Los Angeles, Chicago, Baltimore, and, possibly, New York-New Jersey-Connecticut, Salt Lake City, and Denver.

New Jersey While all three sites show a slight long-term downward trend, the 1971-1972 data indicate a stabilization. Any trend determination appears marginal. Average levels at all three sites are closely comparable,

although the Newark site is slightly above the annual standard and the Bayonne site is slightly below the standard. The Camden site is still lower. (Figure 11.)

Costs of Control

Fossil-Fueled Power Plants - The costs of combustion modification for nitrogen oxides control will vary considerably depending on the design of the boiler. Capital investment increases will range from zero to 7% as a minimum. Operating cost increases will range from zero to 4%. (Table 28.)

One estimate of the annualized total cost for retrofitting flue-gas recirculation to boilers averaging 375 MW in capacity is \$220,000 (20-year lifetime, interest at 10%). Nationwide, this amounts to about \$200 million annualized cost to reduce nitrogen dioxide emissions by about 1.3×10^6 tons/y in fossil-fueled power plants.

The cost associated with the Tyco process are highly sensitive to scrubber efficiency. This is pointed out by noting that the range of cost has been reported to vary from about \$20/ton of nitrogen oxides removed at 98% scrubber efficiency to about \$60-120/ton of nitrogen oxides removed at 92% scrubber efficiency for a 1000-MW coal- or oil-fired power plant, respectively.

The cost estimates associated with alkaline scrubbing for nitrogen oxides removal are unreliable. Note that these cost estimates may vary greatly with the size of the installation, fuel type, and product. (Table 29.)

Mobile Sources, Automobiles - Expected annual costs of nitrogen oxides emission controls range from zero (for lean engine operations) to \$45/car/y (for an exhaust-manifold reactor with exhaust-gas recirculation). Costs to meet the level required by the Clean Air Amendment of 1970 (for 1976 model cars) may be considerably higher, possibly several hundred dollars per car for meeting the emission standards for nitrogen oxides as well as those for carbon monoxide and hydrocarbons.

As discussed under carbon monoxide control, the costs for controlling nitrogen oxides in light- and heavy-duty vehicles of model years 1968-1977 will be of the order of \$25 billion using the best presently known technology. For all vehicles in 1977, the annualized cost for controlling nitrogen oxides would be about \$4.2 billion. (Table 30.)

Mobile Sources, Aircraft - Given a satisfactory combustor with a given emission index, the cost of new engine development might be \$250 million. Whether or not the use of a new combustor would increase such costs is not

clear, although should such a combustor require additional volume, additional costs might be incurred.

Development costs on a new combustor itself are difficult to estimate, but assuming an orderly and successful development program, they should not be unacceptably high. The costs of such a program would tend to be limited by the number of appropriate specialists to pursue the necessary work.

Monitoring for the effects of stratospheric pollution will cost (in 1971 dollars) approximately \$5 million/y for the 1975-1980 period and about \$22 million/y past 1980. These costs represent insurance against unwarranted overexpenditure for either adverse impacts of abatement measures.

References - Nitrogen Oxides

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1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974).

Table 25. Nationwide emissions of nitrogen oxide, 1972 (10^6 tons).*

Transportation	8.6
Stationary fuel combustion	6.3
Industrial processes	2.9
Solid waste disposal	0.4
Miscellaneous combustion	6.4
	<hr/>
Total	24.6

*[1972 National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Table 26. Estimated nitrogen oxide production from nuclear tests.*

Year	Mton TNT	NO production 10 ³ kg	Equivalent No. of fully operational Concordes
1952	11.1	5.5	54
1953	0	0	0
1954	48.5	24.2	237
1955	2.0	1.0	10
1956	26.0	13.0	127
1957	13.5	6.7	66
1958	61.9	30.9	303
1959	0	0	0
1960	0	0	0
1961	120.6	60.3	591
1962	213.5	106.7	1,047
1963	0	0	0
1964	0	0	0
1965	0	0	0
1966	1.4	0.7	7
1967	3.5	1.7	17
1968	7.6	3.8	37
1969	3.0	1.5	15
1970	6.1	3.0	30
1971	1.6	0.8	8
1972	0	0	0

*[Goldsmith, P., Nature 244 545 (1973).]

Table 27. Nationwide estimates of nitrogen oxides emissions, 1940-1972
(10^6 tons/y).*

Source category	1940	1950	1960	1968	1969	1970	1971	1972
Fuel combustion in stationary sources	3.5	4.3	5.2	9.7	10.2	10.0	10.2	6.3
Transportation	3.2	5.2	8.0	10.6	11.2	11.7	11.2	8.6
Solid waste disposal	0.1	0.2	0.2	0.4	0.4	0.4	0.2	0.4
Industrial process losses	Neg ^a	0.1	0.1	0.2	0.2	0.2	0.2	2.9
Agricultural burning	0.2	0.2	0.3	0.3	0.3	0.3	-	-
Miscellaneous	0.8	0.4	0.2	0.2	0.2	0.1	0.2	6.4
Total	7.9	10.4	14.0	21.3	22.5	22.7	22.0	24.6
Total controllable ^b	7.1	10.0	13.8	21.1	22.3	22.6	21.8	18.2

^aNegligible (less than 0.05×10^6 tons/y).

^bMiscellaneous sources not included.

*[Cavender, J. H., D. S. Kircher, and A. J. Hoffman, Nationwide Air Pollutant Emission Trends, 1940-1972, Environmental Protection Agency, Research Triangle Park, NC, Publ. AP-115 (1973); 1972 National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Table 28. Combustion modification control costs in public utility boilers.*

Control method (1)	Boiler size, in 10^3 MW of fuel gas, fixed costs, in 10^3 dollars			Load factor 6120 h/y, operating costs, in 10^3 dollars		
	Start-up costs (2)	Capital equip- ment costs (3)	Capital charges (4)	Mainte- nance, supplies, and overhead (5)	Other opera- tional costs (6)	Total cost per year, in 10^3 dollars (7)
Low excess air	---	120	17	21	(133) ^a	(95)
Two-stage combustion	---	0	0	0	0	0
Low excess air + two-stage combustion	---	120	17	21	(133) ^a	(95)
Flue-gas recirculation	---	600	84	52	66	202
Low excess air + flue-gas recirculation	---	720	101	73	(76)	107
Water injection	---	23	3	2	139	144

^a Figures in parenthesis indicate operating savings.

*[Bartok, W., et al., Systems Study of NO_x Control Methods for Stationary Sources, Esso Research and Engineering, Linden, NJ, Rept. GR-2-NOS-69 (1969).]

Table 29. Estimated control costs and reduction of NO_x emissions, for a 1000-MW boiler used 6120 h/y by selected methods^x and by ton.*

Control method	NO _x reduction (%)	Fuel used	Control cost/y (dollars)	NO _x reduction (tons/y)	NO _x control costs (dollars/ton,
Uncontrolled	0	Gas	0	53,000 ^a	0
(base case)	0	Oil	0	30,000 ^a	0
	0	Coal	0	30,000 ^a	0
Low excess air	33	Gas	- 95,000 ^b	17,500	- 5 ^b
	33	Oil	-297,000 ^b	9,900	-30 ^b
	25	Coal	- 79,000 ^b	7,500	-11 ^b
Two-stage combustion	50	Gas	0	26,500	0
	40	Oil	0	12,000	0
	35	Coal	299	10,500	29
Low excess air plus two-stage combustion	90	Gas	- 95,000 ^b	47,700	- 2 ^b
	73	Oil	-297,000 ^b	21,900	-14 ^b
	60	Coal	220,000	18,000	12
Flue-gas recirculation	33	Gas	202,000	17,500	12
	33	Oil	202,000	9,900	20
	33	Coal	202,000	9,900	20
Low excess air plus flue-gas recirculation	80	Gas	107,000	42,400	3
	70	Oil	- 95,000 ^b	21,000	- 5 ^b
	55	Coal	123,000	16,500	8
Water injection	10	Gas	144,000	5,300	27
	10	Oil	179,000	3,000	60
	10	Coal	143,000	3,000	48

^aUncontrolled method, total NO_x emitted; no reduction.

^bWhere the installation of control equipment results in a savings, control costs are listed as negative numbers.

*[Bartek, W., et al., Systems Study of NO_x Control Methods for Stationary Sources, Esso Research and Engineering, Linden, NJ, Rept. GR-2-NOS-69 (1969).]

Table 30. Estimated costs of catalytic reduction for three control systems.*

	Decolorizer	Selective abater	Two-stage non- selective abater
NO _x before reduction, ppm	3000	3000	3000
NO _x after reduction, ppm	3000	300	300
Fuel	Natural gas	Ammonia	Natural gas
Investment, 10 ³ dollars dollars/scfm	60 2.60	140 6.10	255 11.00
Costs, 10 ³ dollars/y ^a			
Natural gas	14	--	82
Ammonia	--	33	--
Catalyst	4	12	8
Steam	(50)	(21)	(144)
Investment-based costs ^b	30	70	128
Total cost, 10 ³ dollars/y	(2)	94	74
Total cost, dollars/ton HNO ₃	(0.02)	0.95	0.75
Total cost, dollars/ton NO _x removed	--	34	27

^a Parentheses indicate negative costs or savings.

^b Includes 20% return before taxes.

*[Bartok, W., et al., Systems Study of NO_x Control Methods for Stationary Sources, Esso Research and Engineering, Linden, NJ, Rept. GR-2-NOS-69 (1969).]

Fig. 8. Sources of global man-made emissions of nitrogen oxide, 1971.
 [Compiled from data in Robinson, E., and C. E. Moser, in Proceedings of the 2nd International Clear Air Congress, Washington, DC, H. M. Englund and W. T. Berry, Eds. (Academic Press, New York, 1971).]

Fig. 9. Global quantities of nitrogen oxide emissions for 1968. [Compiled from data in Robinson, E., and C. E. Moser, in Proceedings of the 2nd International Clear Air Congress, Washington, DC, H. M. Englund and W. T. Berry, Eds. (Academic Press, New York, 1971).]

Fig. 10. Sources of nationwide emissions of nitrogen oxide, 1972. [National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Fig. 11. Trends in nitrogen dioxide concentrations for some selected cities in New Jersey. [1972 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-73-004 (1973).]

Photochemical Oxidants

Sources

Photochemical smog is derived from photochemical reactions in the atmosphere of reactive (nonmethane) hydrocarbons, nitrogen oxides, and oxygenated organic compounds in the presence of sunlight and oxygen.

Reactive hydrocarbons and nitrogen oxides are the primary contaminants (those emitted into the atmosphere, as opposed to secondary contaminants that are manufactured in the air). The hydrocarbons come mainly from automobiles, the nitrogen oxides from automobiles and from the combustion of fossil fuels in electric power plants.

The recognized photochemical oxidants that have been measured in ambient air are ozone, the peroxyacyl nitrates (mostly as peroxyacetyl nitrate, PAN), and hydrogen peroxide. The effect on ozone is quite different from nitrogen oxides produced by automobiles and factories on the ground, by regular aircraft at 12 km, and by supersonic aircraft at 20 km. Insofar as hydrocarbons are concerned, substantially different sets of reactions are needed in these three regions.

Ozone can be formed naturally by atmospheric electrical discharge. Ozone is also formed in the stratosphere by the action of solar radiation, with maximum concentrations occurring at altitudes of about 15 to 40 km. These processes are not capable of forming significant concentrations at ground level and thus do not account for the high concentrations of ozone found in some areas.

Figure 12 shows the interaction of hydrocarbons with the atmospheric nitrogen dioxide photolytic cycle. The chemistry of this cycle is very complicated and still not completely understood. But under certain conditions nitrogen oxides and hydrocarbon take part in a photochemical reaction that eventually forms sufficient ozone and other associated substances to produce undesirable effects. Thus, in several steps,

The conditions needed are: (1) that the main reactants (nitrogen oxide and hydrocarbon) be present and (2) that sunlight be present of sufficient intensity and duration to initiate and sustain the reaction in the air for

several hours. The reaction is rather slow, and it is typically 3 to 5 h after its initiation before significant quantities of ozone build up.

Trends

Oxidant/ozone concentrations appear to have decreased appreciably at central urban monitoring locations not only in the Los Angeles Basin, but at CAMP sites in Denver, St. Louis, Cincinnati, Washington, D.C., and Philadelphia. Frequency of days of elevated oxidant, highest oxidant concentrations, and clustering of days of elevated oxidant all have decreased between the mid-1960's and the early 1970's. However, it cannot be concluded from these results that oxidant concentrations at suburban locations have decreased proportionately to those at center city locations. (Figure 13.)

The dimensions of the downwind urban plumes of large urban areas must be defined. Such urban plumes may be responsible for elevated oxidant/ozone concentration levels at either downwind urban or rural locations depending on the nature of the surrounding region and meteorological conditions. However, the contribution of natural sources also must be adequately evaluated. The impact of new results on the control strategies related to several current air standards could be substantial.

Data on oxidants in the rest of the country are not yet extensive enough to define national trends, but in 1973 oxidant concentrations in 51 out of 57 AQCR's reporting were still exceeding the national primary standard for that pollutant. For many AQCR's the individual States are not required to monitor for oxidants because the air quality levels were originally considered to be well below primary standards. Recent investigations have uncovered elevated oxidant levels in several nonurban areas in the U.S. (Figure 14.)

Ozone data gathered from as far back as late 1957 do not support the contention that the period 1960-1962 is of any particular significance with respect to the periods of nuclear testing. The upwards tendency of the trace since 1961 agrees with other findings that there has been an increase of total ozone of up to 10% at a number of stations during the past decade (1961-1970). (Figure 15.)

Costs of Control

Cost of control for mobile sources is related to the cost of air pollution devices installed on automobiles to control hydrocarbon, carbon monoxide, and

nitrogen oxide emissions - \$300/car in 1977. No accurate data is available on stationary sources.

Damage costs by ozone and smog run into the millions of dollars annually. The total damage to plants and vegetation amounts to \$132 million/y, a value lower than previous estimates that ranged from \$200 to 500 million/y.

References - Photochemical Oxidants

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Fig. 12. Interaction of hydrocarbons with atmospheric nitrogen dioxide photolytic cycle. [Air Quality for Photochemical Oxidants, U.S. Dept. H&W, NAFCA, Washington, DC., March 1970, p. 2-7, HP-63.]

Fig. 13. Status of oxidant/ozone levels, 1972. [National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Fig. 14. Trend in oxidant results by year at CAMP sites. [Altshuller, A. P., J. Air Poll. Cont. Assoc. 25, 19 (1975).]

Fig. 15. Smoothed deviations from monthly means of total ozone from 17 stations in the period 1957-1970, and the intensity and timetable of nuclear explosions in this period. [Goldsmith, P., *et al.*, Nature 244, 545 (1973).]

Sulfur Oxides

Sources

Natural - Natural sulfur dioxide sources are volcanoes. Hydrogen sulfide, dimethyl sulfide, and/or unidentified sulfurous gas also enter the atmosphere in large quantities from the natural decay of organic materials. This is oxidized in the air to sulfur dioxide. (Table 31.)

These natural sources of sulfur produce an estimated sulfur dioxide of background level of 2 parts per billion ($5.7 \mu\text{g}/\text{m}^3$).

Man-Made - Most primary sulfur dioxide is emitted from two sources: the combustion of fossil fuels containing sulfur, namely coal and oils, and certain industrial processes involving sulfur compounds or impurities. Some secondary sulfur dioxide is formed by the oxidation of hydrogen sulfide. (Table 32.)

Oil shale and tar sand development activities could be an important regional contributor to sulfur oxide emissions in the atmosphere. Natural gas contains very little sulfur. Some sulfur is retained in the coke that is used as a source of heat and in blast furnaces. Sulfur dioxide is produced during the refining of oil, the lighter fractions of which are extensively used as a source of power for transportation. (Table 33 and Fig. 16.)

On a national basis, stationary sources, such as steam electric power plants and industrial boilers, are the major contributors to sulfur oxides pollution. (Table 34.)

Coal combustion is by far the largest single source of sulfur oxides pollution in the U.S., with a preponderance of the total emissions concentrated in the geographical area east of the Mississippi River.

In California, industrial processes such as chemical manufacturing, petroleum refining, and metallurgical production are the major contributors to sulfur oxides pollution.

Trends

Global - Global emissions of sulfur oxides have doubled during the last 30 y. Total emissions in 1937 have been estimated at 62×10^6 metric tons, made up by emissions from the combustion of coal (42×10^6 metric tons) and oil (7×10^6 metric tons), and from smelting (13×10^6 metric tons). By 1965 worldwide emissions from coal had doubled; those from oil had trebled.

Insufficient data exist to make any estimate of whether or not there has been an increase in world atmospheric sulfur concentrations during the last 100 y, as has occurred in the case of carbon dioxide. Measurements of sulfur in Greenland ice showed no increase in concentration since 1915, despite much higher worldwide emissions. However, this is hardly surprising. If the half-life of man-made sulfur oxides is only a few days, very little sulfur oxides pollution would reach Greenland. In general, gaseous sulfur oxides appear not to have any global significance, at least at the present time. (Figure 17.)

United States - Between 1940 and 1970 estimated nationwide emissions of sulfur dioxide increased from about 22 to 33×10^6 tons/y. Much of this increase was due to steam electric power plants. From 1940 to 1970 the annual average increases in power plant sulfur dioxide emissions were nearly 5 times the national average rate for all sources. Since 1970 nationwide increases have been reduced somewhat by regulated changes in the types and sulfur content of fuels used by power plants, factories, and other stationary sources. Installation of stack controls has also contributed to reducing these emissions. (Table 35 and Fig. 18.)

In spite of increased nationwide emissions ambient sulfur dioxide concentrations in urban air decreased by 50% over the 8-y period 1964-1971. The trend was reversed in 1972. In view of these trends, claims for the success of the clean air act in reducing concentrations by 90% must be treated with caution.

The apparent discrepancy between rising emissions and decreasing ambient measurements probably reflects in part the siting of new power plants and other large industrial facilities in outlying areas away from center-city National Air Sampling Network (NASN) monitoring sites, as well as the increased use of natural gas and fuel oil rather than coal by small urban stationary sources. Only 100 AQCR's reported a full year's data for sulfur dioxide in 1973. Ten exceeded the annual primary standard. At least one quarter's sulfur dioxide data was reported from 187 AQCR's; 17 AQCR's contained stations exceeding 24-h primary standards. Furthermore, as the energy shortage developed, and some shifts were made back to more readily available higher sulfur fuels, there were indications that sulfur dioxide levels in some areas may be rising again. For example, concentrations were found to be rising at a number of monitoring stations in the New York metropolitan area during the 1973-1974 winter season. (Figure 19.)

Regional - Evidence from other monitoring programs supports the ambient improvements indicated by NASN data. Ambient sulfur dioxide levels also declined at most National Aerometer Data Bank (NADB) stations.

The sulfur dioxide problem is most serious in the heavily populated and industrialized areas in the northeast and north-central regions of the U.S. In 1970 approximately 60% of the population (34 million) in the northeast and over 40% of the population (24.5 million) in the north-central regions were exposed to annual average sulfur dioxide levels exceeding $20 \mu\text{g}/\text{m}^3$. In the west and south regions approximately 20% (9.5 million) and 15% (8 million), respectively, were exposed to these levels.

In 1967 and 1968 over 40% of the total U.S. population was exposed to pollution levels exceeding $20 \mu\text{g}/\text{m}^3$. In 1971 and 1972 less than 33% of the total population was exposed to these levels.

Figure 20 shows national and regional trends in sulfur dioxide during 1970-1973. A downward trend is apparent throughout the nation with, perhaps, a certain degree of leveling off at stations at which concentrations are well below the annual standard.

Major U.S. Cities - The percentage of NASN monitoring sites nationwide at which ambient sulfur dioxide standards were exceeded has shown progressive reductions since the mid-1960's. For 10 selected cities this improvement was also evidenced by yearly trends in the ratio of annual average sulfur dioxide levels to EPA's primary standard.

Nationwide, out of 162 Air Quality Control Regions for which data were sufficient for analysis, 19 reported violation of some primary standard in 1972 and 7 exceeded the secondary 3-h ambient standard. However, the full impact of recent variances and fuel-use shifts on these improvements has not yet been determined. (Figure 21.)

Present information indicates that it may be necessary to focus more on sulfates than on sulfur dioxide in the monitoring and assessment of ambient air quality. Although ambient standards and monitoring have mostly been directed at sulfur dioxide, studies by EPA's Community Health and Environmental Surveillance System have suggested that human respiratory diseases are more closely associated with sulfates than with sulfur dioxide and that sulfates may in many cases be an order of magnitude more toxic than sulfur dioxide.

Figure 22 shows a comparison of sulfur dioxide trends in Chicago with regulations governing percent sulfur content in fuel. Note that the trend

was for decreasing sulfur dioxide emissions even before regulations were introduced showing the same general decline seen at sites throughout this region. The slight upturn in the fourth quarter of 1972 was caused primarily by a single high observation. Data from other sites indicate that the steady decline in sulfur dioxide levels is being maintained.

Figure 23 shows a comparison of sulfur dioxide trends in Philadelphia with regulations governing percent sulfur content in fuel. Again, the trend was toward decreasing sulfur dioxide emissions even before regulations were introduced. The first concentration decrease closely followed the May 1970 regulation, which established a minimum limit of 1% sulfur in residual oil and coal and 0.3% sulfur in distillate fuel. The annual average sulfur dioxide continued to decline until it leveled off at the National Ambient Air Quality Standards (NAAQS's) in the second quarter of 1971. It then remained at that level for the next 2 y. After the implementation of the second sulfur regulation in October of 1972, which limited residual oil to 0.5% sulfur and distillate fuel and coal to 0.3% sulfur, the average air quality appeared to continue to improve. Prior to the implementation of the May 1970 sulfur regulation, the short-term, 24-h NAAQS had been consistently violated at levels of more than twice the primary standard. Subsequently, the observed maximum 24-h levels have decreased significantly.

Figure 24 shows a comparison of sulfur dioxide trends at Bayonne, New Jersey, with regulations governing percent sulfur content in fuel. The trends indicate a significant decrease in sulfur dioxide levels from a high of nearly $300 \mu\text{g}/\text{m}^3$ in 1967 to a current low of approximately $50 \mu\text{g}/\text{m}^3$. The quarterly sulfur dioxide averages clearly fluctuate about the long-term trend line with peaks occurring in the winter months corresponding to peak heating demands. The short-term sulfur dioxide concentrations (maximum 24-h sulfur dioxide concentration per quarter) are also improving. Concentration peaks that were well over the standard in the winter of 1969-1970 have declined to values somewhat below the primary 24-h standard in 1972.

Figure 25 shows sulfur dioxide concentration vs time in years for New York City. The improvement in sulfur dioxide air quality at this site can be attributed primarily to sulfur dioxide regulations that have become effective in New Jersey and New York. A significant improvement is noted between 1967 and 1968, when sizeable shifts in the use of high-sulfur fuel oil and coal (~2.5% sulfur) occurred. The fuel shift occurred in advance of the effective

date of the regulations (May 1968) because fuel supplies were available to users somewhat earlier than the prescribed compliance date.

Costs of Control

The cost of particulate and sulfur dioxide control by the installation of a stack-gas scrubbing system has been estimated at capital costs of \$30-50/kW capacity when the wet limestone installation is included in a new plant. Thus, for a 200-MW existing plant (which might supply power for a city of average temperature and industrial development with a population of about 100,000), the investment could run from \$9 to 13 million. Annual operating costs would range from 1.1 to 3.0 mills/kWh. (Tables 36-40.)

Tall stacks and intermittent control systems make it possible to meet ambient sulfur dioxide standards in carefully defined situations, with operating costs ranging from 0.15 to 0.4 mills/kWh and capital costs from \$4 to 10/kW.

To desulfurize gasoline and have it available nationally in conjunction with low-lead fuel would require upwards of 4 y. According to EPA estimates, sulfur-content reduction of gasoline from its present 300 ppm to 100 ppm would require a capital outlay of \$4 to 6 billion and a fuel penalty of 0.5%. After reduction a catalyst-equipped car would still emit sulfates at a level 20 times that of a noncatalyst-equipped car. To further reduce sulfur content of fuel to 50 ppm would cost \$8 to 12 billion and a fuel penalty of 1 to 5%. Reduction to 30 ppm would cost \$16 to 24 billion and a fuel penalty of 2% or more. (Table 41.)

Table 42 gives the costs of alternative sulfur dioxide control strategies. Under Strategy 1 both existing and new plants are required to comply with plant-by-plant emission limitations, including dual emission limitations where supplemental control systems are appropriate, to assure compliance with primary ambient air quality standards for sulfur dioxide. Strategy 2 assures compliance with both primary and secondary standards under the same conditions. Strategy 3 is the same as Strategy 2, except that new plants are required to comply with state implementation plans or new source performance standards. Strategy 4 adds the prohibition of supplemental controls in the 21-state high-sulfate area. Strategy 5 bars supplemental control systems everywhere. Under Strategy 6, existing plants are required to meet state implementation plans, and new plants are required to meet new source performance standards.

Strategy 7 is the same, except that new plants would be required to use scrubbers. Under Strategy 8, existing oil-fired plants are required to meet state implementation plans, existing coal-fired plants are required to assure compliance with primary and secondary standards as in Strategy 2, and new plants are required to meet new source performance standards.

References - Sulfur Oxides

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1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Triangle Research Park, NC, Publ. EPA-450/1-74-007 (1974).

Table 31. Main reservoirs of sulfur.*

Source	Mass of sulfur (metric tons)	Sulfur content in each source (%)
Sea	1.3×10^{15}	0.09
Fresh water	3×10^9	0.0011
Ice	6×10^9	0.00003
Atmosphere	3.6×10^6	0.00001
Evaporites	5×10^{15}	17
Sediments (mainly shales)	2.7×10^{15}	0.19
Metamorphic and igneous rock	7×10^{15}	0.03

*[Holser, W. T., and I. R. Kaplan, Chem. Geol. 1, 93 (1966); Friend, J. P., et al., J. Atmos. Sci. 30, 465 (1973); Friend, J. P., in Chemistry of the Lower Atmosphere, S. I. Rasool, Ed. (Plenum Press, New York, 1973).]

Table 32. Global sulfur dioxide pollutant emissions (10^6 tons).*

Source	Total SO ₂	Northern hemisphere	Southern hemisphere
Coal ^a	102	98 (96%)	4 (4%)
Petroleum ^a			
Comb. and Refin.	28.5	27.1 (95%)	1.4 (5%)
Smelting ^b			
Copper	12.9	8.6 (67%)	4.3 (33%)
Lead	1.5	1.2 (80%)	0.3 (20%)
Zinc	1.3	1.2 (90%)	0.1 (10%)
Total	146	136 (93%)	10 (7%)

^aUnited Nations Statistical Papers, World Energy Supplies 1963-1966, Series J, No. 11, Tables 2 and 9.

^bU.S. Bureau of Mines, Mineral Trade Notes Vol. 64, Nos. 9 and 12 (1967).

*[Robinson, E., and R. C. Robbins, J. Air Poll. Cont. Assoc. 20, 233 (1970).]

Table 33. Quantity of nationwide sulfur oxides emissions, 1972.*

Source	Quantity (10 ⁶ tons)
Fuel combustion stationary	18.4
Miscellaneous combustion	7.2
Industrial processes	6.8
Solid waste disposal	0.2
Transportation	0.6
Total	33.2

*[1972 National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Table 34. Sulfur oxides: rates of change in estimated weight of total nationwide emissions for selected stationary source categories (%/y).*

	1940-1960	1960-1970
Industrial process	1.3	3.0
Fuel combustion	0.2	4.2
Steam electric utilities	6.5	6.7

*[1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974).]

Table 35. Sulfur dioxide: estimated total nationwide emissions (10⁶ tons).*

	1940	1950	1960	1970
Controllable	22.2	24.3	22.6	33.3
Total	22.8	24.9	23.2	33.4

*[1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974).]

Table 36. Costs of long-term options.*

	Flue-gas treating	Low-Btu gas	Solvent- refined coal	Low-sulfur fuel oil from coal
Capital investment (10^6 dollars)	84-65	150	5	23
Annual charges (10^6 dollars/y)				
Annual capital charges	14.0-10.9	25.1	0.8	3.8
Additional fuel costs	0	10.0	37.6-51.5	48.6-59.8
Operating and maintenance costs	7.8-11.5	10.0	(0.5)	(1.0)
Derating cost	2.5-5.5	5.5	0	0
Forced outage cost	9.0-58.4	9.0	0	0
Total annual cost	33.3-86.3	59.6	37.9-51.8	51.4-62.6
Added power cost, mills/kWh	3.3-8.5	5.9	3.8-5.1	5.1-6.2

*[Salmon, R., and J. P. Nichols, data presented in a paper at 2nd AEC Pollution Control Conference, Albuquerque, NM, April 16-19, 1974.]

Table 37. Estimated costs of flue-gas treatment.^{a,*}

	Wet limestone scrubbing	Wet magnesia scrubbing	Na solution scrubbing (Wellman-Lord)	Cat-ox process
Capital investment (10 ⁶ dollars)	83.6	78.6	86.4	61-95
Annual charges (10 ⁶ dollars/y)				
Annual capital charges	14.0	13.1	14.4	10.2-15.9
Operating and maintenance costs	10.3	12.7	10.8	7.6-8.2
Total annual cost	24.3	25.8	25.2	17.8-24.1
Added power cost, mills/kWh	2.4	2.6	2.5	1.8-2.4

^aNot including derating and forced usage costs.

*[Salmon, R., and J. P. Nichols, data presented in a paper at the 2nd AEC Pollution Control Conference, Albuquerque, NM, April 16-19, 1974.]

Table 38. Summary of sulfur dioxide control process systems.*

Processor method	Reactant input requirements	Throw-away or recovery	Investment costs	Operating costs (\$/11% kwh)		Sulfur dioxide removal efficiency	Comments
			(\$/11% kwh for coal boilers)	No credit for sulfur recovery	Credit for sulfur recovery		
Low-sulfur fuel	NA	NA	0	2.0-5.0	NA	NA	Costs dependent on location and fuel type
Dry limestone injection	Limestone, 200°, Steich	Throw away	12-14 (200 MW new)	0.6-0.8	NA	22-45*	Costs dependent on solids removal, variables removal dependent on limestone type, and boiler load limited in applicability
Wet lime limestone scrubbing	Lime, 100-1200°, stock limestone 120-150°, Steich	Throw away	27-46 (200-1000 MW new or retro)	1.1-2.2	NA	80-90*	Costs dependent on solids removal considerations, new or retrofit scrubber type, lime or limestone, size of unit, etc. Considered most advanced technology. Several commercial units in operation testing on EPA prototype initiated
Magnesium oxide scrubbing	MgO alkali water fuel for regeneration and drying	Recovery of conc. H_2SO_4	33-58 (200-1000 MW new or retro)	1.5-3.0	0.9-2.6	80-90*	Costs dependent on same factors for wet limestone. Boston electric unit to start up in March 1972. H_2SO_4 assumed marketed at \$18/ton on-site acid production
Monsanto catalytic oxidation (add-on)	Vanadium pentoxide catalyst (periodic replacement)	Recovery of dilute H_2SO_4	45-50 (1000 MW new)	2.1-2.5	1.8-2.2	80-90*	Costs dependent on same factors as for wet limestone. Boston electric unit to start up in March 1972. H_2SO_4 assumed marketed at \$9/ton (conc. basis)

*[Princiotta, F. T., Environmental Protection Agency, Research Triangle Park, NC, Publ. PB-228706 (1972).]

Table 39. Estimated capital and annual cost of meeting ambient sulfur dioxide standards at TVA coal-fired plants.*

Capital costs	Amount
Development and installation of emission limitation programs and monitoring networks	\$ 4 million
New tall stacks (3 plants)	38 million
Coal switching capability (3 plants)	8 million
SO ₂ removal system, Widows Creek unit 8	<u>42</u> million
Total capital cost of proposed TVA program for SO ₂ control	<u>\$92</u> million
Annual cost	
Annual capital charges on \$92 million investment at 10%	\$ 9.2 million
Operation and maintenance of emission limitation programs, stacks, and monitoring equipment	2.5 million
Incremental cost of low-sulfur coal for coal switching, including added transportation and handling costs	1.5 million
Operation and maintenance of SO ₂ scrubber at 1.2 mills/kWh, Widows Creek unit 8	<u>3.8</u> million
Total annual cost of proposed TVA program for SO ₂ control	<u>\$17.0</u> million

*[Hearings before the Subcommittee on Energy, U.S. House of Representatives, 93rd Congress, September 25 and 27, October 4 and 18, 1973.]

Table 40. Estimated capital and annual cost of adding SO₂ removal systems on all TVA coal-fired plants.*

Capital cost	Amount
Installed cost of scrubber, Widows Creek unit 8 at \$76/kW	\$ 42 million
Installed cost of scrubbers on remaining 17,176,000 kW on system at \$68/kW ^a	<u>1168</u> million
Total installed cost of scrubbers	<u>\$1210</u> million
Annual cost	
Annual capital charges on \$1.2 billion investment at 10%	\$120 million
Annual operating and maintenance expense at 1.2 mills/kWh ^b	<u>105</u> million
Total annual cost	<u>\$225</u> million

^aThe weighted average estimate of installing scrubbers on all TVA units other than Widows Creek unit 8 is \$68/kW.

For comparison, the cost of the limestone scrubber installed on Commonwealth Edison's Will County Station has been reported as \$85/kW, not including sludge treatment costs.

^bBased on estimate for Widows Creek unit 8, distributed as follows:

	<u>Mills/kWh</u>
Raw material, limestone at \$3/ton delivered	0.26
Operating labor and supervision	0.05
Utilities	0.33
Analyses	0.01
Maintenance	<u>0.55</u>
Total direct operating and maintenance	<u>1.20</u>

*[Hearings before the Subcommittee on Energy, U.S. House of Representatives, 93rd Congress, September 25 and 27, October 4 and 18, 1973.]

Table 41. Costs of near-term options.*

	Low-sulfur fuel oil	Low-sulfur coal
Capital investment (10^6 dollars)	23	10
Annual charges (10^6 dollars/y)		
Annual capital charges	3.8	1.7
Additional fuel costs	32.9-42.4	32.9
Operating and maintenance costs	(1.0)	1.0
Derating cost	0	5.5-16.6 ^a
Forced outage cost	0	0
Total annual cost	35.7-45.2	41.1-52.2
Added power cost, mills/kWh	3.5-4.5	4.1-5.2

^aEstimated derating, 5-15%

*[Salmon, R., and J. P. Nichols, data presented in a paper at the 2nd AEC Pollution Control Conference, Albuquerque, NM, April 16-19, 1974.]

Table 42. Cost of alternative sulfur dioxide control strategies (NERA Study).^a

	Cost of SO ₂ control to consumers in 1980 (10 ⁹)		Aggregate capital requirements through 1980 (10 ⁹)		Compliance strategy that meets demand at lowest aggregate cost
	1975 dollars	1980 dollars	1975 dollars	1980 dollars	Strategy No.
Strategy 1:	\$ 4.9	1.19 ^b	\$ 2.35	\$ 12.0	1975: 100% unattainable 1980: 100% unattainable 1985: 100% unattainable 1990: 100% unattainable
Strategy 2:	118	27	14.7	11.2	1975: 100% unattainable 1980: 100% unattainable 1985: 100% unattainable 1990: 100% unattainable
Strategy 3:	215	142	8	11.7	1975: 100% unattainable 1980: 100% unattainable 1985: 100% unattainable 1990: 100% unattainable
Strategy 4:	1.02	1.06	0	1.27	1975: 100% unattainable 1980: 100% unattainable 1985: 100% unattainable 1990: 100% unattainable
Strategy 5:	1.17	1.17	0	1.1	1975: 100% unattainable 1980: 100% unattainable 1985: 100% unattainable 1990: 100% unattainable
Strategy 6:	1.24	1.2	1.4	1.1	1975: 100% unattainable 1980: 100% unattainable 1985: 100% unattainable 1990: 100% unattainable
Strategy 7:	4.41	42	11.4	1	1975: 100% unattainable 1980: 100% unattainable 1985: 100% unattainable 1990: 100% unattainable
Strategy 8:	13.9	13.4	13.6	11.1	1975: 100% unattainable 1980: 100% unattainable 1985: 100% unattainable 1990: 100% unattainable

^aFor analysis purposes it was assumed that oil plants presently capable of switching to coal did so without regard to economics.

^bThese strategies cause some plants to switch from SCS to low sulfur fuel, decreasing capital costs.

^cThese strategies were considered because evaluation of Strategy 6 showed it to place unattainable demands on eastern low-sulfur coal. Strategy 8 succeeds in balancing supply and demand, but Strategy 7, which substantially increases costs, does not.

*[Air/Water Pollution Report 13, 173 (1975).]

Fig. 16. Nationwide sources of sulfur oxides emissions, 1972. [National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Fig. 17. Estimated historical global sulfur dioxide emissions. [Robinson, E., and R. C. Robbins, J. Air Poll. Cont. Assoc. 20, 233 (1970).]

Fig. 18. Status of sulfur dioxide levels, 1973. [National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Fig. 19. Trends in sulfur dioxide concentrations, 1964-1972, NASN stations. [1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974).]

Fig. 20. National and regional trends in sulfur dioxide, 1970-1973. [1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974).]

Fig. 21. Downward trends of annual sulfur dioxide averages at downtown CAMP stations. New York curve added from data by Simon and Ferrand. [Ludwig, J. H., G. B. Morgan, and T. B. McMullen, "Trends in Urban Air Quality," *Trans. Amer. Geophys. Union* 51, 468 (1970), copyright by American Geophysical Union.]

Fig. 22. Comparison of sulfur dioxide trends in Chicago with regulations governing percent sulfur content in fuel. Note that the trend was for decreasing sulfur dioxide emissions even before regulations were introduced. [Health Consequences of SO₂, a Report from Chess 1970-1971, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-650/1-74-004 (1974).]

Oil	5/1	7/1	10/1
Fuel oil No. 5 and 6	1.0%		0.5%
Fuel oil No. 4	0.7%		0.4%
Fuel oil No. 2	0.3%		0.3%
Coal			
Bituminous	2.0%	1.0%	0.3% *
Anthracite	0.7%		0.3% *

*Bituminous and anthracite coal of this sulfur content are not being used because of scarcity.

Fig. 23. Comparison of sulfur dioxide trends in Philadelphia with regulations governing percent of sulfur content in fuel. Note that the trend was toward decreasing sulfur dioxide emissions even before regulations were introduced. ¹Health Consequences of SO₂, a Report from Chess 1970-1971, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-650/1-74-004 (1974).

Fig. 24. Comparison of sulfur dioxide trends at Bayonne, New Jersey, with regulations governing percent sulfur content in fuel. Health Consequences of SO₂, a Report from Chess 1970-1971, Environmental Protection Agency, NC, Publ. EPA-650/1-74-004 (1974). }

Fig. 25. Sulfur dioxide concentration vs time in years for New York City. [Health Consequences of SO₂, a Report from Chess 1970-1971, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-650/1-74-004 (1974).]

Nonradioactive Particulates

Natural Background Particulate Sources and Composition

The natural sources of direct injection into the atmosphere are wind-raised soil and sea salt, forest fires, and volcanic eruptions.

There is a background level of particulate matter, even in the most isolated areas. This material is largely evaporated sea spray (NaCl); sulfate from oxidation of hydrogen sulfide, usually as $(\text{NH}_4)_2\text{SO}_4$ or $(\text{NH}_4)\text{HSO}_4$; nitrate from oxidation of nitrogen dioxide; pollens; and organic material.

Data shows that benzene-soluble materials, presumed to be organic in nature, and sulfate constitute significant fractions of nonurban aerosols. Other data show that chloride from sea spray is also a ubiquitous aerosol constituent, but its mass concentration decreases over inland areas.

The organic materials are emitted by forests, particularly coniferous forests, hay fields, and so forth.

Terpenes, which constitute a large portion of the emissions, and other reactive hydrocarbons are rapidly photo-oxidized and photopolymerized in the presence of air, light, and nitrogen dioxide.

Anaerobic decay of vegetation produces hydrogen sulfide, which is oxidized first to sulfur dioxide by background ozone and then to sulfate. Some sulfate is traceable to evaporated sea spray.

The source of nitrate is not well understood; explanations include reaction of hydroxyl radicals with nitrogen dioxide to give nitric acid, and oxidation of nitrogen dioxide to nitrogen trioxide by ozone.

Aitken particles (0.005 – $0.1 \mu\text{m}$) are produced during combustion and photo-oxidation of organic materials and other natural processes. The chemical composition of these particles has not been established, partly because of the difficulties in collecting them. They apparently are not important nuclei for cloud, rain, or fog condensation, but, in view of their comparatively large surface area, could serve as sites for further reactions of other chemical constituents of polluted atmospheres, such as catalytic oxidation of sulfur dioxide and polymerization of hydrocarbon derivatives.

Particles whose radius is greater than $10 \mu\text{m}$ are so large that their rate of gravitational settling is high. These particles have significant concentrations of chloride, sulfate, and complex silicates from wind erosion of rocks and dust. Their importance on a number basis is negligible, but it can be significant on a mass basis.

Figure 26 is a schematic of the sources contributing to the composition of inorganic aerosols near the ocean-atmosphere interface: the oceans themselves, continental dust, volcanic ash, atmospheric production of particulates, and, to lesser extents, human activity and extraterrestrial inputs. Characteristic elements and elemental ratios can be used to determine some of these sources and detect ion fractionation at the sea-air interface.

Primary Particulate Sources and Composition

The major source of man-made primary particulate emissions nationwide are stack emissions from industrial processes such as used in the crushed stone industry, the cement industry, the iron and steel industry, and the forest products industry. (Table 43.)

Particulate stack emissions, particularly from coal-fired power generation plants, are significant nationwide, but are of secondary importance in California. Solid waste disposal and transportation are the next most important contributing sources in California. (Table 44.)

Particulate matter contributed by motor vehicle sources consists of carbon, metallic ash, aerosol hydrocarbons, and metallic particles. Particles larger than about 10 μm come mainly from mechanical processes such as grinding and spraying. Particles between about 1 and 10 μm come mainly from mechanical processes and from combustion. Those less than about 1 μm are generally produced by condensation of atmospheric gases. (Figure 27.)

Lead aerosols are an exception. These come from the combustion of leaded gasoline and have effective diameters generally between 0.1 and 10 μm . The main constituent of particulates from automotive sources is the lead salt $\text{PbCl}_2 \cdot \text{PbClBr}$. Elemental lead, lead oxybromides ($2\text{PbO} \cdot 3\text{PbBr}_2$, $\text{PbO} \cdot \text{PbBr}_2$), lead oxychlorobromide ($\text{PbO} \cdot \text{PbClBr}$), lead phosphate ($\text{Pb}_2\text{P}_2\text{O}_7$), and lead sulfate (PbSO_4) were also found in the particulate matter.

Lead halides and lead oxyhalides result from scavenging agents (ethylene dichloride and ethylene dibromide) added to fuel with tetraethyl lead (TEL). Elemental lead and lead oxide result from decomposition of TEL in the combustion chamber.

In urban air, particles bearing the elements aluminum, scandium, iron, and thorium are predominantly of large size. The most likely sources of large particles are fly-ash particles from coal combustion and windblown soil and rock dust. (Figure 28.)

The size distributions for cobalt, manganese, and cerium in urban particulates show both small- and large-particle components, indicating that each of these elements originates from two or more sources of comparable magnitude.

The size distributions for urban particles containing zinc, selenium, and antimony strongly favor small diameters. The size distributions suggest that all are released primarily by vaporization followed by condensation. (Figure 29.)

Secondary Particulate Sources and Composition

Secondary particulates, sulfates, nitrates, photochemical products, and carbonaceous aerosols are formed in the atmosphere from gaseous emissions such as nitrous oxides, sulfur oxides, and hydrocarbon vapors. Combustion-generated soot plays an important role in this gas-phase transformation process by first acting as catalyst to increase reaction rates and form new chemical species and then providing nucleation sites for deposition of materials and clustering and growth to form the final particle. (Figures 30 and 31.)

Three reduced forms of nitrogen are associated with ambient air pollution particulates: volatile ammonia (an ammonium compound other than, and in addition to, ammonium nitrate or ammonium sulfate) and two additional species assigned to amine and/or amide and to nitrile.

Nitrogen species of the same type and behavior can be synthesized in soot (or graphite) interactions with nitrogen oxide or ammonia.

Volatile hydroxyl and/or carboxyl ammonium salts are produced in soot-nitrogen oxide and soot-ammonia reactions at ambient temperatures, while amines, amides, and nitriles are produced at higher temperatures.

Particulate matter for Los Angeles smog sources is 70% inorganic (water, silicon dioxide, aluminum oxide, iron), 15% organic (hydrocarbons), and 15% miscellaneous, including fibers, pollens, high polymers, and carbon. About 15% of the particulate matter of the Pasadena aerosol resulted from primary natural sources and 25% from primary man-made sources. Forty percent of the total results from atmospheric reactions, and 25% is produced by the conversion of gas-phase hydrocarbons to particulate form. Altogether, about 70% of the total particulate burden has been accounted for, with water probably making up a significant portion of the missing 30%. (Tables 45 and 46.)

Because aromatics comprise a major portion of the total fraction, it can be assumed that the major sources given for benzo(a) pyrene (BaP) also apply to the benzene-soluble organics (BSO) fraction. The largest single source of

BaP is attributed to the rather inefficient combustion of coal in residential furnaces. This characterization is strongly contrasted with coal used in steam-electric utilities, where total BaP emissions represent less than 0.1% of the total. The other major sources of BaP in urban areas are: wood burning, 40 tons/y; enclosed incineration, 33 tons/y; vehicular exhaust, 32 tons/y; and, in certain areas, industrial processes, 200 tons/y, depending on the type of industry and its proximity to the main urban area. Coal refuse fires (340 tons/y) and forest and agricultural burning (140 tons/y) are major sources, but their contribution to urban concentrations of BaP are relatively minor because of their remoteness from an urban area. Thus, the major source of BaP emissions likely to be present in all urban areas that have a major impact on concentrations of BaP and BSO monitored at the center-city-oriented NASN stations are those from residential coal combustion, enclosed incineration, urban open burning, and vehicular travel. (Table 47.)

Trends

Total Suspended Particulate (TSP) Emissions - Nationwide total emissions of TSP matter from controllable and uncontrollable sources has been declining since 1940. During the 1960's, average ambient TSP levels in urban areas reportedly declined on the order of 25%. Composite TSP average for urban NASN stations decreased from approximately $110 \mu\text{g}/\text{m}^3$ in 1960 to $82 \mu\text{g}/\text{m}^3$ in 1972. At NADB stations, annual average TSP concentrations also exhibited nationwide declines, although most levels were still above the secondary standard in 1973. (Figure 32 and Table 48.)

Some of the apparent improvement can be attributed to the siting of power plants and other industrial point sources in outlying areas, away from the center-city locations of most NASN monitoring sites. Many industries around the country have installed control equipment to reduce particulate matter. A significant number of fuel users have shifted from coal to fuels that produce less particulate matter. (Figure 33.)

Individual cities have exhibited mixed trends in the past few years, as indicated by the ratio of annual average levels to EPA's primary ambient standard. (Figures 34-37.)

Although EPA's primary and secondary standards for ambient TSP were exceeded at most NASN stations in 1971, the nationwide percentage of NASN sites at which ambient TSP standards were exceeded declined during the past

decade. This improvement has been observed at a number of NASN locations where TSP readings had been highest in the 1960's. In 1972, for example, no violations of air quality standards were reported in 12 of the AQCR's that EPA had formerly classified as TSP Priority I (most severe) and Priority II.

Despite this improvement, most NASN stations continue to detect violations of ambient TSP standards. Moreover, some of the stations at which the lowest TSP levels were formerly observed have exhibited some apparent recent degradation. Of the 28 AQCR's classified as TSP Priority III (least severe) for which available 1972 data are sufficient for analysis, 9 exceeded the primary annual standard and 12 exceeded the primary 24-h standard. Thus, although it appears that ambient urban TSP levels have somewhat improved nationwide, especially in some of the worst areas, there also are signs of degradation in regions not previously assigned a high priority for TSP enforcement.

Values derived for the man-made effect on the trend in total worldwide airborne particulates (if assumed monotonic) range from 0.06 to 0.4% increase per year. Since such an effect would be only marginally detectable in the available record, the much larger rates of increase that have been published as proof of an upward trend must be due to local or temporary effects and cannot be representative of a global trend.

On the other hand, almost all urban areas plagued by dirty skies prior to 1950 have in recent years shown measurable improvement in terms of visibility, dust fall, suspended particulates, or the ratio of sunshine in the central city to that at an outlying station. This leads to the conclusion that while an upward trend in airborne particulates has existed throughout human history, it was halted and may even have been reversed over the past few decades. Regardless of how one feels about the reality of this former upward trend in airborne particulates, projections of currently estimated growth rates do not indicate any significant effect on global climate before exhaustion of our fossil fuels would bring such a trend to a halt.

Atmospheric levels of man-made organic particulate air pollution are on the decline in most urban areas. The term organic particulates refers to that of total particulate matter (dust, spray, and mist) that is soluble in benzene. These benzene-soluble organics include BaP, a potential carcinogen. BSO can constitute up to 10% of particulate matter in certain urban areas. Major sources of this type of pollution are coal burning in residential furnaces, wood burning, motor vehicle emissions, and open refuse burning.

Figure 38 shows the trends in BSO and BSO percent of TSP at 32 urban and 19 nonurban NASN stations, and Fig. 39 shows the composite annual average of BaP concentrations for 32 urban and 19 nonurban NASN stations. The decline in BaP and BSO in urban areas appears to be the result of existing control regulations affecting the burning of coal. Because the decline between 1960 and 1972 has been so dramatic, no national standard for control of these pollutants is anticipated. The present national strategy is to continue monitoring and to take no direct control action.

Figure 40 shows the trends in national coal consumption, BSO, and BaP annual averages. Even though the use of coal in electric utilities has about doubled from 1960 to 1970, its effect on center-city concentrations of BaP and BSO is generally minor. The two factors that account for this are:

1. The combustion process in power plants is more efficient, resulting in lower emissions of hydrocarbons
2. Usually the large electric generating plants are located outside the main urban area.

Another factor that has likely contributed to this downward trend has been the enforcement of regulations to control smoke emissions in most large metropolitan areas. In addition, there has been a trend toward the elimination of open burning and the use of more efficient combustion technology for solid waste disposal. (Figures 41-43.)

Figure 44 shows the estimated chronology of worldwide atmospheric particulate loading by volcanic activity and by human activity from 1850 to 1970. The average of volcanic loading is added for comparison (thin solid line). A rough calibration of volcanic loading in terms of planetary average temperature effect is shown outside the figure box on the right.

A crude relationship seems to exist between the dust content of the upper atmosphere and earth temperature. Various explanations have been offered for this relationship, the simplest and most plausible of which seems to be the reflection by dust particles of solar energy that would otherwise have reached the ground. The inference, therefore, is that particulate matter released to the atmosphere by whatever source will generally tend to depress earth temperatures.

Figure 45 shows the atmospheric extinction at Lowell Observatory, Flagstaff, Arizona. Routine measurements of atmospheric extinction made since

1955 reveal no evidence of any extinction increase caused by human activity. The middle curve, V.L., is Mitchell's estimate of volcanic dust loading of the stratosphere. The upper dots, Q, show the mean vertical extinction in the blue, and the lower dots, K, show the blue-yellow color index or reddening for an (unreddened) A0 star. It appears that the blue extinction and reddening vary with volcanic dust loading and suggest no trend over the period of record.

Figure 46 shows the chronology of mid-Atlantic aerosol data. In the North Atlantic the implication from air conductivity data is directly contradicted by the available Aitken nuclei counts. These show that in 1934, when U.S. consumption of fossil fuel was reduced because of the depression to about one-third of its present value, Landsberg found an average of 950 nuclei/cm³, well above the 1966-1971 average.

Figure 47 shows the Smithsonian aerosol extinction data at 0.391 and 0.395 μ m for Mount Montezuma, Chile. There has been no detectable change in the global atmospheric transmission measured from remote, high-altitude sites in the last half century.

Sulfates - With few exceptions, annual sulfate levels have essentially stayed unchanged during a period that evidenced numerous downward trends in TSP and sulfur dioxide. In effect, the observed decreases in TSP consisted of changes in its nonsulfate portion. As a consequence, the TSP sulfate percentage had consistently increased during the study period 1964-1970.

Of the 62 urban sites examined that had at least 6 annual means of TSP and sulfate for the 7 y of the study period, 23 sites (37%) showed significant downward trends in TSP. In fact, almost all (95%) had downward patterns, and none were significantly increasing. On the other hand, only 9 sites (15%) had significant trends in sulfates, some increasing and some decreasing. Sites that experienced declines in sulfates had more highly significant trends and, in most cases, had accompanying downward trends in sulfur dioxide and TSP.

Conversely, sulfates basically stayed unchanged at a majority of locations that experienced significant declines in sulfur dioxide or TSP. In fact, there is one instance where an upward trend in sulfate existed in spite of downward trends in both TSP and sulfur dioxide.

Although sulfate concentrations have basically remained unchanged while ambient levels of sulfur dioxide and TSP have declined in center-city locations, there is still significance in the broad geographic similarity that exists between overall ambient concentration levels of sulfur dioxide, the

sulfate fraction of the TSP, and area-wide sulfur dioxide emission densities. This is suggestive of different spatial distributions of emissions around center-city locations or different transport mechanisms affecting the source-receptor relationship between ambient sulfur dioxide and particulate sulfate.

The independent temporal behavior of sulfates as compared with TSP and ambient sulfur dioxide is also exemplified by the temporal change in the annual sulfate percentage of the total particulate. In almost all cases its overall pattern was increasing, and it was statistically significant at 16 sites (26%). An extreme example occurred when the sulfate percentage of TSP increased despite a significant decrease in both TSP and sulfur dioxide, as well as a decrease in the quantity of sulfates. (Figure 48.)

Because it has been assumed that a significant portion of sulfate compounds originate with the major sources of particulate or sulfur dioxide either directly or through atmospheric reactions working on the sulfur dioxide, the relatively constant level of sulfates presents something of a mystery. The circumstances responsible for these sustained levels of sulfates must be better understood before effective control strategies for sulfates can be developed. Factors identifying the actual formation of particulate sulfate and its relationship to sources of sulfur dioxide and other sulfur-bearing compounds must be identified to further pursue this absence of trend in the particulate sulfate fraction. (Figure 49.)

Respirable Aerosols - At the present time there exist no systematic direct measurements of respirable dust in the atmosphere over a period long enough to establish a trend. There are, however, indirect indications that pollution control measures, socio-economic factors, or meteorological long-term trends in some cities have resulted in long-term increases in small particles. This increase can be obtained from comparison of total suspended particulates from high-volume filter measurements that have a large-particle cutoff of about 80 μm and visibility and turbidity measurements that are most sensitive to particles with sizes close to visible wavelengths (about 0.5 μm).

A 10-y study of high-volume filter data from 58 urban sites and 20 nonurban sites showed no significant change in suspended particulates (33 and 13, respectively). A statistically significant number of urban sites (23) showed a decrease in particulates, while 6 nonurban sites showed an increase.

Visibility measurements made prior to 1957 showed obvious improvements in most cities from 1930 to 1945 as compared to the late 1950's. On the other

hand, deteriorating visibility or turbidity has been reported for the following areas:

1. Akron, Ohio; Lexington, Kentucky; and Memphis, Tennessee.
2. Tucson, Arizona
3. Los Angeles, California
4. Lick Observatory, California

There is some question as to whether the respirable aerosol is increasing in Los Angeles, because although the number of very good visibility days is decreasing this may have little effect on the total amount of aerosol. Few would suggest visibility is improving, however, and this is in contrast to a decrease in average high-volume sample concentration of $164.2 \mu\text{g}/\text{m}^3$ from 1957 to 1961 to $124.5 \mu\text{g}/\text{m}^3$ from 1962 to 1966. (Table 49 and Fig. 50.)

Tentative conclusions are that respirable size particulates are remaining constant or increasing. This matches the conflicting evidence that since 1957 high-volume aerosol mass measurements show a decrease apparently not matched by a visibility increase. In fact, in many cases there has been a visibility decrease.

Highly speculative evidence also comes from the fact that the physical appearance of high-volume filter mats in California with collected particles is changing to a uniform gray coat from a more granulated and less uniform appearance.

It is quite possible that present control strategies are not successful in reducing the respirable particulates in many major American cities. With the probability of future reduced control requirements resulting from increased energy needs, it is important to establish a monitoring program now for respirable particulates because these particles are dispersed great distances and trapped in the lung.

Figure 51 shows the Smithsonian aerosol extinction data at $0.391 \mu\text{m}$ for Table Mountain, California.

Figure 52 shows the trend of deteriorating visibility or turbidity as recorded at Lick Observatory.

Figure 53 shows a long-term deteriorating trend of atmospheric transmittance for solar radiation at Phoenix, Arizona. The transmittance is best in winter when surface concentration of particulates is highest.

Costs of Control

The EPA has estimated that the marginal additional cost resulting from the Federal emission standard on new steam generation would require a 6% increase in the total capital investment and a 4% increase in operating costs, on the basis of certain assumptions about ash content of fuel and efficiencies of precipitators, scrubber systems, and baghouses. If operating expenses of the U.S. electric utility industry are taken as \$10 billion per year, the 4% operating-cost increase would imply an additional cost of \$400 million annually for particulate control. (Tables 50-52.)

Particulate damages to data are estimated to fall between \$2 to 7 and 8 to 9 billion, with the best estimate at \$5 to 8 billion.

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Table 43. Nationwide particulate emissions, 1972 (10^6 tons).*

Transportation	0.8
Stationary fuel combustion	3.7
Industrial processes	9.3
Solid waste disposal	1.9
Miscellaneous combustion	4.1
Total	19.8

*[Lawrence Livermore Laboratory, staff compilation.]

Table 44. Summary of estimates of man-made emissions of primary particulates (10⁶ metric tons/y).*

Types of emissions	U.S. only				Worldwide				
	NAPCA	SCEP	Hidy and Brock	MRI	SCEP	Hidy and Brock	Peterson and Junge	Robinson and Robbins	Adopted for this study
Stationary combustion	8.1	8.1		5.4		21	43.8	43.8	24
Transportation	1.1	1.1		1.1			2.2	0.8	3
Industrial (total)	6.8	40.6	16.1	11.2	158		56.4	33.6	50
Iron & steel	1.7	13.9	1.3	1.6	54.6			10.2	
Other metals	0.24	0.58		0.54				1.8	
Minerals	0.75	2.3		0.82				2.3	
Cement, sand, etc.	2.1	14.9		5.64	60.9	11.7		5.9	
Fuel processing	0.26	0.96		0.21				3.7	
Pulp & paper	0.65	4.3	3.1	0.53	9.5			0.4	
Grain, feed, etc.	1.0	3.3		1.65	33.0			8.4	
Chemicals	0.08	0.38		0.22				0.93	
Solid wastes	1.0	1.0		0.84			2.4	3.8	2
Agricultural burning	2.2	2.18		2.2	21.8				22
Slash & litter burning				15.4					
Miscellaneous	0.45			1.16			28.8	7.0	25
Totals	19.6	86.8		37	179.8	35-100	133.2	83	126

*[Ellsaesser, H. W., The Changing Global Environment, S. F. Singer, Ed. (D. Reidel, Dordrecht-Holland, 1975).]

Table 45. Typical composition of particulate matter in Los Angeles smog.*

Type	Component		Percent of total
	Metal	Nonmetal	
Inorganic (70%)		H ₂ O	10
	Si(SiO ₂)		10
	Al(Al ₂ O ₃)		10
	Fe		10
		NO ₃ ⁻	5
	Ti(TiO ₂)		5
	Ca		4
		SO ₄ ⁻⁻	1
	Mg		1
	Ba		1
	Na		1
	K		1
		NH ₄ ⁺	0.7
	Pb		0.5
	Zn		0.5
		Cl	0.3
	V(V ₂ O ₅)		0.1
	Mn		0.1
	Ni		0.1
		F	0.05
Organic (15%) (solvent soluble)	Trace metals: Sn, Cu, Zr, B, Cr, Bi, Co		less than 0.01
	Hydrocarbons (aliphatic: aromatic = 15.1)		
	Acids		15
	Aldehydes		

Table 45. (Continued)

Type	Component		Percent of total
	Metal	Nonmetal	
Miscellaneous (15%)	Fibers		
	Polens ($>5\mu$)		
	High Polymers		15
	Carbon		

*[From Cadle, R. C., Particles in the Atmosphere and Space (Reinhold Publishing Co., New York, 1966), © 1966 by Litton Educational Publishing, Inc.
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Table 4b. Source contributions to Pasadena aerosol, September 3, 1969.*

	Percentages
Natural background	
Primary	
Sea salt	1.3
Soil dust	11.4
Secondary	
Organic vapors from plants	Unknown
Ammonia	
Hydrogen sulfide	
Man-made	
Primary	
Automobile exhaust	8.2
Tire dust	0.8
Cement dust (roads and construction)	1.7
Fuel oil fly ash	0.1
Diesel exhaust	1.8
Aircraft exhaust	2.7
Industrial emissions	7.3
Secondary	
Sulfur dioxide → sulfite	>10
Nitrogen oxides → nitrate	>0.1
Organic vapors → particulate	26.7
	Total >72.3

*[Friedlander, S. K., *Env. Sci. & Tech.* 7, 235 (1973), reprinted with permission. Copyright by the American Chemical Society.]

Table 47. Estimated benzo(a) pyrene emissions in the U.S., 1968.*

Source category	Emissions (tons/y)
Heat and power generation	
Coal	
Residential furnaces	420
Intermediate units (commercial)	10
Steam power plants	1
Oil	2
Gas	2
Wood	40
Refuse burning	
Enclosed incineration	33
Open burning	
Coal refuse fires	340
Forest and agricultural burning	140
Other (vehicle disposal and domestic, commercial, and industrial burning)	74
Industrial processes	~200
Vehicular traffic	32
Total	~1300

*[Lawrence Livermore Laboratory, staff compilation.]

Table 48. Total suspended particulates: estimated total nationwide emissions (10⁶ tons/y).*

	1940	1950	1960	1970
Controllable	19.2	20.8	21.0	22.3
Total ^a	44.9	33.2	29.9	25.5

^aIncludes sources considered "uncontrollable" by EPA's definition. These include such categories as forest, structural, and agricultural fires. Because the year-to-year variability in "uncontrollable" sources can be great, the apparent downward trend in estimated total emissions should be viewed with caution. Estimated total TSP emissions for 1969, for example, were 35 million tons.

*[1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974); Council on Environmental Quality, Environmental Quality, 5th Annual Report, USGPO, Washington, DC (1974).]

Table 49. Percent frequencies of visibilities in the range 0-6 mi after excluding hours with rain and hours with relative humidities exceeding 69% for the periods June-September 1962-1965 and June-September 1966-1969. The trend is of deteriorating visibility.*

Period	Hours (EST)					
	0700	1000	1300	1600	1900	All
Akron, Ohio						
1962-1965	27.3	18.9	11.0	6.3	7.8	11.3
1966-1969	37.0	39.0	25.5	23.5	23.1	27.3
Change	+9.7	+20.1	+14.5	+17.2	+15.3	+16.0
Lexington, Kentucky						
1962-1965	0.0	12.2	9.5	10.0	7.7	9.4
1966-1969	20.0	27.2	22.2	22.3	24.6	23.8
Change	+20.0	+15.0	+12.7	+12.3	+16.9	+14.4
Memphis, Tennessee						
1962-1965	0.0	10.0	7.0	4.1	3.0	5.8
1966-1969	7.7	17.0	11.2	8.6	5.4	10.2
Change	+7.7	+7.0	+3.3	+4.5	+2.4	+4.4

*[Miller, M. E., et al., "Visibility Changes in Ohio, Kentucky, and Tennessee from 1962 to 1969," Monthly Weather Rev. 100, 67 (1972).]

Table 50. Costs of specific disposal systems.*

Industry	Collected material	Treatment	Transport	Storage	Final disposal	Cost estimate (dollars/ton)
Power generation	Fly ash	Sedimentation	Pipeline	Settling pond	Landfill (sediment)	0.75
Power generation	Fly ash		Truck	Mound	Landfill	0.55
Power generation	Fly ash		Truck	Mound	City dump	1.10
Power generation	Fly ash	Form pellets	Vacuum system, truck, barge	Transfer bins, storage silo at sea	Landfill or dump	2.00
Power generation	Fly ash	Form slurry	Pipeline	Settling pond	Landfill (sediment)	2.00
Power generation	Fly ash	Wetted	Pneumatic pipeline truck	Storage silo	Landfill	2.00
Power generation for chemical plant	Fly ash	Sedimentation	Pipeline		Lagoon	1.60
Power generation for chemical plant	Fly ash		Truck	Silos	Landfill	0.90
Chemical		Slurry (100,000 gal/d)	Barge	Tank	Dump at sea	3.00
Chemical	Weak acid (large volume)		Barge	Tank	Dump at sea	1.00
Power generation for pulp and paper	Fly ash	Sedimentation	Pipeline		Lagoon	2.30
Gray iron foundry	Cupola dust	Water clarification	Sediment by truck	Dempster dump	Landfill	1.40
Petroleum refining	Non-dewatered sludge		Contract hauling		Landfill	4.75
Petroleum refining	Dewatered sludge		Contract hauling		Landfill	2.50
Petroleum refining	Sludge, filter cake, oily solids		Truck		In-plant landfill	20.00
Petroleum refining	Oily solids		Barge		Dump at sea	7.50
Petroleum refining	Catalyst fines		Contract hauling		Landfill	2.75
Portland cement	Waste dust	Slight wetting	Conveyor, truck	Bins	Landfill	1.05
Soaps and detergents	Suspended solids		Pipeline		Municipal treatment plant	2.50

*[Control Techniques for Particulate Air Pollutants, USHEW, National Air Pollution Control Administration, Washington, D.C., January, 1969.]

Table 51. Total installation cost for various types of control devices expressed as a percentage of purchase costs.*

Equipment type	Cost (%)			
	Low	Typical	High	Extreme high
Gravitational	33	67	100	---
Dry centrifugal	35	50	100	400
Wet collector:				
Low, medium energy	50	100	200	400
High energy ^a	100	200	400	500
Electrostatic precipitators	40	70	100	400
Fabric filters	50	75	100	400
Afterburners	10	25	100	400

^aHigh-energy wet collectors usually require more expensive fans and motors.

*[Control Techniques for Particulate Air Pollutants, USHEW, National Air Pollution Control Administration, Washington, D.C., AP-61, January, 1969.]

Table 52. Installed costs of control equipment.*

Collector type	Approximate installed cost (10^3 dollars)						
	Gas flow rates (1000 actual ft^3/min)						
	2	5	10	15	100	300	500
Gravity	0.5	1.2	2.6	15	28	---	---
Mechanical	---	---	4	13	23	80	---
Wet	---	7.5	10	30	55	150	---
High-voltage electrostatic precipitator	---	---	---	85	120	265	415
Low-voltage electrostatic precipitator	---	13	24	105	200	---	---
Fabric filter:							
High temperature (550°F)	---	---	30	88	155	430	720
Medium temperature (250°F)	---	---	15	45	82	225	375
Afterburner, direct flame catalytic	8.2	12	18	---	---	---	---
	16	20	29	---	---	---	---

*[Control Techniques for Particulate Air Pollutants, USHEW, National Air Pollution Control Administration, Washington, DC, AP-51, January 1, 1969.]

Fig. 26. A marine aerosol. [Data presented in Bressan, D. J., et al., paper No. 123 at the 162nd Amer. Chem. Soc. Meeting, September 15, 1971.]

Fig. 27. Nationwide sources of particulate emissions, 1972. [Lawrence Livermore Laboratory, staff compilation.]

Fig. 28. Chemical elements in polluted atmospheres. The inner ring encloses elements present in the natural background (soil dust and marine aerosols). The second ring encloses primary particulate matter introduced by man. The outer ring encloses secondary material formed in the atmosphere. [Friedlander, S. K., *Env. Sci. & Tech.* 7, 235 (1973), reprinted with permission. Copyright by the American Chemical Society.]

Fig. 29. Status of suspended particulate levels, 1973. [National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Fig. 30. Nonurban average sulfate concentration. [Health Consequences of SO_2 , a Report from Chess 1970-1971, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-650/1-74-004 (1974).]

Fig. 31. Urban sulfate concentrations, 1970. Within approximately the eastern half of the continental U.S., levels of sulfate were higher at urban sampling sites than at nonurban sites. [Health Consequences of SO_2 , a Report from Chess 1970-1971, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-650/1-74-004 (1974).]

Fig. 32. National and regional trends in total suspended particulate, 1970-1973. A general decline in total suspended particulate levels occurred throughout the nation. This trend occurred in all five geographic areas, as indicated by the regional and national composite averages. [1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974).]

Fig. 33. Trends in total suspended particulate concentrations, 1960-1972, at NASN stations. (a) Composite annual averages at urban and nonurban stations. (b) Composite averages and 90th percentiles of annual maximum daily concentrations at 95 urban stations. [Council on Environmental Quality, *Environmental Quality, 5th Annual Report*, USGPO, Washington, DC (1974).]

Fig. 34. Dustfall data for six cities: Pittsburgh, Cincinnati, Chicago, New York, Detroit, and Philadelphia. [Ludwig, J. H., G. B. Morgan, and T. B. McMullen, "Trends in Urban Air Quality," *Trans. Amer. Geophys. Union* 51, 468 (1970), copyright by American Geophysical Union.]

Fig. 35. Trends in particulate matter for Montana, Salt Lake Basin, New York City, and the Chicago area. [Health Consequences of SO_2 , a Report from Chess 1970-1971, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-650/1-74-004 (1974).]

Fig. 36. Total suspended particulate vs time, Chicago, 1950-1970. [Health Consequences of SO_2 , a Report from Chess 1970-1971, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-650/1-74-004 (1974).]

Fig. 37. Dustfall particulate vs time, Chicago, 1950-1970. [Health Consequences of SO_2 , a Report from Chess 1970-1971, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-650/1-74-004 (1974).]

Fig. 38. Trends in BSO and BSO percent of TSP at 32 urban and 19 nonurban NASN stations. [1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974).]

Fig. 39. Composite annual average of BaP concentrations for 32 urban and 19 nonurban NASN stations. [1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-74-007 (1974).]

Fig. 40. Trends in national coal consumption, BSO and BaP annual averages. [1973 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-45/1-74-007 (1974).]

Fig. 41. Dustfall concentration vs time in years for New York City. [Health Consequences of SO₂, a Report from Chess 1970-1971, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-650/1-74-004 (1974).]

Fig. 42. Coefficient of haze (COH) vs time in years for New York City. [Health Consequences of SO_2 , a Report from Chess 1970-1971, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-650/1-74-004 (1974).]

Fig. 43. Total suspended particulate concentration vs time in years for New York City. [Health Consequences of SO₂, a Report from Chess 1970-1971, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-650/1-74-004 (1974).]

Fig. 44. Estimated chronology of worldwide atmospheric particulate loading by volcanic activity and by human activity, 1850-1970. Average of volcanic loading added for comparison (thin solid line). Rough calibration of volcanic loading in terms of planetary average temperature effect is shown outside margin at right. [Mitchell, J. M., Jr. "A Reassessment of Atmospheric Pollution as a Cause of Long-Term Changes of Global Temperature," in The Changing Global Environment, S. F. Singer, Ed. (D. Reidel Publishing Co., Dordrecht, Holland, 1975).]

Fig. 45. Atmospheric extinction at Lowell Observatory, Flagstaff, Arizona. (V. L.) Mitchell's estimate. (Q) Mean vertical extinction in the blue. (K) Blue-yellow color index. [Jerzykiewicz, M., "A Study of Atmospheric Extinction Observations Made at Flagstaff, Arizona, 1955-1972," in *Project ASTRA*, Publ. 15, N. Laulainen and P. W. Hodge, Eds. (University of Washington, Seattle, Washington, 1972).]

Fig. 46. Chronology of mid-Atlantic aerosol data. [Hogan, A. W., M. H. Degani, and C. Thor, Study of Maritime Aerosols, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-R3-72-025 (1972).]

Fig. 47. Smithsonian aerosol extinction data at 0.391 and 0.395 μm for Mount Montezuma, Chile. [Roosen, R. G., R. J. Angione, and C. H. Klemcke, "Worldwide Variations in Atmospheric Transmission: 1. Baseline Results from Smithsonian Observations," Bull. Amer. Meteorol. Soc. 54, 307 (1973).]

Fig. 48. Urban and nonurban long-term sulfate trends at NASN monitoring stations. [Compiled from data in 1972 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-73-004 (1973).]

Fig. 49. Nationwide distribution of average sulfate (a) concentrations, 1968-1970, and (b) fractions expressed as percent of total particulates, 1968-1970. [1972 Monitoring and Air Quality Trends Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/1-73-004 (1973).]

Fig. 50. Average daily noontime visibilities in Los Angeles. The trend is of deteriorating visibility. [Keith, R. W., Downtown Los Angeles Noon Visibility Trends, 1933-1969, Air Pollution Control District, Los Angeles, CA, Air Quality Report No. 65 (1970).]

Fig. 51. Smithsonian aerosol extinction data at $0.391 \mu\text{m}$ for Table Mountain, California. There has been no detectable change in the global atmosphere transmission from remote, high-altitude sites in the last half century. [Roosen, R. G., R. J. Angione, and C. H. Klemcke, "Worldwide Variations in Atmospheric Transmission: 1. Baseline Results from Smithsonian Observations," Bull. Amer. Meteorol. Soc. 54, 307 (1973).]

Fig. 52. Trend of deteriorating visibility or turbidity, Lick Observatory. [Goodwin, J. P., and A. J. Klien, "A Literature Search for Published Extinction Values," in Project ASTRA, Publ. 14 (University of Washington, Seattle, Washington, 1972).]

Fig. 53. Long-term trend of atmospheric transmittance for solar radiation at Phoenix, Arizona. The trend is of deteriorating transmittance. Note that transmittance is best in winter when surface concentration of particulates is highest. [Idso, S. B., "Solar Radiation Measurements Augment Air Pollution Studies," J. Air Poll. Cont. Assoc. 22, 364 (1972).]

Organic Gases

Sources

Atmospheric hydrocarbons arise almost totally from one of four separate sources: biological, petroleum, coal, and natural gas. Other sources include industrial processes, organic-solvent evaporation, forest fires, agricultural burning, gasoline marketing, geothermal wells, and coal gasification and liquefaction processes. Biological sources of hydrocarbons are associated with the blue haze of forested areas (terpenes) and swamps, tropical areas, lake sediments, and paddy soils (marsh gas). (Table 53.)

In 1972, 58.3% of all hydrocarbon emissions in the U.S. resulted from the incomplete burning of gasoline and other petroleum-distillate fuels in internal combustion engines. In California 68% of all hydrocarbons come from this source. (Tables 54 and 55 and Fig. 54.)

On a global scale almost half of all hydrocarbon emissions come from the transportation sector. Ninety-five percent of the total man-made emissions originate from sources in the northern hemisphere. (Figure 55.)

Trends

On a national level, emissions of hydrocarbons from fossil-fuel combustion, which have been increasing since 1920 to a high of 37.4×10^6 tons in 1969, are showing signs of decreasing. The 1972 level was at 27.8×10^6 tons/y, about the same quantity as generated in 1965. (Table 56 and Fig. 56.)

Costs of Control

Emissions from Stationary Sources - Costs for reducing hydrocarbon emissions from combustion processes are low and may sometimes show an overall profit due to increased combustion efficiency. Switching to another type of fuel may sometimes be more expensive on a cost/Btu basis. But when operation, maintenance, and combustion efficiency savings are included, the overall cost may be moderate. In addition, other atmospheric emission problems will be reduced when a more easily burned fuel is used.

Emissions from Mobile Sources - Average initial costs of emission-control systems installed in 1971 cars (based on available sticker prices and informed estimates) for both hydrocarbons and carbon monoxide control are estimated at

\$36 to 50/car (cost to consumer). Future costs of systems under development for further reducing hydrocarbons and carbon monoxide exhaust emissions may be from zero to \$45/car/y.

The total cost for controlling hydrocarbons and carbon monoxide for light- and heavy-duty vehicles for the 1968-1977 models is estimated at about \$25 billion. The annualized cost in 1977 for controlling both of these closely associated pollutants is estimated to be about \$4.2 billion.

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Table 53. Global production rates of methane in various fields.*

Source	Average source strength (g/km ² ·y ¹)	Total area (km ²)	Annual production (g/y)
Paddy fields	2.1×10^8	9.2×10^5	1.9×10^{14}
Swamps	2.1×10^{8b}	2.6×10^{6c}	5.4×10^{14}
	1.05×10^{8d}	2.6×10^{6c}	2.7×10^{14}
Enteric fermentation of animals			4.5×10^{13}
			7.3×10^{13}
Forests	0.9×10^4	4.4×10^7	4×10^{11}
Upland fields, grassland, brush- land, cultivated areas	4.4×10^5	3×10^7	1×10^{13}
Humid tropical areas	2.1×10^{7e}	2.9×10^7	6.1×10^{14}
Total Biogenic production rate			5.2×10^{14} to 15.1×10^{14}
Coal fields			2×10^{13}
Amount of CH ₄ in the atmosphere (based on 1.41 ppm mixing ratio)			4.0×10^{15}
Annual output of CH ₄ from natural-gas wells in 1965			5.2×10^{14}
Annual production of dry organic matter			1.65×10^{17}

*[Koyama, T., "Gaseous Metabolism in Lake Sediments and Paddy Soils and the Production of Atmospheric Methane and Hydrogen," J. Geophys. Res. 68, 3971 (1963), copyrighted by American Geophysical Union.]

Table 54. Nationwide emissions of man-made hydrocarbons, 1972 (10^6 tons/y).*

Transportation	16.2
Stationary fuel combustion	0.2
Industrial processes	6.5
Solid waste disposal	4.5
Miscellaneous combustion	0.4
Total	27.8

*[1972 National Emissions Report, Environmental Protection Agency, Research Triangle Park, NC, Publ. EPA-450/2-74-012 (1974).]

Table 55. Methane concentration in geothermal fluids.*

Location	CH ₄ (wt%)
Geysers, California	13.5
Larderello, Italy	0.94
Matsukawa, Japan	1.15

*[Lawrence Livermore Laboratory, staff compilation.]

Table 56. Hydrocarbon emissions from industrial process losses, 1940-1970
(10³ tons/y).*

Source	1940	1950	1960	1968	1969	1970
Petroleum refineries	1680	2880	2710	2780	2300	2960
Natural gas liquids	--	--	--	--	700	810
Coke						
By-products	117	148	143	193	193	199
Beehive	12	23	4	5	5	6
Carbon black						
Furnace, oil	--	18	121	220	220	222
Furnace, gas	32	263	247	138	138	130
Channel	1430	1770	840	431	380	328
Total	3271	5098	4061	3767	3940	4659

*[Lawrence Livermore Laboratory, staff compilation.]

Fig. 54. Nationwide sources of man-made hydrocarbons, 1972. [Lawrence Livermore Laboratory, staff compilation.]

Fig. 55. Global sources of man-made hydrocarbon emissions, 1971. [Lawrence Livermore Laboratory, staff compilation.]

Fig. 56. Emissions of hydrocarbons from fossil-fuel combustion (10^6 tons/y).
[Lawrence Livermore Laboratory, staff compilation.]

Trace Metals

Sources

Sources of airborne metals are the combustion of fossil fuels and refuse, and sewage. Coal and heavy fuel oils provide nickel, which, along with mercury, arsenic, cadmium, beryllium, and lead, is regarded as one of the five most (potentially) hazardous metallic contaminants of the atmosphere. (Table 57 and Figs 57-60.)

Airborne metals derived from the combustion of fossil fuels generally occur in particulate form as the oxides and salts of the metal. Some metals, particularly mercury and arsenic, may appear as vapors in elemental or organometallic forms.

Volcanism and associated geothermal processes are natural sources of trace metals in the atmosphere, particularly mercury.

An indication of what elements may be mobilized more effectively through the volatilization process during the combustion of fossil fuels are found in observations of emissions from the dc arc. The general order of volatility of these elements, listed as volatile oxides, sulfates, carbonates, silicates, and phosphates, is as follows:

As, Hg> Cd> Pb, Bi, Tl> In, Ag, Zn> Cu, Ga> Sn> Li, Na, K, Rb, Cs

For the elemental states the order is as follows:

Hg> As> Cd> Zn> Sb> Bi> Tl> Mn> Ag, Sn, Cu> In, Ga, Ge

For the sulfides we have the following order:

As, Hg> Sn, Ge> Cd> Sb, Pb> Bi> Zn, Tl> In> Cu> Fe, Co, Ni, Mn, Ag

Thus, one would expect a preferential transfer of arsenic, mercury, cadmium, tin, antimony, lead, gold, thallium, silver, and bismuth, for example, to the atmosphere during fuel burning. (Tables 58-60.)

Amounts of such products as sulfur, lead, and mercury from fossil-fuel combustion that are increasing with time are being found in the Greenland glacial deposits. The surface sediments of the Sierra Leone Rise in the Atlantic Ocean contain detectable amounts of elemental carbon produced from fossil-fuel burning. (Figures 61-63.)

The toxic trace elements arsenic, antimony, cadmium, lead, selenium, and thallium were found to be most concentrated in the smallest respirable particles emitted from coal-fired power plants. These elements, or their compounds, are probably volatilized during combustion and preferentially absorb or condense onto the small particles that can most easily pass through conventional control equipment. (Table 60 and Fig. 64.)

It is estimated that over 1-billion tons/y of coal will be burned in 1990. In the conversion process this might result in the following yearly amounts of some trace elements: arsenic, 28×10^6 lb; cadmium 2×10^6 lb; lead, 20×10^6 lb; mercury, 0.4×10^6 lb; and nickel, 30×10^6 lb. These quantities could be emitted in fairly concentrated areas of large coal deposits where the conversion complexes will be located.

Soils around a coal-burning plant are enriched in silver, cadmium, cobalt, chromium, copper, iron, mercury, nickel, titanium, and zinc. Plant materials are enriched in cadmium, iron, nickel, and zinc. Soil enrichments correlate with wind patterns and with the metal content of coal, except for only slightly enriched mercury. (Table 61.)

Trends

The amount of trace elements mobilized into the atmosphere by various processes has increased exponentially in the last 50 y. (Table 62.)

It is not known what amount of trace elements can be absorbed by plants, aquatic life, or human beings before mobilization processes must be severely interrupted.

Costs of Control

Estimates of the cost of controlling lead emissions are given in terms of additional refining costs for producing gasoline with an octane rating high enough so that the addition of antiknock agents such as tetraethyl lead is not necessary. These costs range from about 0.2 to 0.9 cents/gal for 93-octane gasoline, which is adequate for all cars made in 1971 and later. The cost of converting over to lead-free gasoline would be in the neighborhood of \$200 million/y increased fuel prices.

The costs of controlling beryllium and mercury are probably negligible at present in the energy-producing sector.

The costs of controlling metallic emissions from stationary sources are closely related to particulate control where coal or petroleum are used as fuels.

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Table 57. Trace metals most abundantly found in the atmosphere primarily from the production or consumption of energy.*

Metal	Major source
Cadmium	Fire smelters, some in coal
Beryllium	Coal, incinerators
Lead	Gasoline
Nickel	Coal, petroleum
Arsenic	Coal, petroleum, smelters
Mercury	Coal, geothermal sources

*[Lawrence Livermore Laboratory, staff compilation.]

Table 58. Impact and emission tabulation for the coal fuel cycle data and estimates for the year 1970.*

Rough estimate of airborne trace elements from power plant operation				
Chemical element	Concentration in coal (ppm)	Total, coal-fired plants, element basis (tons/y)	Stack emission	
			Per 10 ⁶ Btu in coal (lb)	Per m ³ of flue gas (STP) (mg)
Arsenic	5	800	2.3×10^{-4}	0.2
Barium	64	1,900	5×10^{-4}	0.6
Beryllium	2	100	3×10^{-5}	0.04
Boron	55	1,600	4.4×10^{-4}	0.53
Cerium	5	150	4×10^{-5}	0.05
Chromium	20	600	1.6×10^{-4}	0.2
Cobalt	12	360	10^{-4}	0.12
Copper	12	360	10^{-4}	0.12
Gallium	5	150	4×10^{-5}	0.05
Germanium	8	240	6.4×10^{-5}	0.08
Lanthanum	10	300	8×10^{-5}	0.1
Lead	9	270	7×10^{-5}	0.09
Lithium	40	1,200	3×10^{-4}	0.4
Manganese	30	900	2.4×10^{-4}	0.3
Mercury	2	600	1.6×10^{-4}	0.2
Molybdenum	6	180	5×10^{-5}	0.06
Neodymium	4	120	3×10^{-5}	0.04
Nickel	20	600	1.6×10^{-4}	0.2
Niobium	4	120	3×10^{-5}	0.04
Rubidium	25	750	2×10^{-4}	0.25
Samarium	1.6	50	1.5×10^{-5}	0.02
Scandium	8	240	6.4×10^{-5}	0.08
Selenium	3	90	3×10^{-5}	0.03
Strontium	85	2,500	7×10^{-4}	0.8
Tin	2	60	1.6×10^{-5}	0.02
Titanium	400	12,000	3×10^{-3}	4
Vanadium	33	1,000	2.6×10^{-4}	0.33

Table 58. (Continued)

Rough estimate of airborne trace elements from power plant operation				
Chemical element	Concentration in coal (ppm)	Total, coal-fired plants, element basis (tons/y)	Stack emission	
			Per 10^6 Btu in coal (lb)	Per m^3 of flue gas (STP) (mg)
Yttrium	12	360	10^4	0.12
Zinc	40	1,200	3×10^{-4}	0.4
Zirconium	76	2,300	6×10^{-4}	0.77

*[Hub, K. A., J. G. Asbury, and W. A. Buehring, Argonne National Laboratory, Argonne, IL, Rept. ANL-8093, Vol. 2 (1973).]

Table 59. Amounts of elements mobilized into the atmosphere as a result of weathering processes and the combustion of fossil fuels (ppm).*

Element	Fossil fuel concentration ^{a,b} (ppm)		Fossil fuel mobilization ^{b,c} (10 ⁹ g/y)			Weathering mobilization (10 ⁹ g/y)	
	Coal	Oil	Coal	Oil	Total	River flow ^d	Sediments ^e
Li	65		9			110	12
Be	3	0.0004	0.41	0.00006	0.41		3.6
B	75	0.002	10.5	0.0003	10.5	360	
Na	2,000	2	280	0.33	280	230,000	57,000
Mg	2,000	0.1	280	0.02	280	148,000	42,000
Al	10,000	0.5	1,400	0.08	1,400	14,000	140,000
P	500		70			720	
S	20,000	3,400	2,800	550	3,400	140,000	
Cl	1,000		140			280,000	
K	1,000		140			85,000	
Ca	10,000		1,400	0.82	1,400	540,000	48,000
Sc	5	0.001	0.7	0.0002	0.7		70,000
Ti	500	0.1	70	0.02	70	0.14	10
V	25	50	3.5	8.2	12	108	9,000
Cr	10	0.3	1.4	0.05	1.5	12	780
Mn	50	0.1	7	0.02	7	36	700
Fe	10,000	2.5	1,400	0.41	1,400	250	2,000
Cu	5	0.2	0.7	0.03	0.7	24,000	100,000
Ni	15	10	2.1	1.6	3.7	11	8
Cu	15	0.14	2.1	0.023	2.1	7.2	160
Zn	50	0.25	7	0.04	7	250	80
Ga	7	0.01	1	0.002	1	720	10
Ge	5	0.001	0.7	0.0002	0.7	3	12
As	5	0.01	0.7	0.002	0.7		
Se	3	0.17	0.42	0.03	0.45	72	7.2
Rb	100		14			36	600
Sr	300	0.1	70	0.02	70	1,800	600
Y	10	0.001	1.4	0.0002	1.4	25	60
Mo	5	10	0.7	1.6	2.3	36	28
Ag	0.5	0.0001	0.07	0.00002	0.07	11	0.03
Cd		0.01		0.002			0.5
Sn	2	0.01	0.28	0.002	0.28		11
Ba	500	0.1	7	0.02	70	360	500
La	10	0.005	1.4	0.0008	1.4	7.2	40
Ce	11.5	0.01	1.6	0.002	1.6	2.2	90
Pr	2.2		0.31			1.1	11
Nd	4.7		0.65			7.2	50
Sm	1.6		0.22			1.1	13
Eu	0.7		0.1			0.35	2.1
Gd	2.6		0.22			1.4	13
Tb	0.3		0.042			0.39	
Ho	0.3		0.042			0.36	2.3
Er	0.6	0.001	0.085	0.0002	0.085	1.8	5.0
Tm	0.1		0.014			0.32	0.4
Yb	0.5		0.07			1.8	5.3
Lu	0.07		0.01			0.29	1.5
Re	0.05		0.007				0.001
Hg	0.012	10 ^f	0.0017	1.6	1.6	2.5	1.0
Pb	25	0.3	3.5	0.05	3.6	110	21
Bi	5.5		0.75				0.6
U	1.0	0.001	0.14	0.001	0.14	11	8

*These average values were obtained from a review of published values for the abundances of elements in coal and fuel oils. Wide variations exist for a given element, and the figures are presented as reasonable estimates from available data.

^bCoal and lignite are combined in this representation.

^cBased upon 1967 production figures.

^dCalculated from the data of Turekian. [Turekian, K. K., in *Handbook of Geochemistry*, K. H. Wedepohl, Ed. (Springer-Verlag, Berlin, 1969), Vol. 1, pp. 293-323.]

^eCalculated from the data of Goldberg. [Goldberg, E. D., in *Chemical Oceanography*, J. P. Riley and G. Skirrow, Eds. (Academic Press, London, 1965), Vol. 1, pp. 163-196.]

^fThis Hg value may be unrepresentative of petroleum in general. It is the only published value for Hg in fuel oils of which we are aware. The samples came from the Cymric oil field of California, an area near known Hg deposits.

*[Bertine, K. K., and E. D. Goldberg, *Science* 1973, 233 (1971), copyright 1971 by the American Association for the Advancement of Science.]

Table 60. Emission sources of lead.*

Source	Emission (tons)
Gasoline	180,000
Coal	830
Waste crankcase oil combustion	1,250
Lead alkyl manufacture	810
Primary lead smelting	680
Primary copper smelting	380
Fuel oil combustion	24

*[Hub, K. A., J. G. Asbury, and W. A. Buehring, Argonne National Laboratory, Argonne, IL, Rept. ANL-8093, Vol. 2 (1973).]

Table 61. Trace metals in soils and plant materials around a power plant.*

Metal	Background soils (ppm)	Enriched soils (ppm)	Background plants (ppm)	Enriched plants (ppm)	Soil enrichment (tons)	Total discharge (tons)	Calculated discharge (tons)
Fe	1500	2840	80	260	20,000	25,000	10,000
Ti	55.6	91.6	None detected		540	680	500
Zn	26.3	35.0	37	51	130	160	50
Co	2.3	4.6	None detected		34	42	5
Cr	4.6	6.5	None detected		28	35	10
Cu	2.8	4.6	10	8	26	32	15
Ni	2.4	4.0	0.5	2.1	24	30	15
Cd	0.55	1.46	0.12	0.35	14	18	
Ag	0.247	0.272	None detected		0.4	0.5	0.5
Hg	0.0079	0.0102	0.09	0.07	0.04	0.05	4

*[Klein, D. H., and P. Russel, Env. Sci. & Tech. 7, 357 (1973), copyright by the American Chemical Society, reprinted with permission.]

Table 62. Total mercury concentrations in four Greenland glacial ices.*

Sample	Depth (m)	Date	Mercury (ng/liter)
Camp Century	56.94	1850	13 ± 10
Site 2	54.12	1870	169 ± 15
Site 2	21.59	1930	100 ± 12
Camp Century	13.75	1940	50 ± 10

*[Carr, R. A., and P. E. Wilkness, Science 181, 843 (1973), copyright 1973 by the American Association for the Advancement of Science.]

Fig. 57. Dispersion of lead in the environment. [Hurtig, H, "Significance of Conversion Products and Metabolites of Pesticides in the Environment," in Environmental Quality and Safety, F. Coulston, Ed. (Academic Press, New York, and Georg Thieme Verlag, Stuttgart, 1972), Vol. 1, p. 60).]

Fig. 58. Mercury in feathers of birds of prey. Moving up the food chain: concentrations of mercury in Swedish birds of prey moved up as they ate birds that in turn had eaten seeds treated against mold with mercury dressings. [Jenkins, D. W. Smithsonian, 62 (April, 1972), copyright by the Smithsonian Institution.]

Fig. 59. Arsenic in tobacco, fish, and shellfish. Arsenic trioxide levels found in U.S. tobacco reflected the use of lead arsenate sprays. A few spot measurements indicate high and now lower levels of arsenic in shellfish. [Jenkins, D. W., Smithsonian, 62 (April, 1972), copyright by the Smithsonian Institution.]

Fig. 60. Mercury in humans, fish, and fish-eating birds. Mercury in tuna (and probably in oceans as a whole) has been fairly constant. But fish in many local areas have been badly polluted along with fish-eating birds. Content in humans may have declined. [Jenkins, D. W., *Smithsonian*, 62 (April, 1972), copyright by the Smithsonian Institution.]

Fig. 61. Trends of lead in glaciers and plants. Lead levels in glaciers, moss, and elm trees have been growing at similar rates, although the actual concentrations vary. Elm trees are graphed above in parts per 100 million, Poland glacier in parts per billion. Moss is shown in parts per million, Greenland glacier in parts per trillion. [Jenkins, D. W., *Smithsonian*, 62 (April, 1972), copyright by the Smithsonian Institution.]

Fig. 62. Trends of heavy metals in moss and trees. Information is sparse for the other toxic heavy metals, but these five are known to be on the increase in two environmental indicators (moss and tree rings). Zinc is shown in parts per 100,000. [Jenkins, D. W., *Smithsonian*, 62 (April, 1972), copyright by the Smithsonian Institution.]

Fig. 63. Lead concentrations in surface air as a function of time. [Volechak, H. L., and D. C. Gogenin, Chemical Analysis of the Environment (Plenum Press, New York, 1973), Vol. 5.]

Fig. 64. Consumption of mercury and estimated discharge of mercury from the combustion of coal and oil. Estimates of mercury discharge by the combustion of coal and oil are based on 1 ppm mercury in oil and 2 ppm mercury in coal. [Greenspoon, G. N., in Mineral Facts and Problems, 1970, Department of the Interior, Bureau of Mines, Washington, DC, Bull. 650 (1970).]

Hydrogen Sulfide

Sources

The primary natural source of hydrogen sulfide is decaying vegetation swamps, intertidal flats, and volcanic activity. Main industrial producers are oil refineries, natural gas plants, and geothermal power producers. (Tables 63-66.)

Trends

Average concentrations of hydrogen sulfide in the urban atmosphere are reported to range from 1 to 92 $\mu\text{g}/\text{m}^3$. Average concentrations at the Geysers, California, is reported to be 0.33% or 16 times the toxic level in undiluted geothermal steam.

The noncondensable gases constitute from 0.2 to 1.8% of the steam flow at the Geysers. Of this, 82.5% is carbon dioxide, 6.6% methane, 1.4% hydrogen, 1.2% inerts, 4.5% hydrogen sulfide, and 3.8% ammonia. Some of these gases dissolve in the condensate. This is the case for hydrogen sulfide, where a portion dissolves in the condensate and later escapes to the atmosphere when the condensate water is evaporated in the cooling tower.

If we assume that only 0.5% of the steam flow is noncondensable gas, the above figures indicate that hydrogen sulfide is present in the steam to the amount of 225 ppm. If a total of 1000 MW of power were produced, this would require 430×10^6 lb/d of steam. Thus, 97,000 lb/d of hydrogen sulfide will be released. This is roughly equivalent to the amount of sulfur released by a fossil-fueled power plant of the same size, burning low-sulfur oil.

An estimate of the amount of hydrogen sulfide in the Imperial Valley, California, assuming a likely steam rate of 20 lb/kWh from a 1000-MW plant, would lead to the production of 1.18×10^6 lb/d of sulfur. This number exceeds that experienced from fossil-fueled plants burning high-sulfur fuel.

The fraction of hydrogen sulfide that enters the atmosphere reacts rapidly with molecular oxygen to form sulfur dioxide and water or is dissolved in fog and cloud droplets where it is hydrolyzed and rapidly oxidized by dissolved molecular oxygen. The mean lifetime of atmospheric hydrogen sulfide due to

its reaction with tropospheric ozone alone would be only 1.7 d. Considering other reactions of hydrogen sulfide in the lower atmosphere, its actual residence time must be appreciably shorter than 1 d.

Hydrogen sulfide, which is added to the atmosphere in uncertain and possibly great quantities, is oxidized to sulfur dioxide, but the rate at which this oxidation takes place depends on a number of factors. Hydrogen sulfide can undergo a number of oxidation reactions involving atomic oxygen (O), ordinary molecular oxygen (O₂), and ozone (O₃). Hydrogen sulfide and ozone react to form mainly sulfur dioxide and water but only very slowly, except possibly in the presence of aerosol particles that can provide surfaces on which the reaction can take place. Hydrogen sulfide does not absorb solar radiation reaching the troposphere, that is, wavelengths greater than about 2900 Å. It does not, therefore, undergo photolysis or react photochemically with molecular oxygen.

Hydrogen sulfide, molecular oxygen, and ozone are soluble in water, and the rate of oxidation of hydrogen sulfide by these oxidants in solution, for example, in fog or cloud droplets, may be very fast. However, little is known concerning such reactions in the atmosphere.

The oxidation of hydrogen sulfide by atomic oxygen probably occurs to an appreciable extent in photochemical smog, and hydrogen sulfide reaching the stratosphere will also be oxidized in this manner. The rate-controlling step of this reaction can be represented by the equation

This reaction is followed by reaction chains producing sulfur dioxide, sulfur trioxide, and sulfuric acid.

Costs of Control

Hydrogen sulfide corrosion of silver has required substitution of gold contacts in electrical appliances at an estimated increased cost of \$14.8 million during 1963.

Abatement of air pollution resulting from the pulp and paper industry, in which hydrogen sulfide is a major factor, has cost approximately \$10 million/y and is predicted to increase to \$15 million/y in the immediate future.

Major expenditures have been made by refineries and natural gas plants to remove hydrogen sulfide from sour gases and to recover sulfide as a valuable by-product. (Figures 65 and 66.)

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Table 63. Sources of hydrogen sulfide emissions in coke plants.*

Source of emission	Cause of emission
<u>Condensation</u>	
Unburnt gases escaping from the gas torches	
In normal operation with torch shut off	Leakage at stop valves
With torch open during operational failures	Failure of ignition device
Gases escaping from water seals	Defective seals
Outflow collectors on coolers; collector and separator tanks	Gas escape from liquids
<u>Ammonia Scrubber</u>	
Outflow collectors and collector tanks	Gas escape from washing of fluid
Secondary coolers for primary-cooler outflow (in semi-direct process)	Escape of hydrogen sulfide with the cooling-tower vapors
<u>Benzol Scrubber and Plant</u>	
Outflow receivers of scrubbers and washing oil tanks	Gas escape from washing fluid
Cooler-ventilating lines	Escape of sulfur-containing compounds with low boiling point, together with ventilating gases
<u>Desulfurization of Gas</u>	
Outflow receivers and tanks for scrubbing fluid	Gas escape from washing fluid

*[Miner, S., Preliminary Air Pollution Survey of H_2S - A Literature Review, National Air Pollution Control Administration, Raleigh, NC (1969).]

Table 64. Deleted.

Table 65. Hydrogen sulfide content of coke-oven gas.*

Type of gas	$\mu\text{g}/\text{m}^3$
Nonpurified	5,000-11,000
Partially desulfurized	1,500-5,000
Municipal gas or pipeline gas	None

*[Miner, S., Preliminary Air Pollution Survey of H_2S - A Literature Survey, National Air Pollution Control Administration, Raleigh, NC (1969).]

Table 66. Total hemispheric hydrogen sulfide emissions (10^6 tons).*

Source	Total	Northern hemisphere	Southern hemisphere
Biological H ₂ S (land)	68	49 ^a	19 ^a
Biological H ₂ S (Marine)	30	13 ^b	17 ^b
Total	98	62	36

^aBased on ratio of land area between 65°N and 65°S.

^bBased on ratio of ocean areas between 65°N and 65°S.

*[Robinson, E., and R. C. Robbins, J. Air Poll. Cont. Assoc. 20, 233 (1970).]

Fig. 65. Approximate cost of gas desulfurization plants in 1967 (amine or other types). [Miner, S., Air Pollution Survey of H_2S , National Air Pollution Control Administration, USHEW, Raleigh, NC (1969).]

* Product capacity based on:

Hydrogen sulfide in sour gas, %	Sulfur recovery in sulfur plant, %
10	89
20	91
50	93
100	95

† Hydrogen sulfide in gas, %.

Fig. 66. Sulfur recovery plant investment. [Miner, S., Air Pollution Survey of H_2S , National Air Pollution Control Administration, USHEW, Raleigh, NC (1969).]

Water Vapor

Sources

The introduction of water vapor into the atmosphere might be considered a significant environmental factor if it results in local fog or icing, as from wet cooling towers or ponds, or if it increases the earth's cloud cover, which has been anticipated as a possible consequence of vapor trails from future supersonic-transport traffic in the stratosphere. (Table 67.)

Trends

The total quantity of water vapor emitted by human activities is small on a global basis compared with natural evaporation and transpiration from trees and plants.

Evaporative cooling towers and ponds can cause local problems. Continued losses from evaporation and drift in cooling towers and evaporation from ponds amount to about 1% of condenser flow. For a 1000 MW(e) plant using wet cooling towers, the water lost annually to the atmosphere would amount to some 15,000 to 20,000 acre-ft.

Under certain atmospheric conditions (temperatures below 60°F, relative humidity above 80%) condensing vapor plumes from cooling towers can descend to ground level as a fog. Cooling ponds produce less intense fogs over larger areas.

Water vapor ejected into the stratosphere by jet aircraft flying at altitudes of 60,000 to 70,000 ft would have a residence time estimated at 18 mo.

Future supersonic transports could increase the water vapor content of the stratosphere significantly if traffic levels of 500 transports are attained.

Costs of Control

The total improvement costs should be relatively small, compared to those of many of the other problems covered in this compilation. The costs associated with limiting of flights in the stratosphere cannot be defined at the present time.

Monitoring for the effects of stratospheric pollution costs (in 1971 dollars) approximately \$5 million/y for the 1975-1980 period and about \$22

million/y past 1980. These costs represent insurance against unwarranted overexpenditure for either adverse impacts of abatement measures. (Figure 67.)

References - Water Vapor

Council on Environmental Quality, Environmental Quality, 1st Annual Report, USGPO, Washington, DC (1970).

Harpporte, D., "Cooling Tower Site Consideration," Power Engineering 74, 682 (1970).

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

Table 67. Amount of water vapor associated with geothermal systems (vol%).*

Geysers, California

98.045

*[White, D. E., L. J. P. Muffler, and A. Truesdell, Econ. Geol. 66, 75 (1971).]

Fig. 67. Deleted.

RADIOLOGICAL FACTORS

Gaseous Radioactivity

Sources

Natural - The two major sources of natural radioactivity are the gases that emanate from minerals in the earth's crust and the interaction of cosmic radiation with gases in the atmosphere.

Soils and rocks contain naturally radioactive minerals such as radium-226 and radium-229 in variable amounts. As a result radon-222, thorium-220, and their daughter products emanate from the soil.

Interactions of cosmic rays with atmospheric gases produce a number of radioactive species, the most important of which are tritium, carbon-14, and beryllium-7. Of lesser importance are beryllium-10, sodium-22, phosphorus-32, phosphorus-33, sulfur-35, and chlorine-39. These interactions produce electrons, gamma rays, nucleons, and muons. At low radiation levels the muons account for 70% of the cosmic radiation. (Table 68.)

Nuclear Power - During nuclear reactor operation and during operation of fuel reprocessing plants volatile radioactive gases and vapors are formed that cannot be removed from air or other carrier gas streams by filtration. The most dangerous of these are tritium and the isotopes of iodine (iodine-131 and iodine-133) and the isotopes of krypton and xenon (krypton-87, krypton-88, xenon-133, xenon-135, and krypton-95). The release of plutonium isotopes and small amounts of other transuranic contaminants in gaseous effluent from fuel plants constitutes a potentially serious environmental hazard.

It is recognized that the potential burnup of nuclear power sources on entering the earth's atmosphere may present a hazard. Such incidents are likely to increase in frequency with time as the number of nations using space systems increases. At least three different isotopes (plutonium-238, promethium-147, and polonium-210) are used in such power sources. (Tables 69-72.)

Underground Nuclear Detonations - Experience with weapons testing and Plowshare cratering experiments indicates that less than 0.5% of the total radioactivity produced would escape even if a prompt venting accident were to occur. The radioactive nuclides most likely released would be tritium and the gaseous elements xenon, argon, krypton, and iodine.

The potential for prompt venting from an underground nuclear explosion is generally assessed in terms of scaled depth of burial (SDOB). This quantity is obtained by dividing the actual depth of burial (DOB) by the cube root of the explosive yield in ktons:

$$SDOB = \frac{DOB}{W^{1/3}}$$

The minimum SDOB for contained underground experiments at Nevada Test Site (NTS) is 350 ft/kton^{1/3}. Of 190 underground test shots at NTS since 1961, 10 had a significant leakage (a total release to the atmosphere of more than 100 Ci of radioactivity). None of the tests with an SDOB greater than 600 ft/kton^{1/3}, however, exhibited leakage. To minimize the possibility of prompt venting from an industrial Plowshare explosion, therefore, a reasonable limitation would be twice the minimum SDOB used at NTS, that is, 700 ft/kton^{1/3}. This limitation would require an actual minimum DOB as shown below:

<u>Yield (ktons)</u>	<u>Minimum DOB (ft)</u>
10	1510
25	2050
50	2660
75	2960
100	3260

The complex neutron spectrum of a nuclear device is capable of producing a variety of induced activities in the atmosphere. Table 73 lists the principle radionuclides induced in the air by a nuclear explosion, their half-lives, and their radiation content.

Nuclear Gas Stimulation Projects and Nuclear Mining Techniques - Experience gained from Projects Gasbuggy and Rulison and their followup studies indicates that natural gas produced from a nuclearly stimulated well field will contain small amounts of man-made radioactivity as it leaves the gas processing plant and enters commercial distribution channels.

Radionuclides found in gas produced from the completed experiments, Gasbuggy and Rulison, were tritium, carbon-14, argon-37, krypton-85, and mercury-203. Of the radionuclides found, tritium, carbon-14, and krypton-85

have been studied in greatest detail because they contribute over 99% of the potential dose equivalent at the radionuclide concentrations observed, and at those projected for future wells. (Table 74.)

The tritium concentration of 1 pCi/cm^3 is the value projected for the average concentration during the lifetime production of future wells. The concentrations for carbon-14 and krypton-85 are scaled to the tritium value on the basis of literature values or fission and activation yield. The tritium inventory is distributed in the $\text{H}_2\text{O-H}_2$ -hydrocarbon system with less than 25% of the total production in the form of hydrocarbons or hydrogen. The remaining 25% appears as tritiated water (HTO) that would normally be removed at the wellhead. (Tables 75 and 76.)

Carbon dioxide is also normally removed from natural gas before it enters commercial distribution channels. The tritium and carbon-14 present as hydrocarbons will be released as HTO and $^{14}\text{CO}_2$, respectively, when the gas is burned.

The critical exposure pathway was determined to be the release of combustion products from unvented appliances in the home. The estimated average total body dose from man-made radioactivity for the pathway is 0.02 mrem/y of gas use. The estimated lung dose due to natural radioactivity (radon) in the gas is 1.5 mrem/y. The critical man-made radionuclides are tritium, carbon-14, and krypton-85. The largest fraction of the local population dose received via the critical pathway is due to tritium followed by krypton-85.

Radioactive contamination of the end product of an industrial flowshare project (such as natural gas, copper ore, etc.) will of course depend on the particular application. The two radionuclides of principal concern in product contamination for natural gas stimulation are krypton-85 and tritium. Both are present in sufficient quantities and have long enough half-lives to pose a hazard. It is generally assumed that the gas released by this method will be consumed, at least partially, in individual households. Two hypothetical studies have been made to evaluate gaseous product contamination: one for Gasbuggy and the other for Rulison. The study for Gasbuggy predicted a maximum exposure from contaminated natural gas of 2.2 mrem/y for residents of Los Angeles and 2.5 mrem/y for residents of San Francisco.

Calculational modeling for Rulison indicated that the total potential dose that an individual would receive in a home in Grand Valley, Colorado, from an unvented gas stove and refrigerator operated with nonflared gas piped from the

project would be 39 mrems the first year; it would decrease correspondingly after that. The same study estimated that the total dose an individual in Grand Valley would receive from the same appliances using gas taken from the Rulison well after the operational flaring of some 400 million ft³ would be 0.03 mrems the first year and even lower doses in following years.

In the case of copper leaching applications, appreciable quantities of some fission products, such as strontium-90, cesium-137, and ruthenium-106, are expected to be present in the chimney in leachable form. Although only a small fraction of this radioactive material would be dissolved and carried to the surface, some radioactive contamination of the process facility will occur. Also, low-level residual radioactivity of the copper itself (produced by neutron activation) may affect its distribution as a consumer product. (Table 77.)

Geothermal - Radium and radon are known to be associated with certain geothermal manifestations, particularly hot springs. The concentration of radium in natural waters generally is below 10^{-9} $\mu\text{Ci/mliter}$, but concentrations exceeding 9×10^{-6} $\mu\text{Ci/mliter}$ have been reported for certain thermal springs in the U.S. and still higher concentrations have been reported for waters in other countries.

Radon, a gaseous radioactive decay product of uranium, has a half-life of 3.82 d and, being gaseous, will escape into the atmosphere through any natural or artificial opening. A small amount of radon would be a component of the noncondensable gas fraction of the stream; however, it ordinarily would pose no health and safety hazard as it would be dispersed into the atmosphere with a very short half-life. About 122 tons of radon gas escape to the atmosphere daily on a worldwide basis from natural sources, and buildups of radon gas are quite common where it becomes trapped beneath air inversion layers in the atmosphere. If inversion conditions were prevalent for an extended period of time over a geothermal area, the resultant buildup of radon gas would add only slightly to man's total radiological burden from other natural sources such as rocks and soils. However, monitoring will be required at each lease site to assure public health and safety protection.

Gamma-ray dose rates measured on-site at hot-spring systems in northern Nevada range from 2 to 500 $\mu\text{R/h}$, and depend mainly on the amounts of natural radioelements in the spring deposits. At several locations radon-222 emanating from the water causes recognizable gamma-ray anomalies. High radioactivities, primarily from radium-226, are associated with hot-spring systems dominated by

calcium carbonate, while silica-dominated systems are relatively low in radioactivity. Gamma spectrometry disclosed the enrichment of radium-226 with respect to its parent uranium in calcium-carbonate-dominated systems. Radium-226 preferentially associated with calcium; therefore, where tufa and siliceous sinter are present in a deposit, the calcareous material is highest in radioactivity. (Table 78.)

In the case of nuclear geothermal stimulation, radioactive contamination of the product steam could present a significant problem. Noncondensable gases present in the steam of a thermal-electric plant tend to collect in the condenser. In natural fields these gases are generally eliminated by venting to the atmosphere. In a nuclear-stimulated geothermal system, the operational venting of gases with radioactive components, primarily krypton and tritium, might be unacceptable. If a direct power cycle using steam from the cavity to operate the turbines were employed, contamination and deposition of radioactive materials, including strontium and cesium, throughout the entire working fluid system becomes an important consideration.

Trends in Releases from Nuclear Power Reactors

The buildup of tritium in the environment from the nuclear power industry will be superimposed on tritium already present from natural production processes and from atmospheric testing of thermonuclear weapons. At present the nuclear power industry production is small compared to the other two sources and will not reach natural production levels until about 1985. (Tables 79 and 80.)

The major source of tritium in the environment continues to be from past nuclear weapons tests. This will continue to be the case up until about 1995, at which point reactor production will become the predominant source if the present trend continues and there are no further thermonuclear explosions. The release of tritium and krypton-85 from fission reactors (and reprocessing facilities) is presently about 17 MCi/y. This is expected to rise to 36 MCi/y for tritium and 270 MCi/y for krypton-85 in 2020.

Overall amounts of power reactor gaseous effluents are increasing.

The average gaseous release rate from boiling water reactors (BWR's) are larger than those from pressurized water reactors (PWR's), but that factor has decreased from about 1000 to closer to 100 between 1967 and 1972.

Overall release rates of tritium in liquid effluents from BWR's and PWR's is the reverse of the situation for gaseous effluents. Those from PWR's have been about 100 times the rates from BWR's. Most of the reduction in the

overall averages is attributed to the lower release rates from "second-generation" plants.

An increase in the use of large heavy-water power reactors could substantially increase environmental tritium levels. It has been estimated that the tritium inventory would be doubled if 10% of the power production was from heavy-water reactors. Development of thermonuclear power sources could also increase tritium levels in the environment. The tritium production rate from a thermonuclear reactor has been estimated to be over 100,000 times greater than in a fission reactor. However, most of this material would be contained in the reactor for use as fuel material. Present information is insufficient to project future estimates of tritium from this source. (Figures 68-74.)

Costs of Control

The gas scrubber system for a typical BWR is estimated to cost about \$200,000.

Total gas scrubber system costs for a fuel reprocessing plant are expected to be under \$1 million.

Costs to maintain a safe environment for both workers and offsite residents, a totally enclosed facility, represent a trivial fraction of the total investment costs of fission and/or fusion plants.

References - Gaseous Radioactivity

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Table 68. Natural tritium distribution.*

	Tritium distribution (%)	Tritium ratio
Hydrosphere	90	<10
Troposphere		
Water vapor	0.1	≤80
Molecular hydrogen	0.02 to 0.2	4×10^3 to 3.5×10^4
Stratosphere		
Water	10	6×10^5
Molecular hydrogen	0.004 to 0.007	3×10^3 to 6×10^4

*[Lawrence Livermore Laboratory, staff compilation.]

Table 69. Gaseous radioactive wastes from U.S. atomic energy plants.*

Location	Type of plant	Amount of waste	Radioactive content
Hanford	Plutonium production plant	1 Ci/d	Iodine-131
Idaho	Reactor testing station	100,000 Ci/y	8 and noble gases
Oak Ridge National Laboratory	Reactor development and chemical processing laboratory	0.25 Ci/y	α (uranium)
Brookhaven National Laboratory	Nuclear research center	700 Ci/h	Argon-41

*[Compiled from data in Air Conservation, American Association for the Advancement of Science, Washington, DC, Publ. No. 80 (1965), p. 161, copyright 1965 by the American Association for the Advancement of Science.]

Table 70. Gaseous emissions from the uranium fuel cycle.*

Gases (including entrainment)	Quantity	Maximum effect per annual fuel requirement of model 1000-MW(e) LWR
Radon-222	75	Principally from mills, maximum annual dose rate <4% of average natural background within 5 mi of mill.
Radium-226	0.02	
Thorium-230	0.02	Results in 0.06 man-rem per annual fuel requirement.
Uranium	0.632	Principally from fuel reprocessing plants, whole-body dose is 4.4 man-rem per annual fuel requirements for population within a 50-mi radius. This is <0.005% of average natural background dose to this population. Release from Federal Waste Repository of 0.005 Ci/y has been included in fission products and transuranics total.
Tritium (thousand) . . .	16.7	
Krypton-85 (thousand) . .	350	
Iodine-129	0.0024	
Iodine-131	0.024	
Fission products and transuranics	1.01	
Total	442.8084	Ci

*[Federal Register 39, 14191 (1974); Parts and Material Directorate of Licensing, Environmental Survey of the Uranium Fuel Cycle, U.S. Atomic Energy Commission, Washington, DC, Repr. Wash 1248 (1974).]

Table 71. Radioiodine releases for 1000-MW(e) plant extrapolated from 1971 reported releases.*

Plant	Thermal power ^a {MW(e)}	Thermal energy produced ^a (MW·d)	Reported radioiodine release ^a (Ci/y)	Radioiodine release extrapolated to 1.141×10^6 MW·d thermal energy ^b (Ci/y)
BWR	700 to 2×2527	99,200 to 513,000	0.49 to 8.11	5.63 to 18.0
PWR	600 to 2200	209,000 to 327,000	< 0.0001 to 0.17	0.0001 to 1.61

^aUSAEC, Report on Releases of Radioactivity in Effluents from Nuclear Power Plants for 1971, Directorate of Regulatory Operations, December 1972.

^bCorresponding to 1000 MW(e), 32% thermal efficiency, 100% load factor, 1-y operation.

*[Compiled from data in Pigrori, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron. Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 33.]

Table 72. Volume of air required to meet concentration standards and average site boundary concentrations for yearly emission from a 1000-MW(e) power station (operated as a base-load plant, with an 80% availability).*

Type plant	Pollutant	Standard ^a	Discharge quantity ^b	Dilution volume (10 ⁹ m ³)	Site boundary Concentration ^c
Coal	²²⁶ Ra	2×10 ⁻¹² Ci/m ³	0.0170 Ci	8.5	4.2×10 ⁻¹⁶ Ci/m ³
	²²⁸ Th	2×10 ⁻¹² Ci/m ³	0.108 Ci	708	2.6×10 ⁻¹⁶ Ci/m ³
Oil	²²⁶ Ra	2×10 ⁻¹² Ci/m ³	6.0×10 ⁻⁴ Ci	0.3	1.5×10 ⁻¹⁸ pCi/m ³
	²²⁸ Th	2×10 ⁻¹³ Ci/m ³	1.3×10 ⁻³ Ci	6.7	3.2×10 ⁻¹⁸ pCi/m ³
Nuclear	⁸⁵ Kr and ¹³³ Xe	3×10 ⁻⁷ Ci/m ³	9,650 Ci	33.2 PWR	2.3×10 ⁻¹¹ Ci/m ³
	Short-lived radioactive	3×10 ⁻⁸ Ci/m ³	1.66×10 ⁶ Ci	5.54×10 ⁴ BWR	1.3×10 ⁻¹⁴ Ci/m ³
	¹³¹ I gases	1.0×10 ⁻¹⁰ Ci/m ³	{ 0.2 Ci 5.3 Ci	2.0 PWR	4.2×10 ⁻¹⁶ Ci/m ³
	¹³¹ I (inhalation)	1.0×10 ⁻¹⁰ Ci/m ³		53.0 BWR	1.3×10 ⁻¹⁴ Ci/m ³
	(Air, grass, milk)	1.4×10 ⁻¹³ ^d	{ 0.2 Ci 5.3 Ci	1,430 PWR 37,800 BWR	4.2×10 ⁻¹⁶ Ci/m ³ 1.3×10 ⁻¹⁴ Ci/m ³

^aEPA "National Primary and Secondary Air Standards," (*Federal Register*, Vol. 36 No. 84, Part II, pp. 8186-87, 4/30/71), and AEC "Standards for Protection Against Radiation," ICRF20, January 1, 1972.

^bDischarges from PWR and BWR are derived from weighted average 1967-1972 release data as summarized by the Directorate of Regulatory Operations, USAEC.

^cBased on average S/Q at 500 m (for release height of 100 m) of 6.2×10⁻⁸ sec/m³, for 25 operational or proposed nuclear power stations.

^d"Concentration factor" of 700 applied to inhalation standard for ¹³¹I.

*[Hull, A. P., Nuclear News 17, 51 (April 1974).]

Table 73. Principal radionuclides induced in air by a nuclear explosion.*

Isotope	Half-life (y)	Ci/Mton
^3H	12.3	<1
^{14}C	5600	3.4×10^4
^{39}A	~260	59

*[Eisenbud, M., Environmental Radioactivity, 2nd Edition (Academic Press, New York, 1973).]

Table 74. Initial radioactivity from some radionuclides of greatest environmental concern (in kCi) for various sizes and types of detonations. A, fission-product activity; B, induced activity in igneous rock.*

Radionuclide	Fission explosion				Fusion explosion					
	5 kton (3.5×10^6 kCi)		100 kton (7.0×10^6 kCi)		3-kton trigger (2.1×10^6 kCi)		100 kton (97-kton fusion)		1,000 kton (997-kton fusion)	
	A	B	A	B	A	B	A	B	A	B
H-3	0.005	1.10	0.1	22.0	0.003	0.66	0.0	a	0.0	a
C-14	0.0	0.0	0.0	0.002	0.0	0.0	0.0	0.002	0.0	0.023
Ar-37	0.0	12.5	0.0	250	0.0	7.5	0.0	700	3.0	7,000
Kr-85	0.10	0.0	2.0	0.0	0.06	0.0				
Sr-90	0.75	0.0	15.0	0.0	0.45	3.0				
I-131	725	0.0	14,500	0.0	435	0.0				
Xe-131	5.0	0.0	100	0.0	3.0	0.0				
Xe-133	1,650	0.0	33,000	0.0	1,000	0.0				
Cs-137	0.90	0.0	18.0	0.0	0.54	0.0				

^a 100 kton, 28.0 + 1,940; 1,000 kt, 280.0 + 19,400 (latter figure in both cases indicates residual tritium at rate of 20,000 Ci/kton).

* [Sandquest, G. M. and G. A. Whan "Environmental Aspects of Nuclear Stimulation," in Geothermal Energy Resources, Production, Stimulation, P. Kruger and C. Ott, Eds. (Stanford University Press, Stanford, CA, 1973).]

Table 75. Relative percentage of total estimated dose from man-made radionuclides in nuclear-stimulated natural gas *

Radionuclide	Projected average first year concentration (pCi/cm ³)	Projected average lifetime concentration (pCi/cm ³)	Percentage of estimated total somatic dose ^a	Percentage of estimated total genetic dose ^b
³ H	<20	1.0	60	93
¹⁴ C	<1	0.02	0.3	0.3
⁸⁵ Kr	65	3.3	39	6
All others			<<1	<<1

^aDose to total body.

^bDose to gonads.

*[Rohwer, P. S., C. J. Barton, R. E. Moore, and S. V. Kaye, data presented in a paper at the 3rd International Radiological Protection Association Meeting, Washington, DC, September 1973.]

Table 76. Comparison of radioactivity in Gasbuggy and Rulison.*

	Gasbuggy	Rulison
Explosive yield (ktons)	29	40
Tritium		
Total in gaseous products (Ci)	2400	1100
Initial concentration (pCi/cm ³)	700	175
Krypton-85		
Total (Ci)	370	960
Initial concentration (pCi/cm ³)	110	150

*[Eisenbud, M., Environmental Radioactivity, 2nd Edition (Academic Press, New York, 1973).]

Table 77. Radiological aspects of copper production using nuclear mining techniques.*

Potential source of exposure	Time during which exposure occurs	Principal population exposed	Exposure path	Estimated exposure ^a
Bleed-off of chimney gases at reentry and/or during chimney flooding.	Starting 6 mo after detonation; duration is a few weeks at most.	Residents of the area downwind from the project. (Workers would receive negligible exposure.)	Inhalation of gaseous radioactivity.	0.000013
Off-gassing of excess oxygen during dissolution of ore.	Starting about 1 y after detonation and lasting for 5 y. ^b	Residents of the area downwind from the project. (Workers would receive negligible exposure.)	Inhalation of gaseous radioactivity.	0.0000001
Transport of soluble radionuclides out of the chimney area and into groundwater. ^c	Exposure could start many years after detonation.	Residents of the area using contaminated groundwater for drinking or irrigation.	Ingestion of soluble radionuclides.	<0.000000000000005
Radionuclides present in the product Cu.	Exposure could start when copper reaches the market (about 1-1/2 y after detonation). Effective duration is no more than 1-1/2 y.	Population using Cu products.	Ingestion of soluble radionuclides	0.00006
In-plant radiation fields.	Starting about 1 y after detonation and lasting for 5 y.	Plant personnel	External gases exposure; inhalation of tritiated water vapor, etc.	0.002

^aExpressed in man-rems/y·ton⁻¹ of product Cu.

^bFive years is the time interval during which the Cu leaching/recovery operation is assumed to take place.

^cNote that of the listed sources of exposure to radiation, this is the one more amenable to prevention. Location of a nuclear chemical Cu mining/refining operation in an area where contamination could enter drinking or irrigation water supplies would in all likelihood never be either proposed or approved.

*[Tewes, H. A., et al., Lawrence Livermore Laboratory, Rept. UCRL-51345, Rev. 1 (1974).]

Table 78. Field gamma radiometry of hot-spring areas in northern Nevada and northern California.*

Location	Gamma dose rates ($\mu\text{R/h}$)		Remarks
	General background	Anomalous high radioactivity	
<u>Northern Nevada</u>			
	<u>Spring systems where CaCO_3 predominates</u>		
Gerlach	6.25- 7.5	60-65	Tufa, high rad. zone
Gerlach		20-25	Mixed sinter and tufa
Fly Ranch	6.25- 8.75	None apparent	Travertine
Kyle	12.5 -25	250-500	Over radioactive pools
Elko	7.5 -10	19	Tufa at edge of pool
Buffalo Valley	6.25- 7.5	30-38	Tufa mounds
Spencers	5 -10	19	Tufa at edge of pools
Diana's Punchbowl	5 -10	16	Springs at base of tufa mound
Wabuska	3.75- 6.25	None apparent	Blowing wells
Darroughs	15 -20	75	Edge of fenced pool
Darroughs	10 -12.5	None apparent	Moderately blowing well
Golconda	12.5 -17.5	37.5-175	Pools and intercon- necting streams
Pumpnickel	7.5 -10	17.5-22.5	Small pool
Pumpnickel	15	17.5	Outflow stream
	<u>Spring systems where SiO_2 predominates</u>		
Brady's	5. - 7.5	---	Sinter soil
Beowawe	2 - 2.5	---	Sinter apron
Beowawe	13.8 -17.5	---	Andesite
Big Sulfur (Ruby Valley)	2.5 - 5	---	Sinter
Leach	5 - 7.5	---	Sinter
Lee	5 - 7.5	20-25	Tufa and sinter
Lee		10	Edge of pool
Steamboat	2.5 - 4	---	Main terrace sinter
Steamboat	6.9	---	Altered granitics, west area, blowing well

Table 78. (Continued)

Gamma dose rates ($\mu\text{R/h}$)			
Location	General background	Anomalously high radioactivity	Remarks
<u>Northern California</u>			
Geysers	3	5000	Personal communication from J. Cohen, Lawrence Livermore Laboratory, Livermore, Calif., June 1, 1974.

*[Wallenburg, H. A., Lawrence Berkeley Laboratory, Berkeley, CA, Rept. LBL-2482 (1974).]

Table 79. Production of fission-product tritium in the free-world nuclear power economy.*

Year	Power production		Tritium production rate (10^6 Ci/y)	Accumulated tritium (10^6 Ci)
	[10^3 MW(e)] ^a	[10^3 MW(th)] ^b		
1965	1.9	6.2	0.03	0.03
1970	9.6	31	0.1	0.3
1975	46	150	0.7	2

^a Assumed load factor of 0.80 at 1980 and 0.70 at 2000.

^b Assumed thermal efficiency of 0.31.

*[Lawrence Livermore Laboratory, staff compilation.]

Table 80. Nuclear weapons yield in energy released and tritium production in kg from 1945 to 1962.*

Production	Fission	Fusion	Total
1945-1958 (Mton)	92	78	170
1959-1962 (Mton)	190	320	510
Total (Mton)	282	398	680
Tritium (kg)	20	796	816

*[Lawrence Livermore Laboratory, staff compilation.]

Fig. 68. Total gaseous effluents for BWR, PWR, and HTGCR plants, 1967-1972. [Hull, A. P., Nuclear News 17, 51 (April 1974).]

Fig. 69. Gaseous effluents for BWR plants, 1967-1972. [Hull, A. P., Nuclear News 17, 51 (April 1974).]

Fig. 70. Gaseous effluents for PWR plants, 1967-1972. [Hull, A. P., Nuclear News 17, 51 (April 1974).]

Fig. 71. Estimated world inventory of tritium in the atmosphere and in surface waters. [Hickman, R. G., Lawrence Livermore Laboratory, Rept. UCRL-75546 (1974); "The Natural Radiation Environment," in Understanding the Atom, USAEC Division of Technical Information (1968).]

Fig. 72. Estimated production of krypton-85 and tritium from the nuclear power industry of the Free World. [Instrumentation for Environmental Monitoring, Radiation Fuel Reprocessing, Lawrence Berkeley Laboratory, Berkeley, CA, Rept. LBL-1, Vol. 3 (1973), p. 9.]

Fig. 73. Thermonuclear tritium in precipitation at continental and marine stations. [Compiled from data in Schell, W. R., *et al.*, *J. Geophys. Res.* 75, 2251 (1970).]

Fig. 74. Tritium injection following the 1962 thermonuclear detonations, corrected for decay to 1963. [Dockins, K. O., A. E. Bainbridge, J. C. Houtermans, and H. E. Suess, "Tritium in the Mixed Layer of the North Pacific Ocean," in Proceedings of the 2nd Symposium on Radioactive Dating and Methods of Low-Level Counting, Monaco, 1967 (IAEA, Vienna, 1967), p. 129.]

Radioactive Particulates

Sources

Radioactive particulate matter from any of the following sources can become airborne:

1. The operation of uranium mines
2. The manufacture of fuel elements for nuclear reactors
3. The accidental release of fission products from nuclear fuel reprocessing plants and nuclear weaponry under abnormal situations
4. The release of fly ash from power plants burning fossil fuel
5. Nuclear detonations aboveground and belowground
6. Geothermal sources

Sources

Plutonium Releases -

The Palomares Accident, January 16, 1966 - The Palomares Accident resulted from an in-air explosion of a B-52 bomber while engaged in an in-flight refueling. Four plutonium-bearing nuclear weapons were jarred loose from the plane by the explosion. Three of the devices impacted on land and one hit in the sea. Two weapons were ultimately recovered intact, one was that from the sea.

Two of the weapons detonated on impact with the ground and dispersed plutonium over some 1200 acres of ground. A wind with an estimated velocity of 30 knots prevailed at the time. Under these conditions the radius of the area with contamination of over $500 \mu\text{g}/\text{m}^2$ (a factor of 5 over suggested Los Alamos Scientific Laboratory values) was about 80 m for one detonation and 65 m for the other detonation.

The cleanup procedure consisted of scraping and removing the top layer of soil from about 6 acres that had contamination levels above $500 \mu\text{g}/\text{m}^2$. The crops in the fields with contamination levels above $5 \mu\text{g}/\text{m}^2$ were removed and destroyed.

All of this material was packaged and ultimately shipped to the U.S. Originally it was planned to plow only the land between the 50 and 500 $\mu\text{Ci}/\text{m}^2$ contamination contours, but with the equipment on hand it was decided to plow the area within the 5 $\mu\text{Ci}/\text{m}^2$ contour.

Crash of a B-52 Bomber in North Star Bay, January 21, 1968 - The cause of this crash in North Star Bay was the necessity for the crew to bail out because of an on-board fire. The plane impacted on the ice with a velocity of about 500 knots at a 15-deg angle to the ground. On impact, the fuel ignited and the four plutonium-bearing weapons exploded.

The debris and flaming fuel propelled by the forward motion of the plane were scattered along a path about 700 m long. A large blackened area about 130 m wide and 700 m long was formed by the combustion products trapped in the refrozen snow and ice.

It has been estimated that approximately 99% of the plutonium within the defined contamination zone was contained in the black crust of ice and snow. The horizontal extent of the fire was about 800 m, and the height of the fire column was about 850 m. The smoke cloud rose even higher and undoubtedly carried plutonium downstream as it drifted toward the south and southeast.

The Danish scientists investigated rather thoroughly the levels of plutonium in the environment and concluded from their findings that the environmental impact was negligible.

Project Roller Coaster, Nevada Test Site - A very elaborate experiment, Project Roller Coaster, was conducted north of NTS for the purpose of determining the exclusion area of a plutonium-weapons storage site. In this operation, plutonium devices were dispersed by the detonation of high explosives. In one case the release of plutonium was accomplished from an uncovered steel plate - so that there would be no interaction with the soil - by conventional high explosive (TNT) in the weight ratio of 1 unit of plutonium to 44 units of high explosive. 88% of the material was airborne beyond 2500 ft.

In another test the release was from an igloo with 8 ft of ground cover. In this case the ratio of the plutonium to TNT was 1 to 835, and 63% of the material was airborne beyond 1250 ft.

These values probably represent a maximum dispersal for an uncontained source and a maximum dispersal from a well-contained source but with the containment destroyed by a very large energy release.

Incident at Oak Ridge - In an accident at Oak Ridge 1100 g of plutonium were involved in a nonnuclear explosion. Less than 0.05% of the plutonium was released from the building and was largely scavenged by the building and plant equipment.

Safety Test of Special Capsules for the Space Nuclear Auxiliary Power (SNAP) Program - Special capsules made of Haynes-25 alloy and containing 80 g of plutonium in a helium atmosphere were safety tested. They were subjected to destructive heat loads, and failure of the capsules occurred after about 3 min at 3600°F.

After failure the capsules were maintained at this temperature in an oxidizing air draft. Less than 3% of the plutonium became airborne. The exact percentage dispersed is not known, since the complete material balance of plutonium was not possible.

About 95% of the plutonium was recovered from the residue. Only a trace was recovered from the absolute filters in the air space above the apparatus. It is believed that the difficulties in analyzing the residue account for the discrepancy in the material balance.

Several kilograms of plutonium were subjected to the heat and the dispersal forces of gasoline jet fuel in a high-explosive fire in a launching pen. Although the flames were 400 ft high, negative readings for plutonium were obtained in a survey at points 50 ft from the pen to 5 mi from the pen. The plutonium contamination was confined to the launching pen and a small adjacent area, a draining ditch contaminated by runoff water used in fire-fighting.

British Workers Accident - The British Workers Accident was the result of heating to ignition 12-g plutonium billets and 2 g of plutonium turnings. About 0.05% of all the plutonium oxide particles from the billet burnings and about 0.01% from the turnings were 3 μ and less in size. It was concluded that the plutonium burned without an active dispersal process.

Only about 0.01%, or markedly less than the total percent of the material, would be dispersed and constitute an inhalation hazard. In the event the oxide residue was dispersed by a forced draft, not more than 0.5% would be in the respirable range.

Release Studies at BNW Laboratories and the Rocky Flats Release - These releases resulted from normal operating conditions and amounted to 42 mCi in airborne effluents or 90 mCi in liquid effluents.

The 1957 fire accounted for a release of 0.06 Ci, and the famous 1969 fire accounted for a release of 0.0002 Ci.

Of interest is that the transference from contaminated soil accounted for a 2.6-Ci release. It emphasizes the fact that the accidents that are going to get you are the unforeseen, unlikely events. This transference of plutonium resulted from the dispersal by high-velocity winds of sandy soil contaminated by contaminated oil that had leaked from drums stored in the open. (Tables 81 and 82.)

Fossil-Fuel Power Plants - Some work has been reported on the releases of uranium, thorium, and their daughters from coal and the hazard from the inhalation of aerosols in the plume from coal-burning plants. For example, it has been estimated that a 1000-MW(e) plant burning approximately 6×10^6 tons/y of coal will release about 17 mCi of radium-226 and about 11 mCi of radium-228 if 2-1/2% of the fly ash produced escapes from the stack.

The actual amounts released can vary considerably, however, because the activity of the coal varies by more than an order of magnitude, depending on its source. The degree of fly-ash control from plant to plant also fluctuates considerably.

Although the nonvolatile nuclides such as radium and thorium remain with the ash during combustion and thus are only partially released, their volatile daughters (such as polonium), which are in equilibrium with them in the coal, may be more readily released, increasing the magnitude of the possible inhalation hazard.

Concentrations of radium-226 and thorium-232 around one of the larger and dirtier coal-burning plants indicated that no significant hazard existed.

Other recent work has demonstrated the deposition of radium in fly ash in fresh snow downwind from a coal-burning plant. (Table 83 and Fig. 75.)

Nuclear Detonation - The present levels of fission products from past nuclear weapons tests, more particularly strontium-90, plutonium-238, and plutonium-239 are low enough in the atmosphere to present no hazard to aircraft crew or passengers. However, the possibility that SNAP devices containing plutonium-238, strontium-90, or other radioactive nuclides may burn up in the atmosphere following reentry and produce local concentrations of these isotopes cannot be disregarded. (Tables 84 and 85 and Fig. 76.)

In 1969 typical plutonium-239 worldwide concentrations were in the range 1 to 50×10^{-8} pCi/liter of air. The higher number is a factor of 40 lower

than the maximum permissible concentration, air $[(MPC)_a]$ value for exposure to large general populations; the smaller number is 2000 times lower.

In 1966 the average plutonium-238/plutonium-239 ratio in air was 0.04, and the monthly surface deposition of plutonium-239 from precipitation ranged from about 0.5 to about 1.0 pCi/m². Studies of plutonium in surface soil in the Livermore Valley of California have found plutonium-239 surface levels of 200 to 2000 pCi/m². Children's diets in 1966 showed plutonium-239 concentrations of about 0.002 to 0.006 pCi/kg. This is more than 5 orders of magnitude smaller than the general population maximum permissible concentration, water $[(MPC)_w]$. These worldwide distributions are mostly due to fallout from nuclear weapons tests, plus a satellite accident, which deposited 17,000 Ci of plutonium-238 in the stratosphere over the Indian Ocean in 1964.

As the numbers reveal, the worldwide levels are not now significant fractions of the MPC limits for general-population exposure, and because fallout hopefully will not increase dramatically the levels should also not increase dramatically. The main radiological hazard is thus more likely local than worldwide in scope.

Local concentrations can range up to values much higher than the worldwide averages just mentioned. One example is at NTS, where many locations have plutonium-239 in soils at levels of hundreds to thousands of pCi/g over several acres. Another example is near the Rocky Flats plutonium production facility, where plutonium air concentrations have occasionally reached as much as 30% of the soluble $(MPC)_a$ for individuals in the general public.

Plutonium deposited on soil is not a significant direct public health hazard. One prime pathway to man is resuspension from the ground into the air, which can result in widespread distribution of an originally well-localized source and which in turn may lead to more widespread public health exposures. This possibility has motivated a program within the USAEC to study the problems of resuspension.

Total weapons-tests production to date of strontium-90 and cesium-137 has been about 9 and 14 mCi, respectively.

Plutonium needs special comment because of its extremely long half-life. It is a very refractory material and condenses with the melt material, and nearly all of it remains in the immediate vicinity of the crater. Very small amounts will be associated with small condensed melt particles carried downwind prior to deposition. However, at very short distances downwind from a

detonation, the amount of plutonium deposited per unit area will be less than that currently present from worldwide fallout, and the total impact away from the detonation site is therefore considered to be small.

The plutonium remaining in the region of an excavated canal will be exposed to aquatic ecosystems in the postdetonation environment. Therefore, potential exposure from plutonium is probably greatest via fish or other seafood obtained from the region.

The best estimate we have of the possible dose from plutonium via the marine food chain comes from our recent radiological assessment of the Eniwetok Atoll. Over 800 fish in the atoll lagoon were collected and analyzed for plutonium. These fish had been exposed to a plutonium inventory similar to that expected from a large-scale excavation project.

A conservative estimate of the 30-y integral dose to an individual from plutonium via the marine food chain would be less than 10 mrem (to bone and liver) even with seafood constituting most of the protein intake as in the Eniwetok assessment.

The released quantities of radionuclides for other explosive yields can be estimated for 170 kton. Fission-product releases can be expected to be constant irrespective of total yield of the individual explosive. Thus, at higher yields the relative contribution of the fission products to radiation dose will become less, and for lower yields their relative contribution will become greater.

Trends

Nuclear Power Industry - Overall average release rates of power-reactor radioactive particulate emissions increased over the period 1967-1972. Gaseous and halogen release rates from BWR's were larger than those from PWR's. This is principally because of increases over this period from the older BWR's and the fact that most of the "second-generation" BWR release rates have been somewhat less than the overall average. (Figures 77 and 78.)

Nuclear Detonations Aboveground - Worldwide deposition of strontium-90 reflects the stratospheric inventory, which has been estimated using data from various high-altitude sampling programs. These estimates show the exponential diminution following cessation of tests by the U.S. and USSR in 1963, with a half-life of about 1 y. The interruption in this decline owing to additions from atmospheric tests between 1967 and 1970 is also apparent. (Figures 79 and 80.)

Costs of Control

Control of particulate emissions from nuclear power plants and fuel reprocessing units are part of the normal cost of doing business.

In fossil-fuel plants, the removal of particulate radionuclides from effluent gas streams is incidental to the primary task of eliminating the gross particulate emissions for which pollution control standards have been established.

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Table 81. Plutonium aerosol airborne under stated conditions at Battelle Northwest laboratories.*

Solids from evaporation of plutonium nitrate solution: ambient to $\sim 130^{\circ}\text{C}$, 10 to 100 cm/s air, sampled 3 to 24 h	10^{-8} to 2.6×10^{-6} wt.%
Oxidation of ignited metal: 560 to 900°C , 3.3 to 50 cm/s air, sampled 74 to 155 min	2.8×10^{-6} to 5.3×10^{-5} wt.%
Oxidizing ignited metal covered with MgO sand: 525 cm/s air, sampled 60 min	0.00030 wt.%
Air drying plutonium nitrate solutions: ambient to $\sim 130^{\circ}\text{C}$, 10 to 100 cm/s, samples 1-1/2 to 24 h	10^{-7} to 0.003 wt.%
Fine oxide from ignited metal: ambient to 900°C , 10 to 100 cm/s air	5.3×10^{-6} to 0.025 wt.%/h
Oxide from ignited metal: ambient, 6.9 cm/s air, sampled 20 to 90 min	8.6×10^{-6} to 0.0311 wt.%
Oxidizing ignited metal: 525 cm/s air, sampled 22 to 90 min	0.0045 to 0.032 wt.%
Fluoride powder: 400 to 1000°C , 10 to 100 cm/s air	0.007 to 0.05 wt.%/h
Nitrate solution: simmer to rolling boil, 2.9 cm/s air, sampled 59 to 151 min	0.00045 to 0.18 wt.%
Solids from evaporation of plutonium nitrate solutions: 400 to 1000°C , 10 to 100 cm/s air, sampled 2 h	0.0046 to 0.012 wt.%(0.125)
Oxalate powder: 400 to 1000°C , 10 to 100 cm/s air	0.005 to 0.9 wt.%/h
Partially oxidized oxalate powder: 400 to 1000°C , 10 to 100 cm/s air	0.041 to 0.82 wt.%/h

*[Mishima, Jr., Plutonium Release Studies, IV, Fractional Release from Heating Plutonium Nitrate Solutions in a Flowing Air Stream, Battelle Northwest Laboratories, Richland, WA, Rept. BNWL-931 (1968); CONF-740115, Plutonium Information Meeting for Ad Hoc Subcommittee on Reactor Safeguards, Los Alamos, NM, January 4-5, 1974.]

Table 96. Annual water effluent from a coal gasification electricity system:
1000-MW power plant, 3% sulfur coal, 75% load factor.*

System process	Effluent type										Other
	Suspended solids (tons)	Organics (tons)	BOD (tons)	H ₂ SO ₄ (tons)	Cl ₂ (tons)	Phosphates (tons)	Boron (tons)	Chromates (tons)	Blowdown water		
									gal/min	Dissolved solids (tons)	
Extraction	0	0	0	0	0	0	0	0	0	0	Same as coal - electricity system
Processing	0	0	0	0	0	0	0	0	0	0	----
Transport	0	0	0	0	0	0	0	0	0	0	Same as coal - electricity system
Conversion	373	56	1.8	62	20	31	248	1.8	3218	3203	----
Transmission	0	0	0	0	0	0	0	0	0	0	----
Total	373	56	1.8	62	20	31	248	1.8	3218	3203	----

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974).]

Table 84. Relative volatilities in steam of potentially volatile gamma emitters produced by a total of 1 Mton of fission explosives in igneous rock, after 180 d.*

Nuclide	Nuclide (g*at)	Volatility in steam, 80 atm at 623K
⁸⁵ Kr	0.57	Permanent gas
¹⁰³ Ru	0.35	Oxidizing, high; reducing, low
¹⁰⁶ Ru (¹⁰⁶ Rh)	2.8	Oxidizing, high; reducing, low
¹²⁵ Sb	0.45	Probably high
^{127m} Te	0.075	High
¹³⁷ Cs	15.1	Initially high, declining with time, CO ₂ decreases volatility, Cl ⁻ increases volatility
¹³⁴ Cs	0.08	Similar to ¹³⁷ Cs

*[Krikorian, O. H., "Corrosion and Sealing in Nuclear Stimulated Geothermal Power Plants," in Geothermal Energy, Resources, Production, Stimulation, P. Kruger and C. Otte, Eds. (Stanford University Press, Stanford, CA, 1973).]

Table 85. Potentially volatile radioactive nuclides present 180 d after a 1000-kton nuclear explosion in igneous rock.*

Nuclide	Half-life	Fission (kCi)	Fusion ^a (kCi)	RCG ^b (pCi/ml)		Volatility in steam (80 atm, 623K)
				Air	Water	
⁸⁵ Kr	10.8 y	20	0.06	0.3	---	Permanent gas
⁹⁰ Sr	28.8 y	150	0.45	3×10^{-5}	0.3	Gaseous precursor
¹⁰⁰ Ru	40 d	1150	3.45	0.003	80	Oxidizing, high; reducing, low
¹⁰⁶ Ru	1 y	1000	3.0	2×10^{-4}	10	Oxidizing, high; reducing, low
¹²⁵ Sb	2.7 y	60	0.18	9×10^{-4}	100	Apparently high
^{127m} Te	109 d	90	0.27	0.001	50	High
¹³⁷ Cs	30 y	180	0.54	5×10^{-4}	20	With CO ₂ , low; without CO ₂ , high (30%)
<u>Radioisotopes induced in soil</u>						
³ H	12.3 y	220	20,290 ^c	0.2	3,000	As permanent gas and tritiated vapors
²² Na	2.6 y	--	0.6	3×10^{-4}	30	---
³² P	14.3 d	2	2.5	0.002	20	---
³⁵ S	88 d	29	40.0	0.009	60	---
³⁷ A	35 d	70	200	100	--	Permanent gas
¹³⁴ Cs	2 y	14	18.3	4×10^{-4}	9	With CO ₂ , low; without CO ₂ , high (30%)

Note: Other radioisotopes of interest that generally exist as nonvolatile compounds include ⁵⁹Fe, ⁶⁰Co, ¹⁴⁴Ce, ²³⁹Pu, ²⁴¹Pu, and many transuranic isotopes.

^aThese amounts assume linear scaling of 50-kton fission and fusion devices. Assume a nominal 3-kton fission trigger for fusion device.

^bThese radiation-concentration guides are maximum values ignoring solubility of compound.

^cAssumes 2 g of residual tritium per kton of fusion yield.

*[Krokorian, O. H., "Corrosion and Sealing in Nuclear Stimulated Geothermal Power Plants," in *Geothermal Energy, Resources, Production Stimulation*, P. Kruger and C. Otte, Eds. (Stanford University Press, Stanford, CA, 1973).]

Fig. 75. Natural radioactivity in soil and fly ash at Turkey Point and Widows Creek, 1967-1969. [Martin, J. E. , E. D. Howard, and D. T. Oakley, Environmental Effects of Producing Electric Power, Joint Committee on Atomic Energy Hearings, 91st Congress, Part I, Appendix 14, p. 787 USGPO, Washington, DC (1969).]

Fig. 76. Ground level inventory of strontium-90 in late 1959. [Kulp, J. L., "Radionuclides in Man from Nuclear Tests," in Radioactive Fallout, Soils, Plants, Food, and Man, E. B. Fowler, Ed. (Elsevier, Amsterdam, 1965), p. 247.]

Fig. 77. Total halogens and particulates for BWR, PWR, and HTGCR plants, 1967-1972. [Hull, A. P., Nuclear News 17, 51 (April 1974).]

Fig. 78. Halogens and particulates in BWR and PWR plants, 1967-1972. [Hull, A. P., Nuclear News 17, 51 (April 1974).]

Fig. 79. The variation with time of total stratospheric inventory of strontium-90 and carbon-14, with periods and yields (in Mtons) of nuclear explosives. [Johnson, et al., *J. Geophys. Res.* 78, 6107 (1973), copyrighted by American Geophysical Union.]

Fig. 80. Concentration of radioactive substances in the air mainly from nuclear weapons tests. [MTR 6013, Mitre Corporation, Bedford, MA, May 1971.]

Thermal Inputs

Sources

Natural - Solar radiation provides 99.99% of the earth's annual energy income and keeps the atmosphere and hydrosphere in motion. Tidal friction is ver. gradually slowing the rotation of the earth, thereby converting kinetic energy to heat, which plays a small role in maintaining the earth's surface temperature before it is radiated to space. Heat is also emerging from the interior of the earth. Current concepts attribute these geothermal sources to natural radioactivity.

Carbon dioxide is a trace gas in the earth's atmosphere with a concentration of a little over 0.03% by volume (about 320 ppm). In spite of its relatively small concentration it plays an important role in determining the temperature of the planet.

Carbon dioxide absorbs by intercepting a part of the ir radiation that is emitted by the earth's surface and reradiating it back toward the earth, cuts down the rate of surface cooling, and at the same time acts to cool the upper atmosphere. The source of this carbon dioxide is the oxidation of carbonaceous materials in processes of respiration by both plants and animals, decay of organic materials, and the combustion of organic fuels.

The atmosphere is a vast heat engine deriving its energy from the sun. A small amount of radiation is absorbed in the stratosphere, producing the ozone layer. The remainder penetrates to the lower atmosphere, or troposphere, where some is reflected by clouds, some is scattered by air molecules and aerosols, and some penetrates to the surface (Fig. 81). In addition, there is a complex interplay of emission and absorption of thermal radiation, from cloud to surface, from surface to cloud, from air molecule to air molecule, from surface to outer space, and so on.

The net interchange of radiation energy at the surface is distributed in heating the air near the surface (a flux of sensible heat), in evaporating water (a flux of latent heat that rematerializes as heat when water vapor turns into liquid water and forms cloud), and in warming the ground or oceans. (Figure 82.)

Man-Made - Hot exhaust gases from thermal engines (such as vehicles, aircraft, and nuclear- and fossil-fuel-power-plant boilers), and industrial process stacks (such as those in steel mills), and heated air from dry cooling towers.

The air heated by dissipated work and electrical energy generated by power plants around cities causes the formation of urban "heat islands," within which many meteorological anomalies occur.

Latent and sensible heat transfer to the atmosphere from heated bodies of water. The heat may be transferred directly from wet cooling towers, canals, and cooling ponds, or from larger bodies of water such as rivers, lakes, reservoirs, and near-shore portions of salt-water bodies that serve as receiving waters for condenser cooling water.

Another man-made source is the alteration of radiative properties of the atmosphere caused by the emission of particles and gases from combustion or geothermal operations.

Because of the long atmospheric residence time of carbon dioxide and the relatively small carbon dioxide contribution from supersonic transports compared with that from other sources of fossil-fuel combustion, there will be no special carbon dioxide problem from these transport operations.

Alteration of surface characteristics related to the production of energy can be placed in one of the two following subcategories: (1) creation of surface waters that produce changes in sensible, latent, and radiative heat transfers and (2) alterations of materials other than water.

The most important activity in the first subcategory is the creation of large lakes behind river dams for the production of electric power (among other uses). The second subcategory would include the alteration of thermal energy transfer between water and air by oil films resulting from spills and incomplete combustion and the coverage of large areas by solar-energy collectors.

Carbon Dioxide - The total amount of carbon dioxide emitted from man-made pollution sources in 1967 totaled 13.4×10^9 metric tons and is increasing exponentially. The concentration today is about 320 ppm, and the total quantity in the atmosphere is thus about 2.5×10^{12} tons.

About 50% of the total carbon dioxide resulted from coal and other solid fuels, 38% from petroleum combustion, and 12% from natural gas, forest fires, incineration of wastes, etc.

On the basis of careful measurements of changes in atmospheric composition and estimates of the amount of carbon dioxide added over a recent 6-y period (1957-1963), it appears that about half of the carbon dioxide remained in the atmosphere; the other half was removed by natural processes that have not yet been thoroughly explained.

The rate of increase shown by the Mauna Loa data seems to be characteristic of global carbon dioxide concentrations. Scandinavian data fit the postulated 0.7-ppm/y rate obtained from the Mauna Loa data. The rate of increase in the Antarctic is about 1 ppm/y, which, considering the limited span of the average 1959 Little America concentration of about 314 ppm, is also comparable to the Mauna Loa average of 313.3 ppm.

Around 1960, carbon dioxide concentrations were increasing by 0.7 ppm or 0.22% of a 315-ppm average concentration, and in this same period emissions from fossil fuel were adding about 10^{16} g/y of carbon dioxide to the atmosphere for a 0.42% addition rate. Thus, it appears that very nearly half the carbon dioxide emitted to the atmosphere remains there.

The data on atmospheric carbon dioxide indicate that any differences between the hemispheres are small and that there has been a readily detectable increase of carbon dioxide in the atmosphere. This increase was originally postulated on the basis of an analysis of nineteenth-century measurements. The increase from a nineteenth-century base of 290 ppm to a late 1960 average of about 320 ppm is 10%.

Looking at the problem from another viewpoint, the ultimate limit on industrial activity is determined by the amount of heat that can be absorbed by the ecosphere. Industrially generated heat at present accounts to 1/15,000 of the heat reaching the atmosphere from the sun and from the earth's interior. If the rate of increase in energy use were to continue at 4%/y, the atmosphere would begin to warm up appreciably, by some 3 deg in 150 y, and serious climatic problems would probably be encountered long before this dangerous threshold is reached.

Geothermal steam is available at low pressure and temperature, as compared to that from conventional boiler or nuclear plants. Thus the heat rejection will be high.

For 100-psi inlet conditions and a water-tower-cooled condenser, thermodynamic calculations show that 3630 MW of heat are rejected by a 1000-MW geothermal electric plant (a 1000-MW nuclear power plant rejects approximately 2000 MW of heat).

This number means little unless we have a basis for comparison. Data exist for the total 24-h average solar heat received in a desert area in summer. This number, called the solar insolation, is 720 MW/mi^2 . Thus, the 1000-MW power plant produces heat equivalent to that received by 5 mi^2 of

desert from the sun. If 10 such plants or their equivalent were installed in the Imperial Valley (and the total geothermal potential there has been estimated to be at least that large, the total heat added to the 1000 mi^2 area of the valley would be 5% of the total summer solar heat. The effect of this heat on the local weather is unknown at this time.

Other contributions to the global heat balance from energy-producing sources are due to the presence of carbon dioxide gas and μ -size particles from the combustion of fossil fuels. Each is considered a potential global problem because of long average residence times in the atmosphere and because the quantities may be sufficient to affect global background values.

Trends

The global production of man-released heat has been estimated at 8×10^6 MW. This thermal input is concentrated in the northern hemisphere and is increasing at the rate of 5.7%/y.

Some of the heavily urbanized regions of Europe, Russia, and North America now produce heat fluxes equivalent to about 10% of net solar radiation at the surface over areas of about 10^4 km^2 . If an energy growth rate of 10%/y were compounded for 100 y, heat fluxes may rise to values as high as 100% of net solar radiation over regions of 10^4 to 10^5 km^2 by 2075.

On a global scale, if 1 K is the maximum permissible change in the average temperature of the climate, we can increase our nonsolar energy production by about 460 times or we could double our production 9 times before this temperature is reached.

However, in 100 to 200 y we will have reached the limit. Clearly the product of the world population and the per capita rate of energy consumption has an upper bound.

The ultimate limits to the production of energy by nuclear fuels are 20 thermal kW/person/d for a population of 20 billion people.

Carbon Dioxide - It is estimated that in the interval from 1850 to 1950 fossil-fuel combustion produced an amount of carbon dioxide equal to 10% of the amount estimated to be in the atmosphere in 1950. Analysis of tree rings and other biological specimens of known age show that there was a 1 to 2% decrease in radioactive carbon-14 (a 1 to 2% "Suess effect") over the same period.

By the year 2000 atmospheric carbon dioxide may increase by 20 to 60% above 1950 levels. This amount may bring about a global increase in average temperature from 1 to 5°F. One unknown factor is the exact percentage of carbon dioxide that will be absorbed by the oceans. (Figure 83.)

There also is the possible multiplier effect: increased temperature would increase evaporation and result in more water vapor in the atmosphere. This, in turn, would tend to increase temperature even more, but it could result in more cloudiness, which would have the opposite effect.

As water temperature rises, the ocean water would have less capacity for holding carbon dioxide, possibly adding more carbon dioxide to the atmosphere. Another unknown that acts to reduce temperature is the amount of dust and smoke in the atmosphere. Also unknown are possible variations in insolation.

By the year 2020, 75% of the world's 1965 known reserves of petroleum and 50% of the coal could be burned. This could increase the atmospheric carbon dioxide by 30 to 100% above 1950 levels and bring about a global temperature increase from 2 to 10°F. (Figures 84 and 85.)

As shown in Fig. 86, the northern hemisphere temperature trends increased 0.6°C up to 1940, followed by a cooling of 0.4°C from 1940 to 1970. This type of variability makes it difficult to assess on a purely observational basis the warming or cooling effects caused by carbon dioxide or other agencies. The warming up to 1940 may have been caused by carbon dioxide and the subsequent cooling to particulate matter, but there is clearly considerable speculation involved. (Figure 87.)

Costs of Control

Compliance with thermal pollution control requirements could cost the nation the equivalent of more than 125,000 bbl/d of oil by 1980.

The petroleum refinery industry will invest \$302 million by 1976, \$218 million in 1977, and \$109 million in 1978 for thermal pollution control.

As given by EPA, cooling tower costs are:

1. Investment costs - \$7/kW
2. Operating costs - 0.05 mills/kWh
3. Thermal loss cost - 150 Btu/kWh

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Fig. 81. Primary radiation processes contributing to the global heat budget. [Data presented in a Oyer, A. J., paper at the International Conference on the Structure, Composition, and General Circulation of the Upper and Lower Atmosphere and Possible Anthropogenic Perturbations, Sydney, Australia.]

Fig. 82. Earth heat balance. [Data presented in a Dyer, A. J., paper at the International Conference on the Structure, Composition, and General Circulation of the Upper and Lower Atmosphere and Possible Anthropogenic Perturbations, Sydney, Australia.]

Fig. 83. Sources and sinks of the global carbon monoxide cycle. [Lawrence Livermore Laboratory, staff compilation.]

Fig. 84. Carbon dioxide produced by fossil-fuel combustion, 1950-1967.
[Lawrence Livermore Laboratory, staff compilation.]

Fig. 85. Carbon dioxide concentration in the atmosphere. Atmospheric concentration of carbon dioxide, observed since 1958 at Mauna Loa, Hawaii, has increased steadily. At present the increase averages about 1.5 ppm each year. [Growth and Its Implication for the Future, Part 7, 93rd Congress, USGPO, Washington, DC (1973).]

Fig. 86. Average temperature changes observed in the northern hemisphere together with estimates of heating effects due to carbon dioxide increase, and cooling effects due to volcanic dust. [Data presented in a Dyer, A. J., paper at the International Conference on the Structure, Composition, and General Circulation of the Upper and Lower Atmosphere and Possible Anthropogenic Perturbations, Sydney, Australia.]

Fig. 87. Global atmosphere thermal pollution effects. Thermal waste energy and carbon dioxide tend to increase global temperature. Particulates tend to decrease it. The net result is uncertain at this time. [Data presented in a Dyer, A. J., paper at the International Conference on the Structure, Composition, and General Circulation of the Upper and Lower Atmosphere and Possible Anthropogenic Perturbations, Sydney, Australia.]

Electromagnetic Emissions

Sources

Electromagnetic emissions include all those forms of radiation whose primary mode of interaction with matter, in their passage through it, does not involve the production of ion pairs, whether directly or indirectly. These radiations are a part of the continuum of the electromagnetic spectrum. (Figure 88.)

The nonionizing portion of the electromagnetic spectrum extends from the low-energy region up to a photon energy of about 100 eV. It includes the high-frequency radiations used in communications and broadcasting; the electromagnetic field radiations from power transmission; the microwave radiations used in radar, television transmissions, and industrial applications; the infrared radiation used in heatlamps; the visible light used in some lasers; and the ultraviolet radiation used in germicidal and "black" lights.

Sources of electromagnetic emissions include, but are not limited to:

1. Those used in the home, such as microwave ovens and weed controllers.
2. Those used in commerce and industry, such as lasers and microwave spectrometers
3. Those used in medicine for diagnosis and therapy, such as diathermy equipment
4. Special devices used for educational, research, and defense purposes, such as radar
5. High-voltage (EHV) power transmission lines

Trends

Ultrasonic Waves - The term "ultrasound" denotes mechanical vibrations at frequencies above the limit of human audibility, that is, from about 16 kHz to about 10 MHz.

Although ultrasound is a relatively new energy source, its versatility has led to its widespread use in various industrial, medical, scientific, and consumer applications.

Industrial ultrasound is used for cleaning and welding plastics, drying fine powders, emulsification, detecting flaws in materials, and nondestructive testing.

The use of ultrasonic devices in medicine includes both therapy (surgery) and diagnosis (detection of tumors). It is also being used in obstetrics, cardiology, neurology, and ophthalmology.

Ultraviolet Radiation - Ultraviolet radiation is that part of the electromagnetic spectrum lying between visible light and the soft x rays. It is present in normal solar radiation and is produced by arcs and incandescent sources operating at high temperatures.

Population exposure results from the use of a wide range of apparatus in homes, industries, places of entertainment, health clubs, and scientific and medical establishments.

Typical apparatus emitting ultraviolet radiation include cosmetic and therapeutic sun lamps, equipment for disinfection and sterilization, and analytical instruments. (Table 86.)

Infrared Radiation - Infrared radiations have longer wavelengths (8000 to 10^6 Å) and are the radiations we "feel" when holding a hand up to the fire or a hot object. From the standpoint of biological effects, the quantum energy in the ir spectrum is sufficient to induce an increase in molecular and intramolecular action that is recognized as heat. Infrared radiation of 12,000 Å has been shown to penetrate tissue to a depth of about 3 mm, but penetration decreased rapidly with an increase in wavelength because of moisture on the skin. The sensation of heat is quickly detected and can therefore give adequate warning that extreme conditions exist, a warning that is adequate because of its shallow penetration.

Laser Radiation - Lasers emit a beam of coherent electromagnetic radiation of wavelengths in the range 0.3 to 10 µm, depending on the nature of the material emitting the beam. They are used for welding and cutting, surveying, communications, and in different measuring devices.

In medicine they are used in bloodless surgical operations, such as re-attaching the retina to the choroid, where advantage is taken of their high precision and combined cutting and coagulant effect. (Table 87.)

Microwave Radiation - Microwave radiations are electromagnetic radiations in the frequency range 30 to 300,000 MHz. Microwave radiation is

emitted from a variety of electronic devices including diathermy units, ovens, heating devices, television receivers, and communications and radar units.

It is impossible, at present, to assess the extent to which such devices are used in the world as a whole, but estimates are available of the use of various selected devices in certain countries.

The numbers of devices generating microwave radiation were expected to increase by 50 to 100% over the period 1969-1973. However, of the various industries using microwave processes, the one in which widespread application seems most probable is the food industry.

The total annual volume of U.S. sales of microwave equipment was in the \$1 to 2 million range, with expectations of rather rapid growth (perhaps to the \$50 to 100 million level) by late in this decade.

A recent study by the U.S. Bureau of Radiologic Health found that one-third of the ovens surveyed leaked radiation in excess of 10 mW/cm^2 . Some of the leakages were significantly higher - sufficient, in fact, to possibly cause cataracts and dangerous overheating. (Figure 88.)

Microwave emissions from television antennas are the second largest source of radiation exposure for the general public. In the case of an average commercial television station, the following field strengths may be produced 30 ft above ground according to the FCC:

Ground distance from TV antenna (mi)	Field strength (V/m)	Power density (mW/cm^2)
1	20.0	0.110
3	6.1	0.010
10	2.0	0.001

While these figures are well below the current U.S. recommendations for exposure, the FCC allowable radiation level at 1 mi from the radiating antenna is more than 10 times the Russian limit for continuous exposure.

Electromagnetic Field Radiation - At the present time there are approximately 1200 mi of 765-kV lines installed and operating in the U.S. By the year 1990 plans reported by the Federal Power Commission call for more than 10,000 mi of lines at this voltage or higher.

Extremely high voltage - carried on bare, unshielded conductors - pass overhead in many places no more than 40 ft above roads and farms and cause very strong electromagnetic fields in the space around these lines. There is a very high voltage difference between one point in space and another point, say 1 m away. The potential difference between these two points may be as high as 50,000 V under a 765-kV line.

Charging currents of about 0.112 mA have been measured in a man standing under a 345-kV line. Body currents up to 0.400 mA have been measured in linemen working on 345-kV lines. There is no published data on body currents experienced around 765-kV lines, but from the comparative field intensity figures it can be estimated that linemen and farmers on large pieces of machinery would experience currents approaching the levels tested in these first Sanguine studies.

Along a typical extra-high-voltage right-of-way many people spend considerably lengths of time planting and harvesting farm crops, tending vegetable gardens, and taking care of rice and cotton fields. A conservative estimate is that for every 1 mi of line about five people are exposed regularly for long periods of time. In 1200 miles, then, approximately 6000 people are now at maximum risk from this exposure. By 1990, 50,000 people would receive this degree of exposure.

In addition, there are many others who receive shorter but frequent exposure. Children of families living near these lines regularly play on the rights-of-way, which are not fenced. Wives and neighbors must often traverse the right-of-way in order to get from house to barn or from house to house. Again it would be conservative to estimate that there are at least twice as many people in this category as the maximum risk cases: 12,000 people now and 100,000 in 1990.

A much larger cross section of the public has occasion to cross the right-of-way on foot or in an open vehicle, such as a snowmobile, bicycle, or jeep - perhaps 100 people/mi. By 1990 this number would amount to 1 million people/y.

Costs of Control

No data available.

References - Electromagnetic Emissions

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Young, L. B., and H. P. Young, Bull. Atomic Sci., 34 (Dec 1974).

Table 86. Number of workers exposed to ultraviolet radiation (estimate from Chicago Metropolitan Survey extrapolated to U.S. population).*

Manufacturing	
Standard Industrial Classifications 19-39	211,000
Transportation and Communication	
Standard Industrial Classifications 40-49	49,000
Wholesale, Miscellaneous Retail, Service Stations	
Standard Industrial Classifications 50,59,55	17,000
Services	
Standard Industrial Classifications 70-89	41,000
	<hr/>
Total	320,000

*[City of Chicago Metropolitan Survey, Chicago, Illinois (1973).]

Table 87. Laser characteristics.*

Laser	Wavelength (μ)	cw power (W)	Peak pulse power (W)	Pulse energy (J)	Pulse rep. rate (pps)	Beam angle (mrad)
He-Ne	0.6328	0.001-0.1	---	(Rarely used pulsed)	---	0.2-1
Ar ⁺	0.4880 0.5145	1-10	20	mJ	60-200	0.5-1
Kr ⁺	0.6471 0.5681 0.5208 0.4762	0.5	2	mJ	60	0.5-1
CO ₂	10.6	10-5000	10 ⁵	0.1-5	~100	~1-4
N ₂	0.3371	Not cw	10 ⁵	---	1-100	2 x 20
Ruby	0.6943	1	to 10 ⁹	1-500	60	1-10
Nd-Glass	1.06	---	to 4 x 10 ⁹	1-5000	1-10	0.5-10
Nd-YAG	1.06	1-250	to 10 ⁵	0.01-1	To 10000	2-20
CaAs	0.84-0.9	1-10	1-100	<1 mJ	100-1000	20 x 400

*[Instrumentation for Environmental Monitoring, Lawrence Berkeley Laboratory, Berkeley, CA, Rept. RAD-1AS.]

Fig. 88. The uv, visible, and near ir spectrum. [Lawrence Livermore Laboratory, staff compilation.]

Fig. 89. U.S. industry sales of home microwave ovens. [Litton Microwave Cooking Products Industries, Minneapolis, MN (1975).]

Noise

Sources

The noise environment is primarily a product of man and his machines and is generated in practically every conversion of energy to mechanical work.

The following sources, listed in order of impact, have been identified as noise polluters and collectively combine to produce community background noise:

1. Transportation systems, particularly aircraft, road and rail vehicles
2. Devices powered by internal combustion engines, such as chain saws and recreational vehicles
3. Industrial plants
4. Construction equipment; for example, the drilling of wells with associated sounds from power sources, racking of drill pipe, and venting of compressed air and cuttings during dry drilling phases, and the venting of steam wells after completion are principal sources of noise
5. Household appliances and building equipment for heating, ventilation, and air conditioning

Noise sources are governed by many factors, such as (a) the design, construction, maintenance, and manner of operating a vehicle and (b) the path that the sound waves travel to reach the observer (that is, distance, obstructions, reflections off surfaces, etc.). Typical values of noise levels from some commonly occurring events are shown in Figs. 90-92 to provide a familiarity with two widely used noise-measuring scales.

Trends

Communities -- Data suggests that noise in our environment is increasing by as much as 1 dB/y, or 10 dB/decade. In New York City, for example, increasing street traffic has been raising city noise levels by 1 dB/y for the past 35 y. In many city business districts the level is above 70 dB, and in subway stations it often rises above 95 dB.

Since the human ear cannot detect changes of less than ± 2 dB, the annual increases are hardly noticeable. Clearly, such a growth rate, if true, would lead to severe consequences.

The limited available data from community noise surveys conducted over the past 34 y indicates that little increase has occurred in the residual noise level, except where land use has changed. Where such change has occurred, the noise has generally increased, probably in accordance with the expected change between land-use categories such as +10 dB from quiet suburban residential to urban residential or +20 dB from quiet suburban residential to very noisy urban residential. A significant spread of noise has occurred in this manner because of the large growth of urban and suburban areas, and their populations, in the last 20 to 30 y.

A significant increase in noise in the past 20 y has resulted from the rapid growth of commercial aviation and from its use of jet aircraft that are about 10 to 20 dB noisier than the older, smaller piston-engined aircraft. A somewhat less, but still significant, increase in noise has resulted from the construction and use of freeways located within urban and suburban residential areas. It is estimated that at least 2000 mi² of urban and suburban area have been severely impacted by noise from these two major sources, with a lesser degree of impact extending over a much larger area.

Aircraft - The FAR 36 (Federal Aviation Regulation) noise regulation has lowered the sideline noise levels from aircraft dramatically. Over the years a comparison of the 100 EPNL noise footprints for a landing/takeoff cycle shows that the acreage exposed has been reduced from approximately 8600 acres for the early 707 jet transport to 1400 acres for a wide-bodied DC-10 or an L-1011. Not only are these individual footprints being reduced as a result of technological progress, but the wide-bodied aircraft's greater capacity results in greater productivity and hence fewer trips are needed to carry the same number of passengers. In terms of in-service turbojet aircraft, there are in excess of 300 aircraft that have been certified to the FAR 36 levels operating today. This is equivalent to approximately 15% of the total fleet. In addition, the FAA has accomplished approximately 100 certification actions under FAR 36, which insured that modifications to existing aircraft were accomplished without increasing the aircraft's noise levels.

The EPA concluded that 16-million people are presently exposed to aircraft noise levels, with effects ranging from moderate to very severe.

Although some noise reduction has been accomplished, it appears that existing FAA flight and operational controls do not adequately protect the public health and welfare from aircraft noise. (Figure 93.)

Costs of Control

The cost of noise abatement in the U.S. will depend on a myriad of factors, such as the stringency of future regulatory standards, the time schedule of regulations, and whether or not these regulations will require retooling, redesign, or retrofits before equipment, vehicles, and machinery have reached the normal end of their useful lives.

Tradeoff studies will have to be made to find the best solutions where alternative courses of action are available.

New technology could also affect the future cost of noise-abatement programs. The diversion of road traffic to mass transit systems could change the highway noise levels. The widespread use of V/STOL aircraft could reduce the area of the noise footprint around some airports, although the number of people exposed to noise in flight could increase, as V/STOL aircraft tend to be quite noisy.

While the costs over the next decade or so are uncertain, it is clear that expenditures of the order of several billion dollars could be required. A large part of this would result from the purchase of residential and around existing airports for the creation of buffer zones to reduce the number of people subjected to unacceptable noise levels.

The Nation's federal funding for pollution control and abatement of noise is:

1973	\$66 million	(actual)
1974	\$88 million	(estimated)
1975	\$62 million	(estimated)

Projected outlays for aircraft noise pollution control in 1980 is estimated to be \$300 million.

An EPA study on the 90-dB limit put the cost at \$13.5 billion and estimated that an 85-dB standard would cost \$18.1 billion.

References - Noise

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Fig. 90. Typical noise levels. Approximate relation between EPNdB scale and dB(A) scale is shown. [Transportation Noise and Its Control, Department of Transportation, Publ. DOTP5630.1 (1972).]

Fig. 91. Comparison of five surveys of outdoor noise levels in residential areas in the U.S. between 1937 and 1971. [Report to the President and Congress on Noise, Document No. 92-53, February 1972.]

Fig. 92. Sideline noise. [Power, J. O., data presented in a paper at the 66th Annual Meeting of the Air Pollution Control Association, Chicago, Illinois, June 24-28, 1973.]

Fig. 93. Aircraft noise comparison. [Power, J. O., data presented in a paper at the 66th Annual Meeting of the Air Pollution Control Association, Chicago, Illinois, June 24-28, 1973.]

Magnetic Field Emissions

Sources

Magnetic confinement for containment of plasma is the basis for most of the current fusion experiments being conducted in the U.S. and other nations.

High magnetic fields are also an element in the repulsion/magnetic levitation of high-speed-ground-transport vehicles.

Trends

Controlled thermonuclear reactors and superconducting levitated ground transportation could potentially expose millions of people each year throughout the developed nations of the world to magnetic fields.

Costs of Control

No data available.

X Radiation

Sources

Medical and dental x radiation, principally for diagnostic purposes, produces the largest dose to man of any man-made source of radiation today.

Other sources are television receivers in private homes; cold cathode gas discharge tubes; accelerators and medical facilities; and high-voltage electronic devices (such as klystrons) that function improperly so as to leak x radiation. (Tables 88 and 89 and Figs. 94-99.)

Trends

In 1970, 129-million individuals made 179-million medical visits and received 210-million examinations in which 650-million films were exposed. All these figures were some 20 to 30% greater than those of 1964.

The total genetically significant dose (GSD) for medical roentgenography to the U.S. population in 1964 was estimated to be 55 mrem/person, with an average of 0.53 diagnostic medical examinations per person in that year. Thus, the average examination produced a GSD of 104 mrem. Radiographic procedures accounted for 96% and fluoroscopic procedures 4% of the diagnostic-medical GSD. The GSD was 82% to males, 16% to females, and 2% to the fetus.

In the 1970 study the preliminary data show a reduction in GSD from 55 to 26 mrem/person, a substantial improvement largely attributed to improved collimation of x-ray beams.

The average annual dose of 320 mrem/person (for about 195,000 nonfederal medical x-ray workers) and 125 mrem/person (for 171,000 nonfederal dental x-ray workers). About 38,000 radium workers receive an average of about 540 mrem/person/y and about 50,000 radioisotope workers receive about 262 mrem/person/y.

The industrial dose rates show a total of about 24,500 industrial workers of all kinds in agreement states (1970), with a mean exposure of 274 mrem/person/y. It is probable that the number in nonagreement states is roughly comparable, making the total somewhat above 50,000 workers in the U.S.

Another estimate placed the number of units used for x-ray analytical work (diffraction studies, x-ray spectrographs, x-ray fluorescence) at "several thousand," based on 1968 numbers in Pennsylvania and New York of 311 and 258, respectively. Perhaps another few thousand are in use in the rest of the world.

Of the 311 in Pennsylvania, the total number of accidentally exposed persons in 1968 was found to be 15, of whom 9 suffered clinical symptoms and 2 severe injury.

Diagnostic uses of radiopharmaceuticals in 1966 amounted to 0.26 mrem/person, distributed over an exposed population of about 1-million people, only about one-eighth of whom were under age 30. Radiation therapy contributed an estimated 5.6 mrem of GSD, of which 0.6 was from radiopharmaceuticals and 5.0 from x and gamma radiation (administered to about 75,000 individuals).

Another index of total genetic dosage is the average gonad dose. The mean gonad dose in 1964 was 83 mrem/person, distributed similarly to the GSD.

Data on average doses to other organs are harder to determine. The 1964 average dose to bone marrow was 59 mrem/person from medical radiology, 1.2 mrem from dental radiology, and 0.5 mrem from radiopharmaceuticals.

The number of individuals exposed to medical radiology was 67 million, for which sample the average dose was 165 mrem to the bone marrow. To the thyroid the corresponding figures are 26 mrem (medical radiology), 18 mrem (dental radiology), and 225 mrem (diagnostic pharmaceuticals).

The average somatic dose in 1970 was 73.6 mrem/person, 72 mrem from medical radiography and the remaining 1.6 from radiopharmaceuticals and occupational exposures.

In 1964, 60.8% of the procedures were under the supervision of a radiologist, and the mean exposure/film seemed to vary significantly depending on the type of facility. For abdominal examinations the mean exposure/film was twice as high when these examinations were performed in private offices by practitioners other than radiologists.

Costs of Control

No data available.

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Table 88. Estimated mean exposure per film by type of radiographic examination, U.S., 1964.*

Type of examination	Mean exposure at skin entrance
Head and neck	279
Thorax	
Chest, photofluorographic	504
Chest, radiographic	45
Shoulder	213
Thoracic and cervical spine	1265
Other chest and thorax	1657
Upper abdomen	796
Lower abdomen	784
Extremities	117

*[Gitlin, J. N., and P. S. Lawrence, Population Exposure to X-Rays, U.S. Public Health Service, Publ. No. 1519 (1964); Population Dose from X-Rays, U.S. Bureau of Radiological Health, Rockville, MD, Publ. No. 2001 (1964).]

Table 89. Estimated mean exposure per dental film by type of examination, U.S., 1964.*

Type of examination	Mean exposure at skin entrance (mR)
Bitewing	1249
Full mouth	1059
Periapical	1201
All other	1301

*[Gitlin, J. N., and P. S. Lawrence, Population Exposure to X-Rays, U.S. Public Health Service, Publ. No. 1519 (1964); Population Dose from X-Rays, U.S. Bureau of Radiological Health, Rockville, MD, Publ. No. 2001 (1964).]

Fig. 94. Estimated percent distribution of medical x-ray procedures by type of facility and supervision, U.S., 1964. The total number of procedures represented is 119 million. ¹Gitlin, J. N., and P. S. Lawrence, Public Health Service Publication Nos. 1519 and 2001. }

Fig. 95. Estimated mean exposure per film for radiographic examinations of the abdomen by type of facility, U.S., 1964. [Gitlin, J. N., and P. S. Lawrence, Public Health Service Publication Nos. 1519 and 2001.]

Fig. 96. Summary of estimated average whole-body radiation doses in the U.S. [Giflin, J. N., and P. S. Lawrence, Public Health Service Publication Nos. 1519 and 2001.]

Fig. 97. Estimated percentage distribution of genetically significant dose by type of medical roentgenologic examination, U.S., 1964. [Gitlin, J. N., and P. S. Lawrence, Public Health Service Publication Nos. 1519 and 2001.]

Fig. 98. Estimated annual x-ray experience of the population by number of persons, visits, examinations and procedures, and films or exposures, U.S., 1964. [Gitlin, J. N., and P. S. Lawrence, Public Health Service Publication Nos. 1519 and 2001.]

Fig. 99. Estimated percentage distribution of genetically significant dose from diagnostic medical roentgenology by age and sex, U.S., 1964. [Gitlin, J. N., and P. S. Lawrence, Public Health Service Publication Nos. 1519 and 2001.]

Section III

Effects on Water Quality

SUMMARY

Sources

Major energy activities impacting water quality in the nation originate mainly from oil spills, acid mine drainage, operation of atomic energy plants, trace metals, and thermal discharges. (Tables 90-97.)

Trends

A very large portion of all U.S. waters consistently demonstrates quality characteristics that violate established criteria. These violations occur in densely populated and sparsely populated areas; in humid and arid climates; in industrialized, agricultural, and forested regions; and apparently without reference to either the prevalence or the intensity of waste treatment.

The lack of a pattern makes it impossible to judge whether conditions are improving or deteriorating. But the consistency of the pattern of pollution suggests that there may be inefficiencies in current approaches to abatement.

On the basis of the data available we may conclude that substantially the same water quality existed in 1971 and in 1970 and that the western U.S. had better water quality than the eastern U.S. In coming years, as comparable data is developed, the water pollution index will be able to better identify trends in water quality for the nation.

An analysis of the individual discharges in Region IV (Atlanta) shows not only that the major portion of the industrial water emissions is concentrated in a few industries, but that it is concentrated in a few large plants. One percent of all the facilities accounts for more than 50% of the total biological oxygen demand (BOD) discharged.

Although the year-to-year trends (in the Detroit River) were somewhat mixed, the emission levels associated with industry were gradually lessening during the period, while municipal emission levels were generally worsening.

The Federal Water Pollution Control Act Amendments of 1971 and 1972 have reached a culmination in environmental control of surface waters. They call

for a policy of cessation of all discharges by 1985. "Zero discharge" implies total water reuse, with such reuse reducing water withdrawals drastically and improving surface water quality to pretechnology levels.

Costs of Control

Overall, the U.S. energy industry invested an estimated \$1.05 billion in 1973 for plant and equipment to abate water emission control.

Two industries — electric utilities and petroleum — accounted for \$0.07 billion, 6.7% of the total.

Total environmental expenditures by the U.S. petroleum industry for water conservation amounted to \$402 million in 1973.

The energy industrials plan to spend \$1.25 billion for water abatement in 1974: \$0.5 billion by the electric utilities and \$0.32 billion by the petroleum industry.

While some reduction in spending may have resulted from emission control costs during 1973, business in general does not think of abatement regulations as reducing investment in new plant and equipment.

Projected national outlays for water emission control in 1980 are estimated at \$20.7 billion, 55% related to energy activities.

Projected national annual average outlays for water emission control during the period 1971-1980 are estimated to be \$12.2 billion.

The amount spent in 1973 by U.S. energy industries for CIPP to meet environmental water standards was \$0.29 billion, or 27% of the amount spent for emission controls.

Of the \$1.25 billion in water emission control expenditures planned for 1974, \$0.293 billion, or 22.7%, will be for CIPP. (Tables 98 and 99.)

Table 90. Annual water effluent from a conventional nuclear electricity system:
1000-Mw LWR reactor, 75% load factor.*

System process	Total effluent		Effluent type (tons)								
	Tons	Ci	Suspended solids	Nondegradable organics	BOD	Acid	Alkali	Chlorine	Phosphates	Boron	Chromates
Exploration	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Extraction	20,400	1.9	0	0	0	0	0	0	0	0	0
Processing	42.9	2,348	0	0	0	0	0	0	0	0	0
Transport	0	0	0	0	0	0	0	0	0	0	0
Conversion	813	332	425	55	2	68	9	22	25	205	2
Transmission	0	0	0	0	0	0	0	0	0	0	0
Total	21,255.9	2,681.9	425	55	2	68	9	22	25	205	2

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, D.C. (1973).]

Table 91. Annual water effluent from an uncontrolled coal-fired electricity system: 1000-MW power plant, 75% load factor.*

System process	Effluent type (tons)												
	Total effluent	Acid	Dissolved iron	Silt	Blockwater solids	Suspended solids	Non-degradable organics	BOD	Alkali	Chlorine	Phosphates	Boron	Chromates
Exploration	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Extraction													
Deep	2,661	2,129	532	0	0	0	0	0	0	0	0	0	0
Surface	35,820	166	42	35,612	0	0	0	0	0	0	0	0	0
Processing													
Deep	3,853	0	0	0	3,853	0	0	0	0	0	0	0	0
Surface	3,853	0	0	0	3,853	0	0	0	0	0	0	0	0
Transport	0	0	0	0	0	0	0	0	0	0	0	0	0
Conversion	813	68	0	0	0	0	0						
Deep	813	68	0	0	0	425	55	2	9	22	25	205	2
Surface	813	68	0	0	0	425	55	2	9	22	25	205	2
Transmission	0	0	0	0	0	0	0	0	0	0	0	0	0
Total													
Deep	7,327	2,197	532	0	3,853	425	55	2	9	22	25	205	2
Surface	40,486	234	42	35,612	3,853	425	55	2	9	22	25	205	2

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973).]

Table 92. Annual water effluent from an uncontrolled oil-fired electricity system: 1000-MW power plant, 75% load factor.*

System process	Total effluent	Oil spills	Ammonia	BOD	Chromates	COD	Phenol	Sulfides	Suspended solids	Dissolved solids	Non-degradable organics	Acids	Alkali	Chlorine	Phosphates	Boron
Exploration	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Extraction																
Onshore	111	111	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Offshore	102	102	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Processing																
Onshore	4631	167	52	390	0.3	1086	87	52	455	2342	0	0	0	0	0	0
Offshore	4631	167	52	390	0.3	1086	87	52	455	2342	0	0	0	0	0	0
Transport																
Onshore	435	435	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Offshore	527	527	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Import	1711	1711	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conversion																
Onshore	813	0	0	2	2	0	0	0	425	0	55	68	9	22	25	205
Offshore	813	0	0	2	2	0	0	0	425	0	55	68	9	22	25	205
Import	813	0	0	2	2	0	0	0	425	0	55	68	9	22	25	205
Transmission	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total																
Onshore	5990	713	52	392	2.3	1086	87	52	455	2342	55	68	9	22	25	205
Offshore	5673	796	52	392	2.3	1086	87	52	455	2342	55	68	9	22	25	205
Import	2524	1711	0	2	2.0	0	0	0	425	0	55	68	9	22	25	205

*[Council on Environment Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973).]

Table 93. Annual water effluent from an uncontrolled gas-fired electricity system:
1000-MW power plant, 75% load factor.*

System process	Total effluents	Effluent type (tons)								
		Suspended solids	Nondegradable organics	BOD	Acid	Alkali	Chlorine	Phosphates	Boron	Chromates
Exploration	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Extraction	0	0	0	0	0	0	0	0	0	0
Processing	0	0	0	0	0	0	0	0	0	0
Transport	0	0	0	0	0	0	0	0	0	0
Conversion	813	425	55	2	68	9	22	25	205	2
Transmission	0	0	0	0	0	0	0	0	0	0
Total	813	425	55	2	68	9	22	25	205	2

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, D.C. (1973).]

Table 94. Annual water effluents from a geothermal steam electric plant:
1000-MW(e) power plant, 75% load factor.*

System process	Effluent type
Extraction	Negligible when condensate is returned to injection wells.
Processing	
Transport	
Conversion	
Transmission	
Total	

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 181.]

Table 95. Annual water effluent from a solar electricity system:
1000-MW power plant, 75% load factor.*

System process	Effluent type								
	Suspended solids (tons)	Organics (tons)	BOD (tons)	H ₂ SO ₄ (tons)	Cl ₂ (tons)	Phosphates (tons)	Boron (tons)	Chromates (tons)	Slowdown water
									Dissolved solids (ton/yr)
Extraction	0								
Processing	0								
Transport	0								
Conversion	1868	248	9	310	99	157	1,242	9	30,900
Transmission	0	0	0	0	0	0	0	0	0
Total	1868	248	9	310	99	157	1,242	9	30,900

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 207.]

Table 96. Annual water effluent from a coal gasification electricity system:
1000-MW power plant, 3% sulfur coal, 75% load factor.*

System process	Effluent type										Other
	Suspended solids (tons)	Organics (tons)	BOD (tons)	H ₂ SO ₄ (tons)	Cl ₂ (tons)	Phosphates (tons)	Boron (tons)	Chromates (tons)	Blowdown water		
									gal/min	Dissolved solids (tons)	
Extraction	0	0	0	0	0	0	0	0	0	0	Same as coal - electricity system
Processing	0	0	0	0	0	0	0	0	0	0	----
Transport	0	0	0	0	0	0	0	0	0	0	Same as coal - electricity system
Conversion	373	56	1.8	62	20	31	248	1.8	3218	3203	----
Transmission	0	0	0	0	0	0	0	0	0	0	----
Total	373	56	1.8	62	20	31	248	1.8	3218	3203	----

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974).]

Table 97. Annual water effluent from a fusion reactor electricity system:
1000-MW power plant, 75% load factor.*

System process	Effluent type										Blowdown water	
	Depleted water (tons)	Tritium (Ci)	Dissolved solids (tons)	BOD (tons)	H ₂ SO ₄ (tons)	Cl ₂ (tons)	Phosphates (tons)	Boron (tons)	Chromates (tons)	Organics (tons)	gal/min	Dissolved solids (tons)
Extraction	0	0	0	0	0	0	0	0	0	0	0	0
Processing	6788	0	0	0	0	0	0	0	0	0	0	0
Transport	0	0	0	0	0	0	0	0	0	0	0	0
Conversion	0	1095	273	1.32	45.4	14.5	22.9	182	1.32	36.5	2370	2355
Transmission	0	0	0	0	0	0	0	0	0	0	0	0
Total	6788	1095	273	1.32	45.4	14.5	22.9	182	1.32	36.5	2370	2355

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 215.]

Table 98. Capital expenditures by U.S. industries
for control of water quality.*

Industry	New plant and equipment (10 ⁶ dollars)	
	1973 water	1974 (estimated) water
All industries	1762	2196
All energy industries	1048	1243
<u>Manufacturing</u>	390	565
<u>Durable goods</u>		
Electrical machinery	85	122
Machinery, except electrical	28	44
Transportation equipment		
Motor vehicles	62	75
Aircraft	10	6
Other	2	2
<u>Nondurable goods</u>		
Petroleum	203	316
<u>Nonmanufacturing</u>	658	680
Mining	50	47
Railroad	11	16
Air transportation	4	5
Other transportation	5	7
Public utilities		
Electric	503	491
Gas and other	27	27
Communication, finance, service, construction, and other	58	87

*[Data abstracted from U.S. Department of Commerce, Bureau of Economic Analysis; see also Council on Environmental Quality, Environmental Quality, Report, USGPO, Washington, D.C. (1974).]

Table 99. Capital expenditures by U.S. industries for control of water quality.*

Industry	Changes in production process (10 ⁶ dollars)	
	1973 water	1974 (estimated) water
All industries	444	462
All energy industries	285	283
<u>Manufacturing</u>	107	143
<u>Durable goods</u>		
Electrical machinery	21	30
Machinery, except electrical	12	15
Transportation equipment		
Motor vehicles	16	12
Aircraft	0	0
Other	1	0
<u>Nondurable goods</u>		
Petroleum	57	86
<u>Nonmanufacturing</u>	178	140
Mining	5	6
Railroad	2	2
Air transportation	0	0
Other transportation	1	2
Public utilities		
Electric	149	98
Gas and other	11	9
Communication, finance, service, construction, and other	10	23

*(Data abstracted from U.S. Department of Commerce, Bureau of Economic Analysis; see also Council on Environmental Quality, Environmental Quality, 5th Annual Report, USGPO, Washington, D.C. (1974).]

CHEMICAL FACTORS

Oil Spills

Sources

Oil spills involve ships, pipelines, storage tanks, fuel trucks, producing wells, incompletely combusted compounds and volatile plant products, and natural seepages from submarine petroleum deposits and marine plants.

Refineries are another source of oil spills, and many references list them as a major source. However, most of the reported refinery pollution came from a single spill. If this one spill is excluded from the data, refineries are found to be only a minor source of oil pollution.

Seventy-five percent of all spills stem mainly from human negligence, whereas 75% of the total volume of spilled oil comes from technical failure.

Because it is nearly as hard to clean up 1 quart of oil from a stretch of beach as it is to clean up 1 gal from the same spot, if the spills due to technical failure were eliminated, it is likely that much more than 25% of the damage would remain. (Table 100 and Fig. 100.)

Trends

The World's Oceans - The annual average direct influx of all oil into the waters of the world for 1969 and 1970 is estimated to be approximately 35×10^6 bbl (5×10^6 metric tons).

If 5×10^6 metric tons of oil were put into the sea annually and uniformly distributed over the world's oceans, the influx rate would be only 3 oz/mi²/d of oil. Most oil-discharge problems are due not to the overall spillage, but to the spillage of a large amount of oil in a short time. (Figure 101.)

Of the total of all oil in the world's waters, approximately 30% can be attributed to tankers and tank barges and 17% to all other vessels. Slightly less than 50% came from nonmarine operations such as industrial and petrochemical plants, refineries, and the disposal of automobile crankcase oil.

Normal offshore oil and gas operations contributed only about 2% of the total. This figure is somewhat misleading because it does not include abnormal discharges and accidents.

Estimated worldwide seepage from geological formations is considerably less than 700,000 bbl/y. This is less than 2% of the amount that man introduces directly into the world's waters.

The estimated emission of petroleum hydrocarbons to the air in 1970 was about 630×10^6 bbl. All these barrels may find their way to the oceans, and about 10% settles onto the ocean. This 63×10^6 bbl is roughly twice the direct influx of oil into the world's waters and is expected to increase to 126×10^6 bbl by 1980.

United States Waters - In 1970 offshore facilities contributed 25.6% of the total volume of oil spilled; in 1971 the contribution was only 7.3%.

In 1972 the offshore facilities contributed 5644 bbl, or 1.3% of the total volume spilled. For the three years, the percentage contribution to the number of spills was unchanged (roughly 25%). The absolute number of spills, however, changed because of a change in reporting small spills that took place during the last quarter of 1970. The large difference in the volume of oil spilled resulted from two offshore blowouts in the Gulf of Mexico, the Chevron and Shell platform production blowouts, which spilled a combined 83,500 bbl. (Table 101.)

The two other major categories, vessels and onshore facilities, showed large changes from 1970 to 1971, primarily because of a few very large tanker spills and storage tank ruptures.

The size range of individual spills is extremely large, from a fraction of a barrel to over 150,000 bbl.

Most spills are at the low end of this range. In 1972, 96% were less than 24 bbl (1000 gal) and 85% were less than 2.4 bbl (100 gal).

For the four major sources of offshore oil discharges there is a remarkable similarity in the number of oil spills in each volume category for 1971 and 1972. The data suggest that the same processes, equipment inadequacies, and operator errors are causing the spills.

The total amount of oil that has been reported spilled in major outer continental shelf (OCS) accidents is 0.29 to 1.1×10^6 bbl for the period 1964-1972. The average amount of oil spilled during the 1964-1972 period was 140 to 530 bbl/ 10^6 bbl of oil and condensate produced.

Most oil-spill incidents in and around the U.S. take place in areas of high population density and shipping activity. Between 75 and 90% of the spill volume takes place in inland and coastal waters.

Relationships of oil spill to specific areas show wide variations in both volume and incidents from year to year. For the Gulf Coast, where major OCS oil operations take place, the total volume resulting from spill incidents was 12.1% in 1971 and 31.5% in 1970.

For the Pacific Coast, where there are some OCS and state offshore oil operations, the contribution was 24.6% in 1971 and only 2.8% in 1970. Much of the 1970 total can be attributed to tanker spillage.

The Atlantic Coast, where there were no offshore operations, contributed 19.3% in 1971 and 33.5% in 1970, again primarily from tanker operations.

For the Great Lakes, the contribution was 28% for 1971 and 26.0% for 1970. This is primarily from waterborne transportation and industrial operations. It is interesting to note that in 1971 more than twice as much oil was discharged into the Great Lakes as into the waters off the Gulf Coast. (Table 102.)

Costs of Control

The Federal Water Quality Improvement Act of 1970 authorized a \$35 million revolving fund for emergency oil cleanup with the responsible party liable for the costs.

The total social cost of the Santa Barbara oil spill was about \$16.5 million. The direct cost of the oil companies' activities, including the costs of suppressing the spill, collecting oil from the water, and cleaning up the beach area, totaled about \$10.5 million.

After settlement of old suits, the oil companies will have borne most, if not all, of the social costs of the spill. If it is assumed that 2×10^6 gal (about 50,000 bbl) were actually spilled in the Santa Barbara Channel, the social cost amounted to about \$340/bbl of oil spilled. This cost figure is doubtlessly higher than would be encountered in the majority of oil spills. The social costs per barrel of oil spilled would be considerably lower for spills on the open seas or along less valuable coast lines.

Cleanup costs for nearshore oil spills have been variously estimated to range from \$40/barrel to \$120/bbl, depending on the size and location of the spill. The total social cost of oil spills would appear to lie within the range \$50 to 350/bbl spilled.

It is likely that in the future the social costs of major oil spills will be largely internalized by the companies responsible for the spillage. However, the costs associated with operational ballast discharges will continue as external costs.

References - Oil Spills

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Table 100. Estimated annual oil discharges into the oceans, all sources.*

Input	MTA
Transportation tankers, dry docking, terminal operation, bilges, accidents	2.133
Coastal refineries, municipal and industrial warehouses	0.8
Offshore oil productions	0.08
River and urban runoff	1.9
Atmospheric fallout	0.6
Natural seeps	0.6
Total	6.133

*[Report of the Ocean Affairs Board, National Academy of Sciences, Washington, D.C. (1974).]

Table 101. Oil spill statistics (bbl).*

Type of spill	1971	1972
Petroleum industry-related spills		
Terminal		
Number	1,475	1,632
Volume	125,800	54,700
Ships (offshore)		
Number	22	32
Volume	400	51,600
Offshore production facilities		
Number	2,452	2,252
Volume	15,600	5,700
Onshore pipeline		
Number	74	162
Volume	8,700	29,300
Total		
Number	4,023	4,078
Volume	150,500	141,300
All spills		
Number	7,461	8,297
Volume	205,000	518,000

*[The Massachusetts Institute of Technology, Department of Ocean Engineering, 1974, "Analysis of Oil Spill Statistics," prepared for the Council on Environmental Quality using U.S. Coast Guard data.]

Table 102. Oil spill incidents by general area, 1970 and 1971.*

General area	No. of spills	Percent of total	Volume (bbl)	Percent of total
Atlantic Coast				
1971	2,145	24.6	40,565	19.3
1970	886	23.9	121,620	33.5
Gulf Coast ^a				
1971	3,974	45.5	25,482	12.1
1970	1,766	47.6	114,223	31.5
Pacific Coast				
1971	1,609	18.4	51,872	24.6
1970	717	19.3	10,227	2.8
Great Lakes				
1971	377	4.3	58,977	28.0
1970	216	5.8	97,463	26.8
Inland				
1971	631	7.2	33,568	16.0
1970	126	3.4	19,634	5.4
Total				
1971	8,736	100.0	210,465	100.0
1970	3,711	100.0	363,166	100.0

^aWest of longitude 83° 15'.

*[U.S. Department of Transportation, U.S. Coast Guard, "Oil Spill Incidents in and around U.S. Waters, 1970-1971" (unpublished data).]

Fig. 100. Sources of oil spills in the ocean. [Porricelli, J. D., V. F. Keith, and R. J. Storch, "Tankers and the Ecology," Trans. Soc. Naval Arch. and Marine Eng. 79 169 (1971).]

Fig. 101. Type, number, and percentage of the 269 tanker casualties.
[Porricelli, J. D., V. F. Keith, and R. L. Storch, "Tankers and the Ecology," Trans. Soc. Naval Arch. and Marine Eng. 79, 169 (1971).]

Acid Mine Drainage

Sources

Mine drainage is surface water or groundwater flowing through or from mines and mine sites. It is usually characterized by concentrations of acidity or alkalinity, iron, manganese, aluminum, sulfates, and sediment. Although these constituents occur naturally in water as a result of the hydrologic and weathering cycles, they are substantially increased by mining activity.

Underground mines represent 58% of all sources and produce 71% of all acid mine drainage. Of these, the active underground mines represent 5% of all sources and produce 19% of all acid mine drainage.

Surface mines represent 28% of all sources and produce 12% of all acid mine drainage. Of these, the active surface mines represent 1% of all sources and produce 1% of all acid mine drainage.

The remaining 14% of all sources are from combined surface and underground mines, mining waste piles, and coal preparation plants, and these produce 17% of all acid mine drainage. All active mines represent 7% of all sources and produce 22% of the acid mine drainage. Inactive mines contribute 78% of all acid mine drainage.

Trends

Mine drainage affects, continuously or intermittently, the water quality of 10,500 mi of streams in portions of eight Appalachian States, although primarily in Pennsylvania, Maryland, Ohio, Kentucky, and West Virginia. In Appalachia during 1966 more than 6000 tons/d of acidity were discharged to streams and over 10,000 mi of streams were effected by all coal mining operations. A typical acid discharge may have pH levels of 3.5 to 6.6, acidity content of 0 to 1000 ppm, sulfate content of 500 to 1000 ppm, and an iron content of 0 to 500 ppm.

The estimated current rate of pollution is 3.5×10^6 tons/y to all U.S. streams. The flow pattern of surface and subsurface waters is being seriously disturbed in over 11×10^6 acres of land mined for coal in the U.S.

The geographic extent of the streams made acidic by acid drainage is significantly smaller than the area affected by all types of mine drainage. Of the approximately 5700 mi of the Region's streams made acidic, 4300 mi or about 75% are confined to the Susquehanna, Allegheny, Potomac, Delaware, and

Monongahela River Basins. Even though acid streams represent only a small fraction (8.5%) of the total length of streams in these basins in the Appalachian Region, substantial reaches of the larger, more heavily used rivers are frequently polluted, as in the case of the Monongahela River.

The problems will continue to exist for many years unless a solution is found. Mines idle for 30 to 50 y may still discharge large quantities of acid waters.

Costs of Control

The estimated 1969 nationwide cost of reducing acid mine drainage pollution to the 95% degree of abatement was \$6.6 billion; the cost was estimated to be less in proportion to the degree of control. The annual cost to water users of this drainage was estimated at \$3.5 million imposed on individual users, municipal water systems, navigation, and public facilities.

Projected national outlays in 1980 for acid mine drainage control are estimated at \$1 billion. (Table 103.)

References - Acid Mine Drainage

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Table 103. Cost and effectiveness of some techniques for controlling acid mine drainage.*

Technique	Effectiveness (%)	Cost (1969 dollars)
<u>Treatment</u>		
Neutralization	80-90	0.10-1.30/1,000 gal
Distillation	97-99	0.40-3.25/1,000 gal
Reverse osmosis	90-97	0.68-2.57/1,000 gal
Ion exchange	90-92	0.61-2.53/1,000 gal
Freezing	90-99	0.67-3.23/1,000 gal
Electrodialysis	25-95	0.58-2.52/1,000 gal
<u>At the source</u>		
Water diversion	25-75	300-2,000/acre
Mine sealing	10-80	1,000-20,000/seal
Surface restoration	25-75	300-3,000/acre
Revegetation	5-25	70-350/acre

*[Dials, G. E., and E. C. Moore, Environment 16, No. 7, 21 (1974).]

Trace Metals

Sources

Concern over the trace metals from energy-related sources in aquatic environments has developed because: (1) these elements are widely distributed throughout the environment; (2) they are not degraded and hence persist in nature for extended periods of time; (3) generally, they are toxic to living organisms at fairly low concentrations; (4) they tend to be either biologically concentrated or cumulative in plants and animals; and (5) certain metals can be converted to more toxic forms in the environment. (Table 104.)

Regardless of the source, most metallic wastes eventually end up in surface and subsurface waters. Large quantities of many metals released into the atmosphere by industrial plants, incinerators, automobiles, etc., are eventually found in water after sedimentation or after precipitation from the air by rain or snow. Scrubbers for removing waste products from stack gases also transfer metal emissions to water. Solid wastes disposed of on land contribute to water emissions by adding metallic substances to runoff from the disposal area and by the leaching of soluble metallic salts by water percolating through the waste.

While fossil fuels represent a major source for seven contaminants, at the present time only lead, and mercury are believed to represent real or potential hazards to man.

Trends

About 5000 tons/y of mercury are released to rivers by continued weathering.

Line drainage contributes significant amounts of mercury to streams. Soluble mercury introduced into streams is rapidly reduced to its metallic mercury form by various natural chemical processes.

Approximately 8800 lb/y of mercury is discharged into Southern California coastal waters via sewage effluents. The average mercury concentration of the effluent is 0.003 mg/liter.

Localized mercury inputs from sewage outfalls result in mercury concentrations near the outfalls 50 times larger than natural concentrations.

Ocean-sediment samples collected near Los Angeles sewage outfalls contained about 1 mg/liter mercury on a dry-weight basis as compared to a control area concentration of 0.02 mg/liter.

Mercury discharges into soils and streams is primarily a local problem, requiring careful monitoring and regulation of effluents.

Mercury is translocated to the sea only very slowly from soil and stream, but rapidly by precipitation from the air.

Mercury levels in marine fish may rise above acceptable levels if the combustion of fossil fuels with a high (≥ 1 ppm) mercury content continues.

Because of mercury's tendency to vaporize, the atmosphere near ore deposits may contain as much as 0.02 mg/m^3 (2.4 ppb) mercury; however, this vapor is generally washed from the atmosphere by rain.

Limited sampling of oil-field brines and petroleum from California showed them to contain from 1,000 to 500,000 ppb mercury.

Hot springs range generally from undetectable levels of mercury to 3.2 ppb; however, one measurement of 20 ppb has been recorded. Vapors issuing from fumaroles and steam condensates from hot springs have been shown to contain up to 130 ppb mercury.

Condensable steam from the McKinley steam field at Castle Rock Spring, Lake County, California, near the Geysers steam field, contains from 1 to 3 ppb mercury. This is below the maximum level of mercury considered safe for drinking water proposed by the U.S. Public Health Service at 5.0 ppb.

The mercury cycle in the environment (shown schematically in Fig. 102) is a typical example of an ecological system that favors the production of organometallic compounds. Micro-organisms living in the sludge at the bottom of lakes and rivers are capable of transforming inorganic mercury to the more toxic methylmercury form. This latter substance is considerably more water soluble and is readily taken up by smaller aquatic organisms. With each upward step in the food chain, methylmercury becomes more and more concentrated, so that tissues of some carnivorous fish high up in the chain can show a 3000-fold or more concentration compared with the surrounding water. Other trace elements that are capable of being methylated are arsenic, platinum, and thallium.

The uses of lead include the production of storage batteries, cables, and paint pigments. Lead from a 500,000-bbl/d refinery averages 3 tons/y.

The combustion of lead alkyls in gasoline produces aerosol forms of inorganic lead salts such as lead chlorobromide, and rivers become contaminated with lead alkyls from atmospheric fallout. The major pathway by which lead alkyls reach surface waters in urban areas probably is by the discharge from storm sewers. About two-thirds of the urban fallout of lead alkyls, which

are soluble salts, find their way into storm sewers. Such lead contributions amount to about 8800 tons/y. The majority of this comes from automotive exhausts.

Surface waters can become contaminated directly from lead fallout. The seepage of lead wastes from scrap heaps and the weathering products of lead paints all contribute lead to surface waters. In the U.S. these waters rarely exceed the U.S. Public Health Service Drinking Water Standard of 50 $\mu\text{g/l}$ for lead. Typically the water contains 1 to 10 $\mu\text{g/l}$.

Public water supplies do not constitute a significant source of lead exposure to the general population. Almost all public water supplies have lead concentrations less than the 50 $\mu\text{g/liter}$ upper limit.

Sediments in lakes and rivers have been shown to contain 1000 times or more as much lead as the overlying water. This high concentration of lead may be suspended in the water under conditions of high velocity associated with flood flows.

Blota in surface lakes and streams may also have high lead concentrations approaching levels encountered in the bottom sediments, particularly in the case of bottom feeders or organisms that concentrate lead from large volumes of water.

Costs of Control

No data available.

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Table 104. Trace metals in water from various energy sources that may pose health hazards to man.*

Element	Sources
Arsenic	Coal, petroleum, mine tailings
Beryllium	Coal
Boron	Coal
Cadmium	Coal
Germanium	Coal
Lead	Auto exhaust
Mercury	Coal, electrical batteries
Nickel	Diesel oil, residual oil, coal
Selenium	Coal
Vanadium	Petroleum
Yttrium	Coal, petroleum

*[Compiled from data in Chem. Eng. News 49, 29 (July 19, 1971).]

Fig. 102. Mercury cycle in the environment. [Krenkel, P. A., R. S. Reimers, and W. Dickinson Burrows, "Mechanisms of Mercury Transformation in Bottom Sediments, Part I," Technical Report No. 1, p. 28, Environmental and Water Resources Engineering, Vanderbilt University, Nashville, Tennessee, May 1973.]

Tritium

Sources

Tritium is a radioactive isotope of hydrogen with a half-life of 12.33 y. It has four principal pathways of introduction into the aquatic environment, primarily as HTO (tritiated water):

1. Through natural processes — interaction of cosmic ray proton radiation with oxygen and nitrogen atoms in the upper atmosphere followed by rainout.
2. From past tests of nuclear weapons in the atmosphere followed by rainout.
3. From nuclear reactors and fuel reprocessing plants where it may be generated through a variety of reactions within the fuel or the primary coolant.
4. From underground nuclear explosions where it migrates out of the chimney and contaminates groundwater. (Table 105.)

Trends

The relative overall release rates of tritium in liquid effluents from BWR's and PWR's has been the reverse of the situation for gaseous effluents. Although rates for both reactor types have declined in recent years, those from PWR's have been about 100 times the rates from BWR's. Most of the reduction in the overall averages is attributable to the lower release rates from second-generation plants.

If nuclear power production beyond the year 2000 is maintained at the level predicted for that year, a steady-state quantity of 260 MCi of fission-product tritium will be accumulated by about 2060. This quantity will give radiation dose levels about 3 times those estimated for the year 2000. (Figures 103-105.)

Tritium Accumulation in a Large Lake (Lake Michigan) - There will be 7 nuclear power sites on the lake by 1973 comprising some 10 reactors, or about 7030 MW(e). The total U.S. generating capacity provided by nuclear power is scheduled to be 45,600 MW(e) by 1973; thus about 15% of this total will be located on Lake Michigan. Most of this capacity will be furnished by PWR's, a situation not typical of the national trend which tends to be an even distribution between BWR and PWR plants.

Data show that although the estimated tritium activity accumulated in the lake by year 2000 is near 1 MCi, the concentration in the lake would be less than 0.22% of the radioactivity concentration limit of 3×10^{-3} μ Ci/mliter used by the U.S. Atomic Energy Commission. (Figure 106.)

Tritium Levels in Surface Waters - The amount of bomb-produced tritium is uncertain, although estimates indicate that 1900 MCi were produced from 1952 through 1962. This compares with natural tritium production of around 2 to 6 MCi/y.

Additional amounts of tritium have been released into the atmosphere by French and Chinese weapons testing conducted since 1964, but the total is a small fraction of that released during the earlier testing period.

The effect of weapons-produced tritium on tritium concentrations in the environment, in drinking water, in food, and in man has not been monitored in great detail. The concentration of tritium in environmental waters reflects the weapons-testing activity. Sharp increases are indicated following the testing series in 1954, 1956, and 1958.

The very active test period in late 1961 and 1962 caused the peak concentrations in U.S. rivers in 1963-1964. The declines in concentration during the 1959-1960 moratorium and after the 1963 Test Ban Treaty are evident. Recent high yield tests in the northern hemisphere by the Chinese may be responsible for the relatively higher tritium levels measured in 1969-1970 as compared to the previously declining values.

The average U.S. river tritium concentrations declined with a half-time of 3.2 y from 1963 until 1969 and 5.0 y during 1969 and 1970. Tap water analyzed at the Health and Safety Laboratory in New York City reflecting the lower Hudson Valley watershed area, showed somewhat lower tritium concentrations than the U.S. average in 1970.

More recent tap water samples would indicate that the U.S. average beyond 1970 resumes the 3.2-y half-time decline. The absence of high-yield atmospheric tests in the northern hemisphere in the past 2 y would also support this assumption. (Figure 107.)

Costs of Control

No data available.

References - Tritium

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

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Whan, G. A., Battelle Memorial Institute, Columbus, OH, Publ. BMI-171-147 (1972).

Table 105. Annual tritium release in liquid effluents from various nuclear electricity systems: 1000-MW delivery system, 100% capacity factor.*

System process	Light water reactor (Ci)		Uranium-plutonium-fueled breeder reactor (Ci)	Fusion reactor power plant	Uranium-plutonium-fueled water reactor (Ci)	High-temperature gas-cooled reactor
Extraction	0		0	0	0	0
Processing	3340		2396	0	4200	0
Transport	0		0	0	0	0
	<u>BWR</u>	<u>PWR</u>				
Conversion	90	450	0	1460	0	154
Transmission	0		0	0	0	0
	<u>BWR</u>	<u>PWR</u>				
Total	3430	3790	2396	1460	4200	154

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974).]

Fig. 103. Total tritium in liquid effluents for PWR, HTGCR, and BWR plants, 1967-1972. [Hull, A. P., Nuclear News 17, 51 (April 1974).]

Fig. 104. Tritium in liquid effluents for PWR plants, 1967-1972. [Hull, A. P., Nuclear News 17, 51 (April 1974).]

Fig. 105. Iritium in liquid effluents for BWR plants, 1967-1972. [Hull, A. P., Nuclear News 17, 51 (April 1974).]

Fig. 106. Estimates of future tritium concentration in Lake Michigan from nuclear reactor operation. These values are in addition to tritium from fallout and natural sources. [Peterson, H. T., E. Martin, C. L. Weaver, and E. D. Harward, "Environmental Tritium Contamination from Increasing Utilization of Nuclear Energy Sources," in the Proceedings of Environmental Contamination by Radioactive Materials, International Atomic Energy Agency, Vienna 1969, SM-117/78, p. 35.]

Fig. 107. Environmental tritium in surface waters. [Data presented in Bennett, B. G., paper at the 3rd International Radiological Protection Association Meeting, Washington, DC, September, 1973.]

Other Radioactivity in Liquid Effluents

Sources

At least a dozen different radionuclides other than tritium are typically present in measurable concentrations in the liquid-waste discharges from water-cooled power reactors. Individual isotopes include high-yield fission products from the fuel and neutron-activation products associated with fission (such as strontium-89, strontium-90, iodine-131, cesium-134, barium-140, and cerium-144) and activation products from the water, cladding, and other construction materials (such as manganese-54, iron-55, and cobalt-60).

The radionuclides of greatest biological significance at the concentrations found in the liquid wastes are strontium-89 (half-life, 50.5 d), strontium-90 (half-life, 28.5 y), and iodine-131 (half-life, 8.06 d).

The two main sources of strontium-90 in liquid effluents are from nuclear reactors and their fuel reprocessing plants, and from fallout after atmospheric nuclear bomb tests. The potential source for environmental release is mainly the nuclear fuel-reprocessing plants, where the fuel rods are dissolved and the radiostrontium is released from the cladding. However, precautions have been designed into the more recent plants to assure containment in normal operation. (Table 106.)

Trends

Average mixed-fission-and-corrosion-product activity release rates from BWR's have consistently been somewhat larger than those from PWR's. Both have declined somewhat over the period under consideration.

The individual reactor release rate data suggest that for both the BWR's and PWR's the release rates from the second-generation reactors have generally been somewhat less than from the older plants. (Figure 108.)

Costs of Control

No data available.

PHYSICAL FACTORS

Thermal Inputs

Sources

The principal contributor of waste-heat discharge into natural waters is the electric power industry. Industrial effluents, domestic outfall, agricultural runoff, and geothermal sources make a smaller contribution.

It is a physical law of nature that all power plants reject unusable heat, whether they use coal, oil, gas, nuclear, geothermal, solar, or other heat sources (as shown schematically in Fig. 109 for a fossil-fuel power plant, a BWR nuclear power plant, and a PWR nuclear power plant). This is equally true of auto engines, jet engines, and the human body. However, the heat rejected from power plants may be beneficial or harmful, depending on how it is used or released to the environment.

Trends

In a modern, efficient, conventionally fossil-fueled steam electric plant, 40% of the heat energy released from burning the fuel is converted into electricity, 45% is lost in cooling water, and the remaining 15% goes up the stack along with other pollutants. (Figures 110-112.)

In a nuclear fission power plant, the thermal pollution problem is increased. Only about 30% of the input energy is converted into electricity and 70% is lost in cooling water. (Figures 113-117.)

The U.S. Federal Power Commission estimates that power-plant waste heat will more than double each decade, primarily because these estimates are based on rising projections of nuclear power use — from 1.9% of total power production in 1970 to 22.1% in 1980 and 39.7% in 1990.

However, 5.3×10^{15} Btu (1970) will raise the temperature of about 90×10^9 gal/d by 20°F — the approximate average temperature rise for waters passing through power-plant condensers. For 12.8×10^{15} Btu (1980), the amount of water is about 210×10^9 gal/d, and for 28.4×10^{15} Btu (1990) it is 470×10^9 gal/d. Since U.S. national average stream flow is approximately 1200×10^9 gal/d, the appearance of local problems is understandable.

Temperatures vary depending on the flow rate, the initial temperature of the water, etc. Usually the temperature of 30 to 55 gal of cooling water is raised about 150°F for each kWh of electricity generated. But this does not mean the temperature of a river, for example, is raised by 15°F.

Increasingly stringent federal and state water-quality standards and laws may have a strong tendency to shift the current widespread use of once-through cooling to a greater use of cooling ponds and cooling towers, thus transferring more of the rejected heat directly to the atmosphere via receiving waters with elevated surface temperatures.

Only the Mississippi, Ohio, and Missouri Rivers have a large potential for once-through cooling under 10-y low monthly conditions and normal peak temperatures. However, average capacities are typically about 3 times greater, and average monthly lows are approximately double the 10-y extremes within the 230 generation areas examined in the study.

Where average capacities are significant, even though the 10-y low or annual low month may be inadequate, there can be a potential for variable-cycle cooling systems. Such systems could reduce operating costs by utilizing off-stream cooling only on a seasonal basis, or using partial off-stream cooling at all times.

A need exists for guidelines and coordinated advanced planning of thermal effluent releases in order to maximize benefits associated with the development of a limited natural resource, river cooling water supply.

Table 107 and Fig. 118 give river cooling capacity in the U.S. vs the projected requirements and use. Only the Missouri and Lower Mississippi River Basins will have over one-third of their effective capacity still unused by 1990. However, in some regions (notably the Missouri, Ohio-Tennessee, and South Atlantic-Gulf river basins) substantial potentially developable capacity exists outside of presently planned generation areas.

Costs of Control

The total investment in a cooling system for an 800,000-kW plant will range from about \$4.9 million for a fossil-fueled plant with a once-through system using seawater to \$50.1 million for a nuclear plant with a natural-draft dry tower.

In general, the capital costs of a given type of cooling system are about 50% higher for a nuclear plant than for one using fossil fuel. Natural-draft towers cost more than mechanical-draft towers and dry towers more than wet ones. Since investment costs are rising, the impact of fixed charges will increase the cost handicap against natural-draft towers and dry towers.

Assuming an average capital cost of \$200/kW of generating capacity, cooling ponds increase these costs by about 2%, wet towers by about 5%, and

dry towers by about 10 to 20%. Based on generating costs of 8 mills/kWh, cooling ponds increase costs on the order of 1%, wet towers about 2%, and dry towers about 10%.

These statements may tend to obscure the fact that the costs of reducing thermal pollution may mount into millions or billions of dollars. In 1968 about 1.3×10^{12} kWh were produced. If thermal pollution measures had required an increase as small as 0.1 mill/kWh then the total dollar amount involved would have been \$130 million. At the same rate of cost, an estimated 1990 power consumption of, say, 6×10^{12} kWh would require \$600 million for thermal pollution measures.

The EPA says the thermal discharge requirements will cost (in 1974 dollars) \$2.7 billion after 316(a) exemptions are granted. These expenditures would increase capital requirements of the industry by 1.9%. If no 316(a) exemptions were made, cost of the thermal standards would be \$5.2 billion.

The EPA had estimated that the standards proposed in March 1974 would have cost \$5.2 billion for thermal controls after granting 316(a) exemptions. Without 316(a) exemptions the cost of thermal standards would have been \$11.8 billion. (Tables 108 and 109.)

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Table 106. Annual radioactivity release in liquid effluents from various nuclear electricity delivery systems: 1000-MW(e) delivery system, 100% capacity factor.*

System process	Light water reactor		Uranium-plutonium breeder reactor		Fusion reactor		Uranium-plutonium water reactor		High-temperature gas-cooled reactor	
	Ci	Gal	Ci	Gal	Ci	Gal	Ci	Gal	Ci	Gal
Extraction	5.2	---	0.02	---	0	0	1.1	---	2.8	--
Processing	4.0	---	2.65	---	0	0	3.9	---	0.5	--
Inter. level	--	6,900	--	5,400	0	0	--	7,350	--	--
Low level	---	340,000	--	270,000	0	0	--	3.61×10^5	--	--
Transport	0	0	0	0	0	0	0	0	0	0
Conversion	5.0	---	5	0	0	0	6.3	---	0	0
Transmission	0	---	0	0	0	0	0	0	0	0
Totals	14.2	346,900	7.67	275,400	0	0	11.3	3.61×10^5	3.3	0

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974).]

Table 107. River cooling capacity vs projected requirements and utilization^{a,*}

Region	Condenser cooling reqmts. for installed capacity (GW _T) ^b			Potential peak rejection to rivers by once-thru cooling (GW _T) ^c			River cooling capacity (GW _T)	
	1970	1980	1990	1970	1980	1990	In generation areas	Total
North Atlantic	70	165	270	12	17	21	30	35
South Atlantic Gulf	45	125	240	12	29	44	45	65
Great Lakes	45	85	160	0	0	0	0	0
Ohio-Tennessee	70	130	220	37	51	53	60	90
Missouri	17	40	80	13	27	35	60	160
Upper Mississippi	23	50	110	9	20	33	40	45
Lower Mississippi	40	90	170	14	33	69	140	150
Texas-Gulf	30	60	105	0	0	0	0	0
Columbia-Snake	2	10	25	0	0	0	0	0
Pacific	40	95	215	1	4	5	6	14
Nation ^d	380	850	1590	100	180	260	380	560

^aHeat rejection determined from national average efficiencies, considering projected improvements and projected nuclear-fossil plant mix.

^bIncludes requirements for plants built to provide a roughly 20% reserve capacity.

^cHeat rejection if projected capacity additions make full use of locally available cooling capacity.

^dColumns may not add to totals because of rounding.

*[D. E. Peterson, et al., Hanford Engineering Development Laboratory, Richland, WA, HEDL-TME 73-4J, July 1974.]

Table 108. Cost of cooling systems for 800-MW power stations burning fossil and nuclear fuel (10^6 1970 dollars).*

Cooling system	Condenser and auxiliaries		Cooling towers and basin		Pumps and conduits		Makeup system		Cooling lake		Total investment	
	Fossil	Nuclear	Fossil	Nuclear	Fossil	Nuclear	Fossil	Nuclear	Fossil	Nuclear	Fossil	Nuclear
River	1.7	2.6	--	--	3.3	4.8	--	--	--	--	5	7.4
Lake	1.5	2.3	--	--	2.7	3.9	--	--	2.6	3.4	6.8	9.6
Mechanical-draft wet tower	1.9	2.8	1.7	2.6	1.6	2.4	1.2	1.6	--	--	6.4	9.4
Natural-draft wet tower	1.9	2.8	4.2	7.1	1.7	2.5	1.2	1.6	--	--	9	14
Mechanical-draft dry tower	1.1	1.7	12.2	19.3	2.1	3.4	--	--	--	--	15.4	24.4
Natural-draft dry tower	1.1	1.7	28	45	2.1	3.4	--	--	--	--	31.2	50.1

* [Lawrence Livermore Laboratory, staff compilation.]

Table 109. Types of cooling systems and estimated cooling costs (1970 dollars).*

System	cost/kW
Cooling lakes	\$2 to 15
Wet mechanical draft tower	\$4 to 16
Wet natural draft tower	\$6 to 20
Dry mechanical draft tower	\$15 to 37
Dry natural draft tower	\$25 to 65

*[Lawrence Livermore Laboratory, staff compilation.]

Fig. 108. Mixed fission and corrosion products in liquid effluents, 1967-1972. [Hull, A. P., Nuclear News 17, 51 (April 1974).]

Fig. 109. Schematics of power plant operation. (a) Fossil fuel. (b) Boiling water reactor. (c) Pressurized water reactor.
[Lawrence Livermore Laboratory, staff compilation.]

Fig. 110. Light-water nuclear plant, waste-heat rejection by once-through cooling, 100% capacity factor. [Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 134.]

Fig. 111. Light-water nuclear plant, waste-heat rejection by evaporative cooling, 100% capacity factor. [Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 138.]

Fig. 112. Light-water nuclear plant, waste-heat rejection by cooling pond, 100% capacity factor. [Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EED 103 (December 1974), p. 147.]

Fig. 113. Light-water nuclear plant, waste-heat rejection by dry cooling, 100% capacity factor. [Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 151.]

Fig. 114. Coal-fired power plant, waste-heat rejection by once-through cooling, 100% capacity factor. [Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 135.]

Fig. 115. Coal-fired power plant, waste heat rejection by evaporative cooling, 100% capacity factor. [Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 139.]

Fig. 116. Coal-fired power plant, waste-heat rejection by cooling pond, 100% capacity factor. [Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 148.]

Fig. 117. Coal-fired power plant, waste-heat rejection by dry cooling, 100% capacity factor. [Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 152.]

Fig. 118. River cooling capacity vs projected requirements and utilization. Once-through cooling from rivers on a year-around basis falls far short of meeting the projected cooling requirements. [Peterson, D. E. *et al.*, Hanford Engineering Laboratory, Richland, WA, HEDL-TME 73-4V, July, 1973.]

Depletion of Water Reserves

Total daily water use in the U.S. in 1970 was 385×10^9 gal, of which 121×10^9 (31%) were for steam electric utilities, 119×10^9 (31%) were for irrigation, 56×10^9 (15%) were for industrial, commercial, and government agencies, 27×10^9 (7%) were for public water utilities, and the remaining 16% for other uses. In 1900 the total water used was only 40×10^9 gal; by 1980 the figure is expected to rise to 443×10^9 gal.

Conventional oil shale development will significantly change the water demand-supply balances that currently exist in the oil shale regions of Colorado, Utah, and Wyoming. (Three barrels of water would be required for each barrel of oil produced.)

Upwardly spiraling water-intensive technologies, continuous growth in standard of living, and continually increasing population together could lead to exponential growth in our use of water.

The high estimates presume different rates of economic population growth than do the medium and low estimates. The need to more than double our use of water in the next 50 y is coupled with a parallel need to maintain or improve significantly the quality of that water. (Tables 110-114 and Fig. 119.)

Table 110. Typical water consumption for recovering oil from oil shale by various recovery methods (10^6 bbl/d).*

Recovery method		Water use (gal/min)
Where retorted	Shale preparation	
<u>Surface</u>	Underground mining, room and pillar	11×10^4
	Open-pit mining	11×10^4
<u>In situ</u>	Mining rubblization (RISE process)	6×10^4
	Nuclear fracturing	4×10^4

*Lewis, A., et al., Lawrence Livermore Laboratory, Univ. of California, Livermore, CA 94550, Rept. UCRL-51768 (1975).]

Table 111. Typical water consumption for a 50,000 bbl/d oil-shale plant.*

- Assumptions:
- (1) Process sequence includes underground mining, surface retorting, processed shale disposal by wetting and compaction, upgrading of shale crude by partial hydrofining.
 - (2) Process cooling primarily by aerial condensers.
 - (3) Raw shale, 30 gal/ton: processed shale wetted with 20% water for compaction.

	<u>Net water consumed</u> gal/min
Mining ^a	135 - 180
Crushing (dust control) ^a	90 - 135
Retorting ^a	359 - 449
Processed shale disposal ^b	152 - 260
Shale oil upgrading	90 - 112
Other (personnel, construction, etc.)	45 - 269
Total	871 - 1405

^aIn situ operation would eliminate most of these water requirements.

^bIf slurry disposal were to be used, this maximum could be as high as 314 gal/min.

*[Department of the Interior, 1972.]

Table 112. Water requirements for coal conversion processes.*

Process			Process water						Cooling water (gal/min)				Totals (gal/min)		
Type	Name	Products (Btu/d)	Boiler	Other	Total			Raw water	Recycle water	Blowdown	Total loss	Air cooling	Raw water	Effluent	Loss
High Btu designs using Lurgi processes	Hygas ^a	$2.5 \cdot 10^{11}$	4890	3810	8700	3801	4899	10800	0	1200	9600	yes	19500	4901	14499
	Synthane	$2.5 \cdot 10^{11}$	700	9800	10500			11500	0			no	22000		
	CO ₂ acceptor ^b	$2.5 \cdot 10^{11}$	2000					5500				no	7500		
	Bigas	$2.5 \cdot 10^{11}$	1100					10500	0			no	11600		
	Wesco	$2.5 \cdot 10^{11}$	3440	1660	5100	3058	2042	0	2240	470	1760	yes	5100	1290	3802
	El Paso	$2.5 \cdot 10^{11}$	4080	2535	6615	3590	3025	441	2854	329	2960	yes	7056	1065	5991
	Lurgi	$5.8 \cdot 10^{10}$	250	0	250			2100	0			no	2350		
	Koppers-Totzek	$8.7 \cdot 10^{10}$	150	0	150	0	150	3000	indirectly	600	2400	no	3150	170	2980
	Bigas - A ^c	$1.2 \cdot 10^{11}$	700	850	1750			2750	0			no	4500		
	Bigas - B ^c	$1.18 \cdot 10^{11}$	870	0	670			460	0			no	1010		
Low Btu processes		$9.85 \cdot 10^8$													

Table 112. (Continued)

Type	Process Name	Products (Btu/d)	Process water					Cooling water (gal/min)				Totals (gal/min)		
			Boiler	Other	Raw water	Effluent	Loss	Raw water	Recycle water	Blowdown	Total	Air cooling	Raw water	Effluent Loss
Liquefaction processes	Coed + low Btu gasification ^d	2.08 × 10 ¹¹ + 1.5 × 10 ¹¹ ^c	1400	5650	6050			6800	0			no	12650	
	Coed + High Btu gasification	2.50 × 10 ¹¹ + 1.55 × 10 ¹¹ ^k	2454	746	3200			37000	0			no	40200	
	CSF - A	0.74 × 10 ¹¹ + 0.62 × 10 ¹¹ + 2.21 × 10 ¹¹ ^h	1200					9560				no	10660	
	CSF - B	1.18 × 10 ¹¹ + 0.67 × 10 ¹¹ + 2.14 × 10 ¹¹ ^h	486					13200				no	13706	
	SRC	4.7 × 10 ¹¹	1500	0	1500	104	1396	1500				no	3000	
	Solid fuel processes													

^aData obtained from reference 1 where the actual numbers are for a 1/3 scale plant; here they are multiplied by 3.

^bFor lignite only. Also, reference 8 gives the cooling tower circulation; the makeup water requirement is assumed to be 5% of the circulation since makeup rates are generally from 3 to 7.

^cReference 13 gives annual water requirements along with the cooling tower circulation; cooling tower makeup is assumed to be 5% of the circulation.

^dReference 21 does not present water figures directly; they were calculated by dividing total cost of water by its cost per unit volume.

^e9.85 × 10⁶ Btu/day of electricity are also produced.

^f1.5 × 10¹¹ Btu/day of low Btu gas are also produced.

^g2.5 × 10¹¹ Btu/day of high Btu gas and 1.55 × 10¹¹ Btu/day of crude oil are produced.

^hProcess A produces:
 .74 × 10¹¹ Btu/day of high Btu gas,
 .62 × 10¹¹ Btu/day of naphtha, and
 2.21 × 10¹¹ Btu/day of crude oil.

Process B produces:
 1.18 × 10¹¹ Btu/day of high Btu gas,
 .67 × 10¹¹ Btu/day of naphtha, and
 2.14 × 10¹¹ Btu/day of crude oil.

*[Stout, G. E., Proceedings of the Workshop on Research Needs Related to Water for Energy, Indianapolis, Indiana, October 20-22, 1974, Water Resources Center, University of Illinois, Urbana, IL, Publ. PB-241346/6G1 (1974).]

Table 113. Water use by cooling towers serving 1000 MW(e) fossil and nuclear plants, based on heat rejection rates of 4500 Btu/kWh and 6750 Btu/kWh, respectively.^{a*}

Fossil-fueled plant							
Range °F	Tower water flow gal/min	Drift gal/min	Evap. gal/min	Bleed required (gal/min) to maintain concentrations			
				Concentrations of make-up water			
				2	4	6	8
15	600,000	180	6,750	6,570	2,070	1,170	784
25	360,000	108	6,750	6,642	2,142	1,242	856
35	257,153	77.2	6,750	6,673	2,173	1,273	887
45	200,000	60	6,750	6,690	2,190	1,290	904
Total make-up required (gal/min)				13,500	9,100	8,100	7,714
Nuclear-fueled plant							
Range °F	Tower water flow gal/min	Drift gal/min	Evap. gal/min	Bleed required (gal/min) to maintain concentrations			
				Concentrations of make-up water			
				2	4	6	8
15	900,000	270	10,125	9,855	3,105	1,755	1,176
25	540,000	162	10,125	9,963	3,213	1,863	1,284
35	385,715	115.7	10,125	10,009	3,259	1,909	1,331
45	300,000	90	10,125	10,035	3,285	1,935	1,356
Total make-up required (gal/min)				20,250	13,500	12,150	11,571

^aTable data based on (1) evaporating 0.075% of recirculated gal/min/°F range, (2) 0.03% drift loss, and (3) concentrations = (evap.+drift+bleed)/(drift+bleed).

*[Kadel, J. O., "Cooling Towers - A Technological Tool To Increase Plant Site Potentials," Proceedings American Power Conference, 32, 537 (1970).]

Table 114. Annual water use by various 1000-MW electrical energy delivery systems (gal): 100% load factor.*

System process	Delivery system												
	Light water	Uranium-plutonium breeder-reactor	Uranium-plutonium water reactor	High-temperature gas-cooled reactor	Fusion reactor	Low-sulfur coal	High-sulfur coal - SO ₂ removal	High-sulfur coal - gasification	Residual fuel oil	Natural gas	Geothermal steam	Solar energy	Combined steam cycle
Extraction	0.023×10^{10}	17×10^5	5×10^7	12×10^7	1×10^6	Deep mining 4×10^7 Surface 1×10^5	Deep mining 4×10^7 Surface 1×10^5	4×10^7	42×10^7	6×10^{10}	---	---	Oil 42×10^7 Gas 6×10^{10}
Processing	1.5×10^{10}	8×10^5	28×10^6	14×10^6	2×10^6	3×10^9	3×10^9	Gasifier 6×10^8 Desulfurizer 6×10^8	14×10^{10}	0	---	---	1.4×10^{10}
Transport	---	---	---	---	---	---	---	---	---	---	---	---	---
Conversion	52×10^{10}	35×10^{10}	49×10^{10}	42×10^{10}	23×10^{10}	31×10^{10}	Plant 31×10^{10} Scubba 19×10^8	31×10^{10}	31×10^{10}	31×10^{10}	2×10^8	300×10^{10}	23×10^{10}
Transmission	---	---	---	---	---	---	---	---	---	---	---	---	---
Storage	---	---	---	---	---	---	---	---	---	---	---	---	---

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974).]

Fig. 119. Projected exponential growth in our use of water.
[Lawrence Livermore Laboratory, staff compilation.]

Section IV

Land Use

SUMMARY

Sources

The land use for the energy systems vary considerably. Gas-fired systems have the smallest and coal-fired units the largest land use. Land use for the energy cycles may be divided into three parts: mining, fuel preparation, and transportation, and generating plant. A reference on power-plant siting gives the following requirement for 3000-MW(e) generating plants:

	<u>Total acres</u>	<u>Acres/MW</u>	<u>Comment</u>
Coal	900 to 1200	0.4	Includes storage and ash disposal
Nuclear	200 to 400	0.1	--
Oil	150 to 350	0.08	Includes fuel storage
Gas	100 to 200	0.05	Pipeline and modest storage

The actual amount of land purchased depends on the utility practice, possible future expansion plans, and the type of cooling facilities for the reject heat. The coal-fired plant in the above does not have sufficient storage area for some residuals, such as wastes from a wet limestone sulfur dioxide removal system.

The land associated with the mining and preparation of coal represents the largest requirement in the energy systems under consideration. The amount and significance of the disturbance depends on the type of mining. Coal mining for a 1000-MW(e) plant in 1980 is estimated to disturb about 500 acres, although many of these acres may be reclaimed for subsequent use. About 200 acres is associated with underground mining, and it is assumed that the disturbance due to subsidence is small.

Changes in land values can result in termination of an operation and passing of the land to a use of higher value. In the case of refuse-type operations or of a mining activity having inadequate reclamation, the passage of land use is not accomplished without a high expense: the options for land use have decreased and this would usually mean increased costs for society. (Tables 115-117.)

Trends

For energy systems the land use is usually of a temporary nature. The period of use can range from a few years to 30 or 50 years. Much of the land associated with the energy system and its operation can be reclaimed after completion of the activity.

Besides reclamation of land used in mining, the major challenges in land use are usually associated with the care of wastes from the conversion operations. These vary from the disposal of radioactive wastes from the fuel reprocessing plants, to the disposal of wastes from sulfur dioxide removal systems, to the disposal of refuse from cleaning of coal at the mines, and from the brine of geothermal resources. Land subsidence from underground mines and the gross alteration of land form and structure by strip and contour mines are, of course, major problems in reclamation.

At the present time the requirement for land by activities can be reasonably well met from existing land resources. The increase in demand for land by a specific user is usually satisfied by buying land from users placing a lower value on land or from surplus. By the year 2000 there may be deficit for certain land uses that cannot be made up from surplus land and there will be a decrease in uses that place a lower value on land.

The land needed by the 1000 MW(e) energy system is mainly determined by the life of the generating plant and by energy produced. The pattern of land use depends on the fuel-cycle activity: for mining, the land is used gradually over the life of the generating plant and use by other social activities may occur before and after the year of mining, depending on the type of mining and the amount of reclamation; for refuse-type operations, such as waste storage from cleaning coal, tailing rejection, ash disposal, nuclear waste storage, etc., the general pattern is usually noted by the accumulation of more and more waste piles; for the generating plant the land is in constant occupancy over the life of the station.

Costs of Control

The U.S. oil industry spent \$100 million on land and other conservation programs during 1973 and \$352 million dollars during the period 1966-1973.

The nation's total federal funding for pollution control and abatement of land was:

1973 \$61 million (actual)
1974 \$62 million (actual)
1975 \$66 million (estimated)

References - Land Use (Summary)

- Barrett, H. J., and Morse, C., Scarcity and Growth, the Economics of Natural Resource Availability (The Johns Hopkins Press, Baltimore, 1963).
- Davies, R. V., et al., "Extraction of Uranium from Sea Water," Nature 203, 1110 (1964).
- Department of Interior, United States Energy -- a Summary Review, USGPO, Washington, DC (1972).
- Division of Industrial Participation, The Nuclear Industry, USGPO, Washington, DC (1970).
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- Landsberg, H., et al., Resources in America's Future (The Johns Hopkins Press, Baltimore, 1963).
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- Potential Nuclear Power Growth Patterns, USAEC-RDT, Washington, DC, USGPO Publ. WASH-1098 (1970).
- Reference Energy Systems and Resources Data for Use in the Assessment of Energy Technology, Associated Universities, Inc., Oak Ridge, TN, Publ. AET-8 (1972).
- Schurr, S. H., et al., Middle Eastern Oil and the Western World (American Elsevier, New York, 1971).

Table 115. Land use in the U.S. for energy activities.*

Use	Amount	Basis
Coal strip mining	$0.021 \times 10^6 \text{ mi}^2/10^6 \text{ Btu}$	Past and projected rate $26.2 \times 10^6 \text{ Btu/ton}$
Power plants		3 to 1000-MW(e) plants at same site
Coal	$1.6 \text{ mi}^2/1000 \text{ MW(e)}$	On-site coal storage and ash disposal
Oil	$0.40 \text{ mi}^2/1000 \text{ MW(e)}$	Adequate on-site fuel storage
Gas	$0.24 \text{ mi}^2/1000 \text{ MW(e)}$	Pipeline delivery and modest on-site fuel storage
Nuclear	$0.47 \text{ mi}^2/1000 \text{ MW(e)}$	Based on exclusion area requirements
Electrical transmission	$19 \text{ mi}^2/1000 \text{ MW(e)}$	Projected transmission line right-of-way and electrical capacity requirements for 1990

*[Lawrence Livermore Laboratory, staff compilation.]

Table 116. Annual land use by various 1000-MW electrical energy delivery systems (acres): 100% load factor.*

	Delivery system													
System process	Light water reactor	Uranium-plutonium breeder reactor	Uranium-plutonium water reactor	High-temp-erature gas-cooled reactor	Fusion reactor	Low-sulfur coal	High-sulfur coal - SO ₂ removal	High-sulfur coal - gasification	Residual fuel oil	Natural gas	Geo-thermal steam	Solar energy	Combined steam cycle	
Extraction	49	0.5	3	21	20	Deep Surface Bit 8000 Sub 510	150	150	150	7,400	125	9,000	Oil 7,400 Gas 125	
Processing	8	4	6	20	15	400	400	400	4,000	30	-	41,000	Oil 4,000 Gas 30	
Transport	0	0	0	0	0	Bit 1700 Sub 9000	1,700	1,700	42,000	16,300	-	-	Oil 42,000 Gas 16,300	
Conversion	168	168	168	247	200	1,200	1,400	306	350	200	125	258	350	
Transmission	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	
Storage	2	1	1	3	0	44	93	76	1	-	-	-	-	

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974).]

Table 117. Land use requirements for oil-shale processing.*

Function	Land required (acres)
<u>Mining and waste disposal</u>	
Surface mine ^{a,b} (100,000 bbl/d)	
Mine development	30/y to 85/y
Permanent disposal, overburden	1000 (total)
Temporary storage; low-grade shale	100 to 200 (total)
Permanent disposal; processed shale	140/y to 150/y
Surface facilities ^c	200 (total)
Off-site requirements ^d	180 to 600 (total)
Underground mine ^b (50,000 bbl/d)	
Mine development (surface facilities)	10 (total)
Permanent disposal	
All processed shale on surface	70/y to 75/y
60% return of processed shale underground	28/y to 30/y
Surface facilities ^c	140 (total)
Off-site requirements	180 to 225 (total)
<u>In situ processing (50,000 bbl/d)</u>	
Surface facilities ^c	50 (total)
Active well area and restoration area	110 to 900
Off-site requirements	180 to 600 (total)

^aArea required is dependent on the thicknesses of the overburden and oil shale at the site. Areas shown are for a Picaence Creek Basin site, with 550 ft of overburden and 450 ft of 30 gal/ton shale (approximately 900,000 bbl/acre).

^bAssumes 30 gal/ton oil shale and a disposal height of 250 ft.

^cFacilities include shale crushing, storage and restoring (excluded for in situ processing), oil upgrading and storage, and related parking, office, and shop facilities.

^dIncludes access roads, power and transmission facilities, water lines, natural gas and oil pipelines; actual requirements depend on site location. A 60-ft right-of-way for roads requires a surface area of about 8 acres/mi. Utility and pipeline corridors 20 ft in width require 2.4 acres/mi.

*[Department of the Interior, United States Energy - a Summary Review, USGPO, Washington, DC (1972).]

CHEMICAL FACTORS

Acid Fallout

Sources

The oxides of sulfur and nitrogen that are released to the air from the combustion of fossil fuels eventually return to earth in particles, as sulfates and nitrates, and in rainfall, as sulfuric acid and nitric acid via precipitation scavenging and dry deposition processes.

Plants require water, carbon dioxide, nitrogen, phosphorus, sulfur, potassium, and other soluble salts. In the absence of man they rely on the atmosphere to recycle these and can grow no faster than they are resupplied from this atmospherically closed loop. These salts are, in fact, fertilizer, and man's contribution on a global basis is small compared to nature's.

Some argue that fossil-fuel carbon dioxide is accumulating at only half the rate it is released, because at the same time it is released we have added enough other elements to permit plants to grow that much more and take up the missing half of the fossil-fuel carbon dioxide.

It is noteworthy that most soils are deficient in sulfur and are likely to become more so as we gradually use higher grade fertilizers not containing sulfate.

Trends

Acid rain or snow now falls on most of the northeastern U.S. The annual acidity value averages about pH 4, but values between pH 2.1 and 5 have been recorded for individual storms. If we accept on faith that it was less acid before we had data, the acidity of precipitation in this region apparently increased about 20 y ago, and the increase may have been associated with augmented use of natural gas and with the installation of particle-removal devices in tall smokestacks. However, coal consumption did not decline significantly.

Natural gas was introduced into the Ithaca, N.Y. area late in 1932 but did not really replace coal as the prime fuel until 1950-1955. The difference in the sulfur content between coal (high) and natural gas (low) is considerable, and thus this shift in use patterns is highly correlated with the decline in the sulfur content of precipitation in 1950-1955.

The effect of coal burning on local precipitation chemistry also is indicated by a shift in seasonal characteristics. Before 1950 the wintertime

concentrations of SO_4^{2-} in precipitation always exceeded the summer values; now maximum SO_4^{2-} concentrations occur during the summer.

Present-day precipitation contains about 70% less sulfur than that prior to 1950. This drop in sulfur concentration at both Ithaca, N.Y. and Geneva, N.Y. is difficult to reconcile with the proposed recent increase in acidity. High concentrations of sulfur in precipitation could reflect the presence of H_2SO_4 . Since the pH of the precipitation apparently was not lowered prior to 1950, much of the sulfur must have existed as un-ionized particulate sulfate or as ionized forms neutralized by equivalent amounts of bases, or, alternatively, it was already low before we started to measure it. (Figure 120.)

Figure 121 shows the acidity of rainfall in the U.S. between March 15 and March 30, 1973. Heavy acidity occurs in substantially all rain that falls east of the Mississippi.

Figure 122 shows the weighted annual concentrations of NO_3^- and NH_4^+ and SO_4^{2-} and the pH of precipitation at the Hubbard Brook Experimental Forest in New Hampshire. Data, since 1963, do not reveal marked trends, although extensive data on precipitation chemistry from Geneva, New York, provide indirect evidence of higher pH's in earlier years. The relatively large increase in the NO_3^- content of precipitation since about 1945 may be correlated with the increased combustion of natural gas and motor fuels.

Costs of Control

The EPA air quality standards (AQS's) could be met by tall stacks, but cost of estimates for such controls is not available.

References - Acid Fallout

- Likens, G. E., and F. H. Bormann, Science 184, 1176 (1974).
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Fig. 120. The acidity of rain in the Finger Lakes Region of New York State and at the Hubbard Brook Experimental Forest in New Hampshire is illustrated by low pH values during 1970-1971 at three sites. Annual averages, weighted to take into account the amount of precipitation that fell, were as follows: Hubbard Brook (June to June): 4.03; Aurora (August to August): 3.91; Ithaca (August to August): 3.98. Values of pH below 5 indicate unusually strong acids in rain. Low values have been found in rain in Massachusetts and Connecticut, as well as in New York and New Hampshire. [Originally appeared in "Acid Rain," by G. E. Likens, F. H. Bormann, and N. M. Johnson, *Environment*, Vol. 14, No. 2, p. 39. Copyright 1972 Committee for Environmental Information.]

Fig. 121. Acidity of rainfall in the U.S. between March 15 and March 31, 1973. Heavy acidity occurs in substantially all rain that falls east of the Mississippi. [Compiled from data in Sci. Amer. 230, 126 (June 1974).]

Fig. 122. Weighted annual concentrations of (a) NO_3^- and NH_4^+ and (b) SO_4^{2-} and the pH of precipitation at the Hubbard Experimental Forest in New Hampshire. [Likens, G. E., and F. H. Bormann, *Science* **184**, 1176 (1974), copyright 1974 by the American Association for the Advancement of Science.]

Solid Effluent

Sources

Large quantities of solid effluent result from the production of energy, principally from the mining, mechanical cleaning, and burning of coal.

Refuse heaps often catch on fire and smolder for decades, contributing to air pollution, and/or are leached by rain contaminating the local streams and groundwater.

Other solid effluent from energy production include: furnace ash and collected fly ash including spent limestone or dolomite from sulfur dioxide removal processes; dustfall near power plants from fly ash that was not collected; refuse from the extraction of uranium concentrates from uranium ores; and spent shale from oil production. (Tables 118-125.)

However, we should not overlook the fact that floods and dust storms used to be valued for bringing soil nutrients. Why not man-made emissions?

Trends

Coal Industry - The amount of solid effluent material in each ton of coal produced was reported at 22% in 1967.

It is estimated that about 1.3×10^9 tons of bituminous rejects from cleaning plants have been accumulated to date, and that an additional 2.5×10^9 tons will be generated by the year 2000. This total, piled in refuse banks to a height of 75 ft, would cover some 32,000 acres or 50 mi².

The quantities of ash collected in coal-fired plants are significant; a 3000-MW plant with a useful life span of 35 y operating at an average 50% capacity would produce sufficient ash to cover 300 to 400 acres to a depth of 25 ft.

If limestone were used for sulfur dioxide control, the total volume of ash would be 2 to 3 times as great.

Conservative estimates of solid effluent accumulations from underground mining exceed 2×10^9 tons annually by the year 2000.

Mining Industry - The quantities of solid effluent from uranium mining and milling are several orders of magnitude smaller than those from coal mining and cleaning. Several millions of tons of uranium mill tailings are heaped on the land in producing areas. Of the estimated total 4.3×10^9 tons produced in the U.S. annually, mining effluent accounts for almost 40%.

Oil Shale Industry - To get 1×10^6 bbl/d of oil from shale would require mining, transporting, crushing, and retorting 1.5×10^6 tons of oil shale, then disposing of 1.3×10^6 tons of residue. Altogether, 2.8×10^6 tons of material would be handled each day, or about 1×10^9 tons/y.

In the course of 9 mo of shale-oil extraction the tonnage would be equivalent to the weight of earth and rocks excavated in constructing the Panama Canal.

By 1979 the developing shale-oil industry in Colorado, Utah, and Wyoming each year will produce some 60×10^6 tons of shale processing wastes containing about 680 tons of carcinogenic materials. By 1987, when the industry is fully developed, the amount of waste matter produced each year could be 7 times larger than in 1979.

After processing, most companies plan to dispose of waste shale above-ground, probably in nearby canyons, rather than store it back underground in the mines at a higher cost. Spent shale from a 50,000-bbl/d plant will fill a typical canyon in the region, such as Davis Gulch where Colony will dispose of its shale, to a depth of 250 ft in 7 y, leaving about 700 acres of bare shale exposed on top.

The amount of spent shale generated in 1979 alone could include up to 2.7×10^6 tons of carbonaceous matter that may contain more than 136,000 tons of benzene-soluble and in part volatile organic compounds. Even a small portion of these organic compounds produced per year could have some as yet unknown effect on the ecosystem. (Table 126.)

Similarly, inorganic trace elements potentially present in carbonaceous shale ash (such as cadmium, lead, selenium, molybdenum, and mercury) and their possible environmental effect should not be overlooked.

Control Industries - Assuming that 90,000 MW of limestone capacity is installed, EPA staff estimates that 120×10^6 tons of sludge would be produced each year of operation. This figure represents less than 20% of the total solid waste generated in the coal fuel cycle.

Land affected by sludge disposal is less than 3% of the total land affected by the total coal fuel cycle.

Costs of Control

Although no estimates of the total costs of reclaiming the land now occupied by refuse banks are available, it is clear that many hundreds of

millions of dollars could be spent in making the land esthetically attractive and bringing land back into productivity. It would cost a Federal agency approximately \$6100, \$8000, and \$9800/acre to establish a grass cover on an abandoned refuse pile using 1, 2, and 3 ft of soil, respectively.

Total cost of air pollution damage to date from solid waste disposal practices has been estimated at \$0.3 billion. The U.S. funding for pollution control and abatement of solid wastes is as follows:

- 1973 \$150 million (actual)
- 1974 \$198 million (actual)
- 1975 \$200 million (estimated)
- 1980 \$8.8 billion (estimated)

Projected annual average outlays for solid waste pollution control in the U.S. during the period 1971-1980 is reported to be \$7.8 billion. Energy-related activities generally account for about 55% of these totals.

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Table 118. Annual solid effluent from an oil-fired electricity system:
1000-MW power plant, 75% load factor.*

System Process	Environmental impact		
	Total effluent from an uncontrolled system (tons)	Total effluent from a controlled system (tons)	Change (%)
Exploration	NA	NA	NA
Extraction	0	0	0
Processing			
Onshore	0	213	+213
Offshore	0	213	+213
Transport	0	0	0
Conversion	0	0	0
Transmission	0	0	0
Total			
Onshore	0	213	+213
Offshore	0	213	+213

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973).]

Table 119. Annual solid effluent from a coal-fired electricity system:
1000-MW power plant, 75% load factor.*

System process	Environmental impact		
	Total effluent from an uncontrolled system (tons)	Total effluent from a controlled system (tons)	Change (%)
Exploration	NA	NA	NA
Extraction			
Deep	97,141	101,346	+4.3
Surface	2,762,000	2,762,328	+0.01
Processing			
Deep	454,092	462,373	+1.8
Surface	454,092	462,373	+1.8
Transport	0	0	0
Conversion			
Deep	50,800	994,000	+1,957
Surface	50,800	994,000	+1,957
Transmission	0	0	0
Total			
Deep	602,033	1,557,719	+159
Surface	3,266,892	4,218,701	+29

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973).]

Table 120. Annual solid effluent from a gas-fired electricity system:
1000-MW power plant, 75% load factor.*

System process	Environmental impact
	Total effluent (tons)
Exploration	NA
Extraction	0
Processing	0
Transport	0
Conversion	0
Transmission	0
Total	Negligible

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 121.]

Table 121. Annual solid effluents from a coal gasification electricity system: 1000-MW(e) power plant, 3% sulfur coal, 75% load factor.*

System process	Effluent type				
	Ash			Sulfur	
	Ra-226		Ra-228, Th-228, Th-230		Other
	(tons)	(Ci)	(Ci)	(tons)	
Extraction	0	0	0	0	Same as coal-electric system
Processing	336,750	0.539	0.909	8.25×10^4	-
Transport	0	0	0	0	-
Conversion	0	0	0	0	-
Transmission	0	0	0	0	-
Total	336,750	0.539	0.909	8.25×10^4	

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 161.]

Table 122. Annual solid effluent from a solar electricity system: 1000-MW power plant, 75% load factor.*

System process	Effluent type
Extraction	
Processing	
Transport	Negligible
Conversion	
Transmission	

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 207.]

Table 123. Annual solid effluent from a fusion reactor electricity system: 1000-MW power plant, 75% load factor.*

System process	Effluent type
Extraction	
Processing	
Transport	Negligible
Conversion	
Transmission	

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 215.]

Table 124. Annual solid effluent from a conventional nuclear electricity system: 1000-MW light water reactor, 75% load factor.*

System process	Total effluent		Effluent type										
	Tons	Cl	Overburden (tons)	Tailings (tons)	Th ²³⁰ (Ci)	Ra ²²⁶ (Ci)	Ash (tons)	Th-U (Ci)	UF ₆		CaF ₂		Buried waste (tons)
Extraction	19.7×10^5	82.6	1.91×10^6	64,148	40.1	42.5	-	-	-	-	-	-	-
Processing	202	42.5	-	-	-	-	28.3	0.20	128	42.2	25.4	0.062	20
Transport	0	0	0	0	0	0	0	0	0	0	0	0	0
Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0
Transmission	0	0	0	0	0	0	0	0	0	0	0	0	0

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 11.]

Table 125. Annual gaseous effluents from a geothermal steam electric plant: 1000-MW(e) power plant, 75% load factor.*

System process	Atmospheric venting of new steamwells prior to operation in tons (not yearly)							Effluent type (tons)						Drift		Humidified air				
	Steam	CO ₂	NH ₃	CH ₄	H ₂ S	N ₂ ,A	H ₂	CO ₂	H ₂	CH ₄	N ₂ ,A	H ₂ S	NH ₃	gal/min	solids (tons)	H ₂ O (tons)	Waste heat kWh	NH ₃ (tons)	CO ₂ (tons)	H ₂ S (tons)
Extraction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Processing	9.07 $\times 10^6$	7.16 $\times 10^4$	6.35 $\times 10^3$	4.53 $\times 10^3$	4.53 $\times 10^3$	2.72 $\times 10^3$	9.1 $\times 10^2$	0	0	0	0	0	0	0	0	0	0	0	0	0
Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conversion	0	0	0	0	0	0	0	3.65 $\times 10^5$	5.44 $\times 10^3$	2.72 $\times 10^4$	1.64 $\times 10^4$	9.1 $\times 10^3$	3.29 $\times 10^4$	341	124	4.49 $\times 10^7$	33.7 $\times 10^9$	3.81 $\times 10^3$	6.45 $\times 10^4$	1.76 $\times 10^4$
Transmission	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	9.07 $\times 10^6$	7.16 $\times 10^4$	6.35 $\times 10^3$	4.53 $\times 10^3$	4.53 $\times 10^3$	2.72 $\times 10^3$	9.1 $\times 10^2$	3.65 $\times 10^5$	5.44 $\times 10^3$	2.72 $\times 10^4$	1.64 $\times 10^4$	9.1 $\times 10^3$	3.29 $\times 10^4$	341	124	4.49 $\times 10^7$	33.7 $\times 10^9$	3.81 $\times 10^3$	6.45 $\times 10^4$	1.76 $\times 10^4$

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974), p. 181.]

Table 126. Estimated schedule of oil-shale development and spent shale ash produced for disposal.^{a,*}

End of year	Production level (bbl/d)	Raw shale processed (tons/d)	Spent shale produced (tons/d)
1977	50,000	72,900	61,000
1979	150,000	216,000	183,000
1984	550,000	792,000	671,000
1987	1,050,000	1,512,000	1,281,000

^aAssumption: Surface retorting (No commercial in situ processing)

*¹Schmidt, J. J., Collierus, Denver Research Institute, Denver, CO,
Publ. PB-231796 (1974).¹

RADIOLOGICAL FACTORS

High-Level Storage

Sources

The nuclear fuel cycle for fission reactors involves many unit process operations including (a) mining, milling, and refining of uranium and thorium ore; (b) conversion of ore to various chemical forms (that is, U_3O_8 , UO_2 , UF_6 , and ThO_2); (c) enrichment of the uranium-235 content of uranium hexafluoride (UF_6) by gaseous diffusion; (d) preparation of reactor fuel materials from uranium and thorium, and recycled uranium-233 and plutonium; (e) fabrication of reactor fuel elements; (f) use of the fuel elements in a power reactor; and (g) recovery of valuable fissile materials from spent reactor fuel for recycle to the enrichment or preparation processes. Each of these processes generates radioactive wastes that, depending on their toxicity and long-term hazard to the environment, must be treated by various processes prior to storage or ultimate disposal.

Fusion reactors would produce smaller and less dangerous amounts of effluent than would fission (approximately 1000 times less for comparable size plants). Thus the radioactive effluent disposal problems would be smaller as would the transportation problem.

The inventories of volatile radioactivity and long-lived radioactive effluent in fission reactors are fixed within narrow limits by the laws of nature. Those in fusion reactors are subject to reduction via human ingenuity.

Trends

The U.S. Atomic Energy Commission has accumulated 75×10^6 gal of intensely radioactive effluent, by-products of its manufacture of plutonium for nuclear weapons. About three-quarters of this total is stored in buried tanks near the Columbia River at the Hanford Atomic Products Operation in south-central Washington State. The remainder is at the AEC facilities in Arco, Idaho, and Savannah River, South Carolina. Each of the storage tanks has a capacity of between 500,000 and 1,000,000 gallons of this highly radioactive liquid effluent, produced by the reactors and chemical-separation plants nearby. About 50×10^6 gallons are actually in storage, which, on the average, contains more than 100 Ci/gal of effluents. (Figures 123-125.)

The volume of solids that will have accumulated by the year 2000 is estimated at about 550,000 ft³. This figure assumes the installed nuclear capacity in that year will be 675,000 MW(e).

By 2070 the area required for storing all the high-level waste from reprocessing of power-reactor fuels in the U.S. will amount to a total of 50 to 100 mi², which is readily accommodated in Kansas Salt Mines. (Figure 126.)

Environmental Protection Agency officials estimate that the present weapons arsenal represents up to 10 MCi of plutonium-239. For power purposes, inventories are projected to increase to 3 MCi by 1980, close to 40 MCi by 2000, and over 100 MCi by 2020. In addition, plutonium-238 is becoming of increasing importance in the space power field: up to 1 or 1½ MCi may be used for this purpose during the next 10 y.

The ultimate production limits are 700,000 MCi/y requiring 30 mi² of salt/y, which is 20 kW/person/d for 20 billion people.

Installed nuclear generating capacity in the U.S. is expected to grow from 11,000 MW in 1970 to more than 900,000 MW in 2000 (Fig. 126). Total amount of stored nuclear effluent, radioactive by products of the energy production, will probably exceed 1000×10^9 Ci by that year. Annual release of nuclear effluent, mostly in the form of krypton gas and tritium in cooling water, will reach 25×10^6 Ci, if present release standards are still in effect.

Costs of Control

Total costs for effluent management have ranged from 37 to 45 mills/MW(e). These costs represent approximately 1% of the total cost of nuclear power. On this basis and assuming 8300 MW(e) installed capacity, 5 mills/kW(e) production cost, and 75% average capacity use, the annual cost (1971) for waste management would be about \$225,000. (Tables 127-129.)

The AEC predicts the private market for atomic garbage disposal will reach \$10 million annually by 1980. Low-level effluent has no more than 1000 times the radioactive concentration considered safe for direct release to the atmosphere and is now being handled almost exclusively by commercial firms.

A nuclear capacity of at least 900,000 MW has been predicted for the U.S. by 2000; the nuclear components alone will cost more than \$100 billion (at present costs) and the plants over \$300 billion.

In contradistinction, every nuclear effluent disposal scheme discussed (except perhaps shooting the effluents into the sun) costs only a small fraction of the above costs - often less than 1%. Thus, public debate on this topic should be viewed somewhat less as bearing on absolute limitations to nuclear acceptance, and more as speculation on the very costly consequences of technical failure of too-cheap disposal schemes. (Table 130.)

Projected annual average outlays for pollution control during the period 1971-1980 total \$200 million for radiation control. Projected outlays for radiation pollution control in 1980 is \$30 million.

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Table 127. Cost of separating and recycling actinides in effluent from a light water reactor. The three cost categories represent 1.1, 1.5, and 2.0 times the current light water reactors reprocessing costs.*

Item	Cost (mill/kWh)		
	Optimistic	Median	Extreme
Salt mine ^a	0.045	0.045	0.045
Recycle actinides	0.119	0.189	0.276
Total	0.164	0.234	0.321

^aThe fission products still require disposal.

*[Kubo, A. S., and D. J. Rose, Science 182, 1205 (1973), copyright 1973 by the American Association for the Advancement of Science.]

Table 128. Cost of separating strontium, cesium, and actinides and recycling actinides. The cost of recycling actinides is the light-water-reactor estimate.*

Item	Cost (mill/kWh)		
	Optimistic	Median	Extreme
Extract Sr and Cs	0.071	0.142	0.710
Store Sr and Cs	0.020	0.025	0.050
Recycle actinides	0.119	0.189	0.276
Salt disposal	0.025	0.025	0.025
Subtotal	0.235	0.381	1.061
Disposal of Sr and Cs	?	?	?
Total	?	?	?

*[Kubo, A. S., and D. J. Rose, Science 182, 1205 (1973), copyright 1973 by the American Association for the Advancement of Science.]

Table 129. Cost range for management of high-level effluent from LWR fuels^{a,*}

Operation	Cost range (mills/MWh(e))
Interim liquid storage from 1 to 5 y	14 to 22
Pot calcination in 6- to 12-in.-diameter pots ^b	4 to 18
Interim solids storage from 1 to 10 y	2 to 10
Shipment of solids 1000 mi	1 to 3
Burial in salt after aging 1 to 10 y	3 to 11
Totals for specific schemes	37 to 45

^a33,000 MWd/Mton exposure.

^b1 ft³ of solids/10,000 MWd(th).

*[Schneider, K. J., et al., in Proceedings of the Symposium on Environmental Aspects of Nuclear Power Stations, New York, 1970 (IAEC, Vienna, 1971), p. 369.]

Table 130. Summary of effluent disposal costs.*

Option	Cost (mill/kWh)
Salt mine	0.045-0.050
Granite	0.050-0.055
Further chemical separation; recycle actinides	0.065-0.320
Further chemical separation; remove Sr and Cs; recycle actinides	0.140-1.100
Melt <u>in situ</u>	0.011-0.016
Melt <u>in situ</u> , central repository	0.031-0.036
Antarctic rocks	
Continental ice sheets	

*[Kubo, A. S., and D. J. Rose, Science 182, 1205 (1973), copyright 1973 by the American Association for the Advancement of Science.]

Fig. 123. The sources and disposition of high-level effluent in the nuclear fuel cycle for fission reactors. [Holdren, J. P., in Proceedings of the Symposium on the Environmental Aspects of Nuclear Power, New York, 1970 (IAEA, Vienna, 1971).]

* Includes emergency spare tanks

Fig. 124. Savannah River high-level waste inventory. (AEC R&D-75-309, December 18, 1974.)

Fig. 125. Idaho high-level waste inventory. [AEC R&D-75-309, December 18, 1974.]

Fig. 126. High-level nuclear effluent. [Atomic Energy Commission, Forecast of Growth of Nuclear Power, USGPO, Washington, DC (1971).]

Natural Background Radiation

Introduction

By "natural background" we mean radiation that is not man-made; exposure to these natural levels may be affected by a person's activities, such as in airplane flight or through use of radioactive building materials. Exposures to naturally occurring radiation from such activities as mining of naturally radioactive ores is excluded from the discussions in this section.

Depending on his location on the earth or above it in aircraft, a person is exposed to varying levels of natural radioactivity. The sources include cosmic radiation, terrestrial radioactivity, airborne radionuclides, and internal radiation from ingestion of normal air and food.

Cosmic Radiation

The composition of primary cosmic radiation entering the atmosphere is about 85% protons, 14% alpha particles, and 1% heavier nuclei. There seem to be few electrons and high-energy gammas, and those mostly at the lower energies where they comprise a few percent of the flux. The primary energy spectrum follows an inverse power law, falling off approximately as $1/E^2$ from about 10^9 to 10^{18} eV.

External Gamma Radiation

Naturally occurring radionuclides produce external gamma exposures that vary with location, time, and meteorological conditions. The state-by-state external whole-body doses average about 60 mrem/y/person over the U.S. The dominant contributions are from radon and its daughters (ultimately from the uranium and thorium deposited in rocks) and from potassium-40. When measurements of low-level gamma emitters are made using gamma spectroscopy, potassium-40 in particular can provide a significant background.

Internal Exposures

The total dose to the whole body is dominated by potassium-40, polonium-210, radon-222, radium-226, and carbon-14. The average whole-body dose is approximately 25 mrem/y, and except for the radon-222 contribution (through inhalation) it is all received through food ingestion. Because agricultural produce in the U.S. receives wide distribution, these figures probably do not fluctuate as significantly from place to place as do the

external or cosmic radiations. In fact, radium-226 concentrations seem to vary more due to dietary differences at a given location than due to geographical effects.

At the earth's surface the flux is predominately muons from the decay of pions produced by the primary protons in the upper atmosphere. These muons are accompanied by an equilibrium mixture of electrons and gammas. There is also a small flux of neutrons. For our purposes it is adequate to assume that the total dose to tissue from cosmic radiation is almost entirely from relativistic charged particles.

Cosmic radiation dose levels vary significantly with altitude, and less strongly with latitude. The average dose in the U.S. is 45 mrem/y, ranging from 35 to 40 mrem/y at sea level in the continental U.S. to 115 to 130 mrem/y in the Rocky Mountain states. The sea-level rates at more southern latitudes (Hawaii, Canal Zone, Samoa) are smaller: about 30 mrem/y. It is estimated that at an altitude of 40,000 ft (conventional jet aircraft) the dose is as large as 0.7 mrem/h. At 60,000 ft (possible supersonic transport altitudes), it is 0.8 mrem/h. Thus a round-trip transcontinental flight will yield total doses of about 6 to 8 mrem, in either conventional or supersonic aircraft. Assuming 310×10^6 passenger miles in 1970, the total man-rem accumulated by passengers in that year was about 200,000 (or an average dose to the entire population of 1.0 mrem). In addition, approximately 15,000 air crew members received an average of 670 mrem/y in 1970, for a total of about 10,000 man-rem. (Table 131.)

Fallout

The term "fallout" describes the radioactive component of the debris resulting from atmospheric nuclear (fission) and thermonuclear (fusion) explosions. Distinctions have generally been made between three different kinds of fallout. Local fallout, confined to the vicinity of a detonation, usually occurs within about the first 48 h. Tropospheric fallout, in a band around the world near the general latitude of the detonation, occurs in the first 2 to 4 w. Stratospheric fallout, giving a worldwide distribution, occurs in 3 mo to several years.

Small weapons contribute all of their fission products to local and tropospheric fallout. The truly worldwide distributions come from stratospheric fallout after the largest (>1 mton) detonations. Only these large

weapons are capable of depositing significant debris in the stratosphere. Once products are carried into the stratosphere, they become widely dispersed. Since about 90% of all weapons-test fission products have come from greater than 1 Mton weapons, stratospheric fallout is the dominant vehicle for world-wide contamination.

From a biological standpoint, the most important long-term fallout constituents are strontium-90 and cesium-137, because of their long half-lives (28 and 30 y, respectively) and relatively high uptake and damage in biosystems. Strontium is chemically similar to calcium, which is used for bone formation, while cesium simulates potassium, crucial for the function of cells. (Figure 127.)

Total weapons-tests production to date of strontium-90 and cesium-137 has been about 9 and 14 MCi, respectively. This activity is not distributed uniformly in space or time after a detonation. Both the large peak in the northern temperate zone and the secondary peak in the southern temperate zone are due to the dynamics of stratospheric-tropospheric mixing: the poorly defined or discontinuous tropopause in the temperate latitudes provides a vehicle for preferential stratospheric deposition.

For strontium-90 depositions in New York City, the cesium-137/strontium-90 ratio is found to be between 1.5 and 2.0 for almost all measurements. The time distribution shows the very obvious effects of the large-scale weapons tests of the early 1960's.

Human exposure to fallout is from three sources: ingestion, inhalation, and whole-body external exposure. Of the nuclides ingested, the main contributors to dose are strontium-90 and strontium-89 (to whole-body and to bone); iodine-131 (to thyroid); cesium-137 (to whole body); and carbon-14 (to whole body and to bone). Because strontium is deposited permanently in bone, the strontium-90 doses have been estimated based on a 50-y (or lifetime) delivery of dose. All other doses are assumed to be delivered in the year of ingestion.

Although the whole-body dose from inhalation is quite small, the 50-y respiratory lymph-node dose from plutonium is large indeed.

For external gamma dose rates, the dominant contributor is cesium-137. Including shielding factors (0.4 due to buildings, 0.8 due to body screening), the 1963, 1965, and 1969 estimated annual average external gamma doses were 5.9, 1.8, and 0.9 mrem, respectively. (Table 132.)

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United Nations, "Radiation from Natural Sources," in Report of the U.N. Scientific Committee on the Effects of Atomic Radiation, General Assembly, 21st Session, Supplement No. 14 (A/6314), New York (1966).

Table 131. The overall average U.S. doses from natural radiation.*

Source	Average dose	Range in U.S.
Cosmic rays	45 mrem/y	30 to 130 mrem/y
External gamma radiation	60 mrem/y	40 to 115 mrem/y
Internal exposures	25 mrem/y	- - - - -
Total	130 mrem/y	- - - - -

*Lawrence Livermore Laboratory, staff compilation.

Table 132. Estimated average U.S. doses from fallout (mrem/capita/y).^{a,*}

Source	Organ	1963	1965	1969
<u>Ingestion</u>				
Carbon-14	whole body	0.3	0.7	0.6
Strontium-89	bone	1.3	0.2	0.2
Strontium-89	whole body	73.0 ^a	72.0 ^a	32.0 ^a
Strontium-90	bone	7.3	7.2	3.2
Iodine-131	thyroid	25.0	4.0	3.0
Cesium-137	whole body	4.3	2.3	0.4
<u>Inhalation</u>				
Cerium-144	lung	8.2	0.4	0.3
Cerium-144	bone	10.6	0.5	0.4
Plutonium-238	respiratory lymph nodes	79.0 ^a	14.0 ^a	19.0 ^a
Plutonium-239	respiratory lymph nodes	1000.0 ^a	175.0 ^a	36.0 ^a
Plutonium-239	lung	4.5 ^a	0.8 ^a	0.2 ^a
Several others	lung	4.3	0.4	0.1
<u>External gamma dose</u>				
Cesium-137	whole body	5.9	1.8	0.9
Others	whole body	7.0	5.0	3.0

^aFifty-year dose from nuclide inhaled or ingested in that year.

*Instrumentation for Environmental Monitoring, Backgrounds and Fallout, Lawrence Berkeley Laboratory, Berkeley, CA, Publ. RAD-FAL.1

Fig. 127. Average strontium-90 intake in New York City (pCi/d).
 [Instrumentation for Environmental Monitoring, Radiation Fuel Reprocessing Backgrounds and Fallout, Lawrence Berkeley Laboratory, Berkeley, CA, Rept. LBL-1 (1973).]

RESOURCE USE

Land Subsidence

Sources

Land may sink naturally because of such processes as (1) underground solution or erosion of rocks; (2) lateral flow of some earth materials under loading; (3) compaction of sediments by loading, drainage, wetting, or vibration; (4) tectonic movements of the earth, such as earthquakes; and (5) volcanic activity. Energy activities can simulate or promote all these processes, except the last, causing land to subside. The past few years have even seen man's advent as a tectonic agent, as underground nuclear blasts cause subsidence.

Underground mining of coal and minerals with inadequate support of the overburden causes rock and earth to settle and land to subside. Withdrawal of petroleum or natural gas can result in a general subsidence over the pool region, although the land is unlikely to settle unevenly, and the surface is less likely to fracture than in old mining areas. Subsidence of the ground surface over and around a geothermal reservoir can result from the withdrawal of large volumes of fluids.

The collapse of underground mines causes subsidence at the surface. In one kind of subsidence (shown in Fig. 128), the ore pillars supporting the mine roof fail, causing some damage directly above the failure. The most severe damage occurs at the perimeter of the subsided area.

Trends

It has been estimated that more than $2 \cdot 10^6$ acres of land have subsided in the U.S. as a consequence of coal mining. Homes and streets have been extensively damaged in Scranton and Wilkes-Barre, Pennsylvania, and in other urban areas in mining districts.

Draining of peat land in the Florida Everglades has caused oxidation and soil shrinkage above the water table. After 40 y of drainage, the soil there has subsided at a rate of about 1 ft every 8 to 12 y. The peat formed at a rate of 1 ft in 400 y. If the subsidence continues, farming will soon be impractical because the peat overlies bedrock into which drainage ditches would have to be deepened.

The Wilmington oil field, which underlies Long Beach, California, is an example of subsidence that reached 27 ft and caused damage amounting to more than \$100 million before remedial measures began to take effect in the early 1960's. Salt water is now injected into the ground, at a rate of 1,000,000 bbl/d since 1965, to repressure the oil zones. This action has arrested subsidence and even caused a 6 to 15% rebound of the land, but at considerable expense. (Figures 129 and 130.)

Cost of Control

In the Wilmington oil field the cost of remedial measures to keep the sea from invading the subsiding lands and to repair equipment damaged by land movement had exceeded \$100 million by 1962.

References - Land Subsidence

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Fig. 128. Collapse of underground mines causes subsidence at the surface.
 [Reprinted from "Problems Underfoot" by Terri Aronson,
 Environment 12, No. 9 (1970), copyright 1970 by Committee
 for Environmental Information.]

Fig. 130. Areas of land subsidence in California. Major subsidence due to fluid withdrawal shown in black; subsidence in Delta caused by oxidation of peat. [Poland, J. F., and G. H. Davis, in Man's Impact on Environment, T. R. Detweyler, Ed. (McGraw-Hill Book Co., New York, 1971), p. 370, used with permission of McGraw-Hill Book Co.]

Strip- and Surface-Mining Activities

Sources

Surface mining consists of nothing more than removing the topsoil, rock, and other strata that lie above mineral or fuel deposits to recover them. In practice, however, the process is considerably more complex.

Surface methods used to recover minerals and fuels are generally classified as (1) open pit mining (quarry, open cast), (2) strip mining (area, contour), (3) auger mining, (4) dredging, and (5) hydraulic mining.

Trends

Coal - Coal mining is the largest single disrupter of the land accounting for over 40% of the affected areas.

In 1965 between 0.05 and $1.3 \cdot 10^6$ acres had been strip mined for coal in the U.S. About half of this was contour mined, the other half area mined. States particularly affected were Pennsylvania, Ohio, West Virginia, Illinois, and Kentucky, where about 70% of the strip mining had taken place.

Of the 209,000 acres projected as being disturbed in the year 2000, 188,000 acres are east of the Mississippi River (Table 133 and Fig. 131.) This same geographic area, which covers far less than 50% of the nation's acreage, contains 59.9% of the population. The Middle Atlantic area, which includes coal-producing Pennsylvania, will have 27,000 acres of land disturbed in the year 2000 according to projections. West Virginia is the major coal producing state in the South Atlantic area and is projected to have 23,000 acres of land disturbed. (Figure 132.)

Table 134 gives the cumulative land required to provide coal fuel for electrical generation according to four different plans. If Plan A, B, or C is adopted, anywhere from 12,400 to $18,300 \text{ mi}^2$ of land could be used up in the production of coal by strip mining between 1968 and 2020. The higher figure is equal in area to the states of Vermont and New Hampshire. Note particularly that almost half the strip mining for coal will be done before the year 2000, when fusion might first be introduced assuming optimistic major scientific and technological advances as well as generous funding. The introduction of fusion at that time could save almost 6000 mi^2 of land from strip mining by 2020.

Minerals - Man's carving of the earth's surface to obtain minerals to support energy activities is increasingly vigorous. By the mid-1960's, 3.2×10^6 acres of land, 5000 mi^2 , had been disrupted by surface mining in the U.S. alone.

Although more than 50 minerals are produced by surface mining in the U.S., two-thirds of the disturbed area has resulted from extraction of coal, sand, and gravel. Quarries and open-pit mines account for 35% of the disturbed area.

The mining of energy-related minerals in California is big business. The state's production of mineral commodities contributes \$750 million to the economy. Nearly 60% of this value is generated from extraction of construction materials. Most of the rest comes from mining iron ore, tungsten, boron minerals, magnesium compounds and asbestos. Mineral production takes place in all 58 counties, and almost all of it at ground level or in an open pit.

Mining and processing these mineral commodities yields annually more than 250×10^6 tons of crude ore and wastes. It also disrupts thousands of acres of land. A recent report of the U.S. Bureau of Mines ranks California fifth among the states in total land devoted to mining. It estimates that between 1930 and 1971, 227,000 acres were disturbed by surface mining and that only 19% of it (43,000 acres) received any rehabilitation. California devotes 0.23% of its land to mining, well above the national average of 0.16%. Thousands of acres more are strewn with tailings and waste from earlier placer gold mining.

Oil Shale and Tar Sands - For a 50,000-bbl/d-capacity plant, open-pit mining and surface retorting would create the greatest potential for land defacement. The minimum area disturbed by this recovery system over a 20-y life would total about 7.5 mi^2 . The maximum area disturbed could exceed 10 mi^2 . In either event the surface area of the mine excavation itself would be several times larger than Utah's Bingham Canyon copper mine, which is the largest copper pit in North America. (Table 135.)

By 1985 approximately 20% of the shale mining might be by surface methods, but whether surface or deep mined (except in situ retorting, which is not considered likely), the spent shale must be managed in some acceptable way. Its bulk by virtue of crushing and retorting will be about 25% larger than originally, even after the oil extraction. Consequently,

returning the wastes to the void will still leave about 0.33×10^6 tons/d (at full 1×10^6 bbl/d development) that must be disposed of on the surface. Each mine supplying 100,000 bbl/d (surface) or 50,000 bbl/d (underground) would require 60 to 150 acres/y as permanent storage of spent shale.

Underground or in situ mining would be preferable to open-pit recovery in that fewer surface acres would be directly affected. With no backfill of spent shale, the surface area disturbed over a 20-y life would total about 3 mi². With 60% backfill, the disturbed area could be reduced to 1.2 mi².

Returning all of the spent shale underground could not be accomplished because the volume of retorted wastes would exceed the in-place volume of the mined rock. Also, mineral extraction would remove support from beneath at least 4.7 mi², thereby creating the hazards of mine collapse and land subsidence. However, surface mining does offer some distinct advantages. It makes possible the recovery of deposits that, for physical reasons, cannot be mined underground; provides safer working conditions; usually results in a more complete recovery of the deposit; is generally cheaper in terms of cost-per-unit of production; and creates opportunities to develop recreational areas where none existed before.

In the case of tar sands, the process returns 4 yd³ of backfill for every 3 yd³ of material mined.

Fusion Power - Problems with land despoilment for fusion power reactors are not likely to be different from those of other heat sources. There is little likelihood that a fusion plant will be any more acceptable in an urban site than fission or fossil plants. The amount of land required for the plant and for fuel/structure mining seems similar for fusion-, fossil-, or fission-fueled plants.

There will be a certain amount of land despoilment due to procurement of materials for construction and operation of fusion plants. Estimates indicate that 60 mi² (160 km²) need to be disrupted over a 20-y period prior to 2020 to provide the necessary ore. This is a factor of about 70 less than the land required only to provide strip-mined coal for the equivalent electrical generating capacity.

Cost of Reclamation

The few U.S. studies on the cost of reclamation may be of limited application elsewhere in the country. In a U.S. Bureau of Mines project in

Pennsylvania in 1966, the costs of grading and filling a strip-mined area ranged from \$912/acre to \$2770/acre, depending on the methods used. Reforestation or planting of forage for grazing could add another \$250/acre to such costs, depending on the type of planting. Another study was of 22 different government-sponsored projects to reclaim 178 acres of strip-mined land for a state park in western Pennsylvania. The costs ranged from \$420/acre to nearly \$2600/acre. (Table 136.)

The West German experience indicates that to restore mined-out lands to full agricultural productivity ranges from \$3000/acre to \$4500/acre, a cost comparable to that in several Appalachian projects. The West German system appears to be profitable in aspects that are neglected in the U.S. The West German approach promotes systematic use of strip-mined material - coal, fertile topsoil, and even sand and gravel. The restored land again provides economic values for agriculture, forestry, or recreation.

In the U.S., by comparison, strip mining has turned large areas into economic liabilities. For example, Appalachia must spend millions of dollars each year to control or repair the damage caused by acidic water that drains from strip and deep mines. The Appalachian Regional Commission estimated in 1969 that a 90% reduction of acid mine drainage at its source in the region would decrease such costs by \$4.2 million for industries, utilities, water-borne commerce, municipal water suppliers, and culvert and bridge authorities.

Projected outlays for control of strip-mining reclamation activities in 1980 is \$600 million. Projected annual average outlays for control of strip-mining reclamation activities during the period 1971-1980 is \$500 million. (Tables 137-139.)

References - Strip- and Surface-Mining Activities

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Table 133. Projected disturbed acreage of the surface mining of coal in the year 2000 (10⁶ tons).*

Area	Production (%)	Production	Disturbed ^a acreage
Middle Atlantic	13	92	28,000
South Atlantic	11	78	23,000
East-North Central	44	312	92,000
East-South Central	22	156	46,000
West-North Central	5	36	10,000
West-South Central	1	5	2,000
Mountain	4	30	9,000
Total	100	709	210,000

^aBased on a production rate of 3400 tons/acre.

*[Lawrence Livermore Laboratory, staff compilation.]

Table 134. Cumulative land required to provide fuels for electrical generation.*

Strip mining of coal	1977	2000 (mi ²) ^a	2010	2020
Plan A ⁵	100	7060	11 500	18 300
Plan B	100	7060	10 600	15 100
Plan C	100	7060	10 100	12 400
Plan D	100	7060	11 500	18 300
Lithium ^b	-	~0	0.35	1.5

^a Cumulative from 1969.

^b To a depth of 30 ft; lithium for cooling.

* [Brobst, D. A., and W. P. Pratt, Eds., "United States Mineral Resources," Geol. Survey Paper 820, USGPO, Washington, DC (1973).]

Table 135. Typical solid waste disposal represented by various methods of recovery oil from oil shale (10⁶ bbl/d).*

Recovery method		Annual disposal required (10 ⁹ tons)
Where retorted	Shale preparation	
<u>Surface</u>	Underground mining, room and pillar	0.5
	Open-pit mining	1.2
<u>In situ</u>	Mining rubbilization (RISE process)	0.23
	Nuclear fracturing	None

* [Lewis, A., et al., Lawrence Livermore Laboratory, Rept. UCRL-51768 (1975).]

Table 136. Summary of estimated acreage and cost data for a basic reclamation program.*

Treatment	Acrea	Cost
Planting	1,760,000	\$408,470,000
Grading	384,000	58,200,000
Drainage control	567,000	111,100,000
Diversion ditches	11,500	10,000,000
Slide damage repair	12,900	12,900,000
Haul road repair	48,000	18,000,000
Stream channel repair	73,000	21,800,000
Pond stabilization	145,446	2,500,000
Highwall access	4,250	5,200,000
Hazardous conditions	100,000	10,100,000
Total		\$658,270,000
Administration, engineering, and planning at 15%		98,740,000
Grand total		\$757,010,000

*1 Department of the Interior, Surface Mining and our Environment, USGPO, Washington, DC (1967).]

Table 137. Summary of estimated acreage and cost data for a limited basic reclamation program.*

Treatment	Acrea	Cost
Planting	374,000	\$126,190,000
Grading	124,000	18,900,000
Drainage control	304,000	59,500,000
Diversion ditches	11,500	10,000,000
Slide damage repair	12,900	12,900,000
Haul road repair	48,000	18,000,000
Stream channel repair	26,400	10,000,000
Pond stabilization	145,446	2,500,000
Highwall access	2,125	2,600,000
Hazardous conditions	38,000	3,800,000
Total		\$264,390,000
Administration, engineering, and planning at 15%		39,658,000
Grand total		\$304,048,000

* Department of the Interior, Surface Mining and our Environment, USGPO, Washington, DC (1967).!

Table 138. Summary of estimated acreage and cost data, by land use, for a rehabilitation program.*

Land use	Acrea (10 ³)	Cost (10 ³ dollars)	Land use	Acrea (10 ³)	Cost (10 ³ dollars)
Cropland:			Recreation:		
Basic reclamation }	43	15,469	Basic reclamation }	217	77,978
Special grading }		13,672	Grading }		42,507
Total	43	29,141	Services }		30,640
			Total	217	151,125
Forests:			Streams:		
Basic reclamation	465	167,748	Basic reclamation }	136	121,800
Total	465	167,748	Services }		12,938
			Total	136	34,738
Occupancy:			Wildlife:		
Basic reclamation }	121	143,744	Basic reclamation }	439	158,176
Grading }		125,796	Planting }		23,313
Total	121	69,540	Total	439	181,489
Pasture:			Total:		
Basic reclamation }		87,044	Basic reclamation }		658,270
Grading }	242	50,070	Construction of new }		145,446
Planting }		12,823	Impoundments }		
Total	242	149,937	Grading }	2,041	163,536
			Planting }		42,311
Ponds-Lakes:			Services }		43,578
Basic reclamation }	145	2,500	Total	2,041	1,053,141
Construction of new impoundments }		145,446	Administration, engineering, and planning at 152		157,971
Total	145	147,946	Grand total	2,041	1,211,112
Rangeland:					
Basic reclamation }		83,811			
Grading }	233	31,491			
Planting }		6,175			
Total	233	121,477			

* Department of the Interior, Surface Mining and our Environment, USGPO, Washington, DC (1967). }

Table 139. 1964 costs attributable to reclamation of surface-mined land in the U.S.*

Area	Complete reclamation		Partial reclamation	
	Acres	Cost/acre	Acres	Cost/acre
Middle Atlantic	4,343	\$362	1,763	\$261
South Atlantic	760	169	1,788	97
East-North Central	12,476	192	4,162	169
East-South Central	2,920	251	2,431	74
West-North Central	987	91	454	126
West-South Central	32	964	304	221
Mountain	13	49	283	96
Pacific	10	400	-	-
Total acreage and average cost	21,541	\$230	11,185	\$149

*[Department of the Interior, Surface Mining and Our Environment, USGPO, Washington, DC (1967).]

Fig. 131. Trend in area disturbed annually by coal stripping. [Earth Satellite Corp., Land Use Indicators of Environment Quality, Report from the Council on Environmental Quality, USGPO, Washington, DC (1972), based on Bureau of Mines data.]

Fig. 132. Land disturbed by surface mining by commodity, to 1965.
[Department of the Interior, Surface Mining and Our Environment,
USGPO, Washington, DC (1967), p. 110.]

Power Plant Siting

General Environmental Siting Guides

Geology and Soils - Adequate data on seismic and geological characteristics of an area being considered as a site for a nuclear power plant should be available in order to provide reasonable assurance that a nuclear power plant can be constructed and operated without suffering damage that will have adverse impact on the environment.

Preferred sites for nuclear power plants are in areas with good soil stability, adequate drainage, and limited topographic relief.

Areas of actual or potential surface or subsurface subsidence, uplift, or collapse that can result from such phenomena as groundwater withdrawal or recharge, mineral extraction, cavernous or karst terrain, and regional warping should be avoided.

Available data on seismic activity, both local and distant, that could induce floods and/or water waves affecting the site where a nuclear plant is to be located should be considered thoroughly relative to the protection of the health and safety of the public and the environment.

Atmospheric Factors - Federal and State regulations that cover air pollution from the construction or operation of new sources must be met. An appraisal should be made of the proposed installation's potential for significantly deteriorating the air quality in the vicinity of the site.

A site should provide atmospheric dispersion of radioactive effluents and waste heat sufficient to protect the surrounding environment.

Valleys and canyons can have a significant effect on local atmospheric dispersion and should be avoided if frequency of temperature inversions, low wind speeds, and the limited wind directions may result in unacceptable dispersion of plant discharges to the atmosphere.

If cooling tower plumes or other atmospheric emissions could deleteriously affect the residential, recreational, or other human resources, then shoreline sites that have low over-water diffusion rates and high over-land turbulent mixing should be avoided. This especially applies to shorelines where there are cold currents.

Sites located in areas of high tornado and waterspout incidence and in regions of high wind speeds may require facilities of special or selected design.

Sites should be avoided where the operation of plants having cooling towers, cooling ponds, or spray ponds, would result in unacceptable fogging and icing.

Hydrology - Potential sites for nuclear power plants should be free from limitation imposed by existing laws or allocation policy with regard to the availability of cooling water, or the expected actions through appropriate legal channels should be consistent with the established management policies of the utilities. Laws and policies can be changed, but the length of time and the effort required to do so should be considered by the utility in its site selection.

An adequate water supply must be available to provide for continued plant operation over the design life of the facility.

Protection of groundwater supplies is needed for the qualification of a site as suitable for a nuclear power plant. If groundwater is used by the plant, the sustained yield of the groundwater system should not be exceeded, that is, groundwater mining would require special evaluation. The location and uses of groundwater at the potential site must be considered in the selection process if any discharge of water to the groundwater system, planned or inadvertent, may occur.

Potential loss of water arising from flooding, erosion, channeling, or other causes needs to be considered during site selection.

The water quality of surface waters at the site must be maintained in accordance with State standards and regulations.

Potential sites on water bodies subject to heavy icing and blockage need special consideration in order to assure continuity of water supply. Because ice can impact on structures, causing plugging or structural failures, this factor should also be considered in the selection of a site.

The site must accommodate a power plant design such that the mixing of all heated or otherwise thermally modified discharges to receiving waters can be carried out within the formal mixing zones established by applicable Federal or State regulations.

Water bodies that are stratified at any time of the year need special consideration of their vertical mixing characteristics if they are to be used for cooling water.

The effects of impoundments that change natural water temperatures need to be considered on a local and regional basis at sites involving thermal releases to rivers and lakes.

Ecology - Water bodies containing important aquatic species with narrow thermal tolerance or important species living near their upper or lower limit of thermal tolerance should generally be avoided if thermal discharges or heat shock during entrainment may have a deleterious impact on the populations. Generally, this guideline is most applicable to sites in southern or northern areas where the temperature of the marine or fresh surface waters is naturally very warm or very cold or other waters with critical temperatures in localized areas throughout the country.

Sites should be carefully evaluated where construction or plant operation could result in physical alteration of, water withdrawal from, or effluent discharge into principal terrestrial or aquatic breeding habitats. This is especially important if any of these stresses would be expected to produce a long-term deleterious impact on populations of important species.

Sites should be carefully evaluated where nuclear power plant structures or plant effluents could block pathways or severely interfere with local or long distance movement of populations of important animals.

Sites should be evaluated for potential effects from construction and from operational releases on vegetation.

Areas containing populations, individuals, or habitats of rare, threatened, or endangered species, or principal habitats of endangered species, as defined by the Bureau of Sports Fisheries and Wildlife or by States, should be avoided if construction or operation of facilities therein may cause further adverse impacts. The development of a site may, in some cases, improve habitat and afford protection for some rare or endangered species and should be taken into account in the site-selection process.

Public Exposure to Radiation - Sites must meet Federal requirements.

Land Use - The compatibility of use of the site for a nuclear power plant with existing land uses should be considered. The process of selecting sites should consider compatibility with current and projected Federal, State, regional, and local land-use policies, plans, and regulations.

The process of site selection should consider Federal and State coastal zone management, policies, plans, and regulations.

The choice of sites should consider effects of the nuclear power plant in its use of water on the overall management of the watershed.

The selection of sites should consider the disturbances of land uses due to the need for acquisition of land for transmission corridors. (Tables 140 and 141.)

Human Interest Factors - Plant sites and transmission corridors should generally be sited to avoid adverse impact on unique natural resource areas, including but not limited to the following Federal and State designations: national and certain State parks, national monuments and similar sites of important State and local interest, wilderness areas, wildlife refuge areas, wild/scenic/recreational rivers, and unique or rare geological formations.

Protection of historically significant areas and places should be assured in the selection of nuclear power plant sites.

Archaeologically significant areas require careful consideration before their selection as plant sites.

Areas containing unique and/or significant fossil or "rare rock" deposits require careful consideration before selection as plant sites.

Esthetics - In selecting and planning nuclear power plant sites the esthetic impact of transmission facilities should be considered. Special architectural design and landscape screening or landscape placement should be considered in relation to site characteristics.

The site characteristics should be evaluated relative to architectural design and landscape screening for improving esthetics. (Table 142.)

Other Considerations - The site should preferably be convenient to either bodies of water or rail or road corridors of sufficient width and load-carrying capacity to enable the delivery of construction materials and equipment and major reactor and turbine components without unacceptable disruption of the surrounding environment.

When a site is being selected, it is important to identify and evaluate the short-term impacts of construction on the environment and to assure that the construction can be conducted without causing unacceptable environmental impacts.

Trends

As of 1970 there were over 550 fossil-fueled power plants with a total capacity of almost 250,000 MW. In the next decade over 300 additional

fossil-fueled units are scheduled to be built, together with almost 100 nuclear units, for a total increase in capacity comparable to that already in existence. There are two areas of concern in regard to these installations: the actual land used by the power plant itself (which includes building, cooling arrangements, fuel storage, and exclusion areas), and the transmission line requirements.

The Energy Policy Staff of the Office of Science and Technology estimates that by 1990 there will be about 500,000 mi of electric transmission lines, or approximately 7×10^6 acres of rights-of-way. Using 115 ft as the average width, this amounts to $19 \text{ mi}^2/1000 \text{ MW(e)}$.

This area could be reduced to $10 \text{ mi}^2/1000 \text{ MW(e)}$ by the introduction of fusion reactors. Placing all the controlled thermonuclear reactors (CTR's) in the cities for the years 2000-2020 would then save over 9000 mi^2 of land for transmission lines, and 950 mi^2 if they take the place of newly installed fossil-fueled plants. Other benefits might accrue from urban siting of plants, such as use of waste heat for residential and industrial heating, industrial processing, or sewage distillation.

The Federal Power Commission reported that in 1968 there were over 300,000 mi of transmission lines of 69 kV or greater in the U.S. The right-of-way occupied by this transmission system was estimated at 4×10^6 acres.

On an industry-wide basis, the average land requirement was 13.3 acres/mi of right-of-way. The total generating capacity in 1968 was 290,000 MW(e), which corresponds to an average transmission line distance of 1034 mi/1000 MW(e) of generating capability. The above data then led to the estimate of 14,700 acres of land for transmission associated with each 1000-MW(e) power plant.

Other environmental effects associated with electrical transmission include visual impact, effects resulting from line and tower construction, and ozone production by corona discharge.

Cost of Control

A recent estimate for the cost of undergrounding a nuclear power plant suggests a range of \$6/kW to \$10/kW of capacity, depending on excavation conditions and other design factors peculiar to particular sites. This is an impact on power-plant capital costs of less than 5%. Undergrounding of transmission lines tend to increase their costs by a factor of about 10,

again depending on the actual terrain and the geological conditions encountered.

Underground cryogenic transmission lines offer the promise of better cost competition with overhead lines, but only at very high power-transmission levels. At single-circuit capacities of the order of 5000 MW, cryogenic lines may cost \$600/MW-mi, whereas oil-filled underground cables will cost more than twice as much. Overhead transmission lines of conventional design run about \$150/MW-mi. (Table 143.)

References - Power Plant Siting

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Table 140. Land requirements for power-plant sites.*

	mi ² /1000 MW(e)	Comment
Coal	1.60	On-site coal storage and ash disposal
Oil	0.40	On-site fuel storage
Gas	0.24	
Fission	0.47	Exclusion area required
CTR	0.47	Assumed to be same as fission for this study

*[Kulcinski, G. L., Energy Policy 2, 104 (1974).]

Table 141. Potential sites off New Jersey and California for shallow-water concepts.*

General location	Latitude		Length (mi)	Minimum distance from shore (mi)	Water depth (ft)
	From	To			
<u>New Jersey</u>					
South of Atlantic City	38°-56'	39°-17'	26	3	20 to 100
Atlantic City	39°-17'	39°-21'	7	3 to 7	20 to 100
North of Atlantic City	39°-21'	39°-52'	35	3	25 to 100
Near Seaside Park	39°-52'	40°-8'	21	3 to 12	50 to 100
North of Asbury Park	40°-17'	40°-36'	29	3 to 15	60 to 100
<u>California</u>					
Near San Onofre	33°-18'	33°-20'	1	3	100
Near Pt. Hueneme	34°-7'	34°-17'	10	3 to 9	60 to 100
Near Pt. Sal	34°-50'	34°-51'	1	3 to 5	90 to 100
Near Oceano	35°-5'	35°-6'	1	3 to 4	90 to 100
Near Santa Cruz	36°-53'	36°-56'	3	3 to 6	72 to 100
Near Pt. Delgada	39°-55'	39°-58'	3	3 to 5	72 to 100
South of Eureka	40°-39'	40°-42'	3	3 to 4	100
South of Trinidad Hd.	40°-59'	41°-1'	2	3 to 5	75 to 100
South of Requa	41°-21'	41°-33'	12	3 to 4	80 to 100
South of Crescent City	41°-41'	41°-42'	1	3 to 4	60 to 100
North of Crescent City	41°-48'	41°-59'	11	3 to 5	80 to 100

*[Klepper, O. H., and T. D. Anderson, "Siting Considerations for Future Offshore Nuclear Energy Stations," Nuclear Tech. 22, 160 (April 1974).]

Table 142. Overall acceptability.*

Concept	Acceptability values
Aboveground (inland)	0.779
Aboveground (floating, lagoon)	0.761
Aboveground (hillside)	0.756
Aboveground (low profile)	0.674
Aboveground (coastal)	0.657
Offshore (floating, deep)	0.649
Underground (nonmassive, poorly cemented materials)	0.642
Offshore (artificial island)	0.637
Offshore (floating, shallow)	0.636
Offshore (tuned sphere)	0.617
Underground (massive sedimentary rock)	0.603
Offshore (natural island)	0.581
Offshore (undersea)	0.549
Underground (massive igneous rock)	0.540
Underground (unconsolidated materials, beach)	0.522
Offshore (seabed)	0.502
Underground (massive rock, faulted)	0.494

* [Perla, H. F., Energy Sources 1, 229 (1974).]

Table 143. Bus-bar costs.*

Concept	Estimated ^a (mils/kW)	Relative rating
Aboveground (coastal)	8.86	1.00
Aboveground (low profile)	8.87	1.00
Aboveground (hillside)	9.18	0.96
Aboveground (inland)	9.65	0.92
Aboveground (floating, lagoon)	9.91	0.89
Underground (massive sedimentary rock)	10.25	0.87
Underground (massive igneous rock)	10.25	0.87
Offshore (artificial island)	10.35	0.86
Underground (nonmassive, poorly cemented materials)	10.39	0.85
Offshore (floating, deep)	10.48	0.84
Offshore (natural island)	10.51	0.84
Offshore (seabed)	10.96	0.81
Underground (massive rock, faulted)	11.30	0.78
Offshore (floating, shallow)	12.01	0.74
Offshore (tuned sphere)	12.06	0.73
Underground (unconsolidated materials, beach)	12.96	0.68
Offshore (undersea)	13.20	0.67

^a1972 dollars.* [Perla, H. F., Energy Sources 1, 229 (1974).]

Hydroelectric Dams

Sources

Dams built for conventional electric power generation or for pumped storage of water during off-peak periods create man-made lakes that can have far-reaching ecological consequences. These may be felt not only in the inundated areas where former valleys are converted into reservoirs, but in the downstream areas as well. They also have a limited lifetime because they fill up with silt - some have done so in as little as 20 y.

Trends

Less than 17% of U.S. electrical energy comes from hydroelectric plants, and there are relatively few remaining sites that could be used economically for large-scale power production. The best have already been developed. However, with the increasing demand for electricity, there will be more man-made lakes for hydroelectric power and for pumped storage.

It was estimated at the end of 1967 that the undeveloped water power of the U.S. was about 130,000 MW compared with an existing installed capacity of almost 46,000 MW, excluding pumped-storage capacity.

Cost of Control

The cost of control depends on specific cases and data are difficult to locate.

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.

Library of Congress Legislative Reference Service, Environmental Policy Division, The Economy, Energy, and the Environment, a background study prepared for the Joint Economic Committee, 91st Congress, 2nd Session, Washington, DC (1970), p. 69.

Fuel Mineral Depletion

Fossil, Natural, and Nuclear Fission Systems

Since it presently takes mostly fossil-fuel energy to obtain energy, the overall environmental impact is involved in a positive feedback loop that causes an ever-increasing depletion of nonrenewable mineral fuel resources. Only natural energy sources are an exception. (Tables 144-150.)

Fusion Systems

Basic fuels for a deuterium-tritium-based fusion economy are deuterium and lithium. It requires roughly 80 g of deuterium (in combination with tritium) to provide 1 MW(e)-y of power assuming a 40% efficiency for converting heat into electricity. This means that in the year 2010, CTR's would require 19 metric tons/y of deuterium. This would most probably come from heavy water (D_2O) plants, so that 96 metric tons/y of heavy water would be required in 2010. This number rises to 425 metric tons/y of D_2O in 2020. Such production rates are not uncommon even today. Canada's Bruce Plant currently produces 800 metric tons/y of heavy water. It is therefore conceivable that one plant could provide the entire deuterium requirements for the U.S. CTR program until 2020.

Calculation of the total lithium requirements for fuel for the projected U.S. fusion economy reveals that the minimum yearly lithium requirement is 225 metric tons in 2010 and about 1100 metric tons in 2020.

It is also possible that future CTR's will use lithium, either in elemental form or in combination with other elements, as a coolant. Typically, 1000 kg of lithium/MW(e) are required for cooling. Hence about 10^6 metric tons of lithium would be required for this purpose until 2020, more than 100 times the cumulative amount required for producing tritium alone.

The volume of ore (or most probably brine) that must be processed can be estimated by noting that the lithium concentration in its ores is about 5% and in brines it is present at 40 to 300 ppm. Hence, if the lithium is obtained from brine, 5×10^9 gal of liquid must be processed and reinserted into the ground to produce the lithium required up to 2020. All this lithium could come from one 72-mi² deposit in Nevada without any appreciable upset in the environment.

If the lithium is processed from ore and if the amount of gangue (for tunnels or overload) is 3 times the volume of ore removed, then approximately 40×10^6 yd³ of earth must be disturbed. Assuming a mining depth for lithium of 10 y, this means that 1.5 mi² must be dug up to provide lithium for CTR cooling.

Table 144. Some fuel resources and consumption rates (measured in 10^{12} GJ = 10^{21} J = 0.948×10^{18} Btu $\approx$ 0.95 Q).*

	Energy (10^{12} GJ)
<u>Fuel</u>	
World oil reserves, 1974	4
World ultimately recoverable gas, oil, coal	240
U.S. uranium to \$250/kg, used in LMFBR	700
U.S. lithium reserves (13,000 to 25,000 kWh/g)	250 to 500
Uranium in oceans, used in LMFBR	200,000
Lithium supply in oceans (25,000 kWh/g)	22,000,000
Deuterium supply in oceans	16,000,000,000
<u>Consumption rates</u>	
World energy use in 1974	0.25
U.S. energy used for electricity in 1974	0.02
Total annual energy for 8-billion people at 6 kW/person ^a	1.5

^aRate corresponds to Sweden in 1973.

*[Holdren, J. P. et al., data presented in a paper at the Conference on Energy and Environment, Georgia Institute of Technology, Atlanta, Georgia, June 23, 1975.]

Table 145. Resource requirements for a hydroelectric system: 1000 MW(e) delivered energy.*

System process	Primary resource required, water (ft ³ /s)	External resource subsidy		
		Natural gas (ft ³)	Petroleum (bbl)	Coal (tons)
Exploration				
Extraction	2.9×10^8	20.9×10^7	35.9×10^3	18.2×10^3
Conversion				
Distribution - primary	1.0×10^8	3.0×10^7	6.0×10^3	2.7×10^3
Delivered resource	9.6×10^8	-	-	-
Total	13.5×10^8	23.9×10^7	41.9×10^3	20.9×10^3

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974).]

Table 146. Resource requirements for a light water nuclear reactor system: 1000 MW(e) delivered energy.*

System process	Primary resource required, uranium-235 (lb)	External resource subsidy		
		Natural gas (ft ³)	Petroleum (bbl)	Coal (tons)
Exploration	-	0.9×10^8	9,956	2,601
Extraction	216	8.4×10^8	12,467	4,485
Transport	-	-	299	658
Process	1,333	17.3×10^8	498,393	161,746
Conversion	3,704	16.7×10^8	142,014	40,362
Distribution - primary	83	0.3×10^8	5,083	5,083
Delivered resource	830	-	-	-
Total	6,166	43.6×10^8	668,212	214,935

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974).]

Table 147. Resource requirements for a geothermal steam electric system: 1000 MW(e) delivered energy.*

System process	Primary resource required, dry steam (tons)	External resource subsidy		
		Natural gas (ft ³)	Petroleum (bbl)	Coal (tons)
Exploration	-	6.0×10^7	5,830	1,704
Extraction	-	9.0×10^7	49,032	8,670
Transport I	8.7×10^1	1.2×10^7	957	1,375
Conversion	7.3×10^7	17.9×10^7	75,043	4,186
Distribution - primary	12.3×10^1	9.0×10^7	7,026	2,063
Delivered resource	1.3×10^7	-	-	-
Total	29.6×10^7	43.1×10^7	137,888	17,998

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974).]

Table 148. Resource requirements for a coal gasification electric system: 1000 MW(e) delivered energy.*

System process	Primary resource required, strip-mined coal (tons)	External resource subsidy		
		Natural gas (ft ³)	Petroleum (bbl)	Strip-mined coal (tons)
Exploration	-	0.002×10^9	6,488	520
Extraction	-	0.3×10^9	698,109	55,909
Transport I	1,166	0.009×10^9	6,488	520
Process	643,097	0.3×10^9	21,915	5,471
Transport II	777	0.003×10^9	2,491	1,689
Conversion - coal gas	3,226,250	0.3×10^9	117,498	31,990
Distribution - coal gas	203,902	0.8×10^9	123,178	33,485
Conversion - electricity	2,446,820	1.5×10^9	127,962	35,578
Distribution - electricity	128,560	0.05×10^9	4,485	1,166
Delivered resource - primary	1,299,948	-	-	-
Total	7,950,520	3.3×10^9	1,108,614	166,328

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974).]

Table 149. Resource requirements for an oil shale electric system: 1000 MW(e) delivered energy.*

System process	Primary resource required, oil shale (bbl)	External resource subsidy		
		Natural gas (ft ³)	Petroleum (bbl)	Coal (tons)
Exploration	-	-	-	-
Extraction	-	7.7×10^9	670,304	184,767
Transport I	1,495	3.6×10^9	11,451	2,601
Process	3,386,501	11.8×10^9	638,314	129,756
Transport II	154,570	0.3×10^9	124,583	20,809
Conversion	9,379,774	1.3×10^9	271,470	40,302
Distribution	492,712	0.1×10^9	6,966	1,824
Delivered resource - primary	4,983,931	-	-	-
Total	18,398,983	24.8×10^9	1,723,088	380,059

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Taknekron, Berkeley, CA, Rept. No. EED 103 (December 1974).]

Table 150. Resource requirements for a coal-fired electric system: 1000 MW(e) delivered energy.*

System process	Primary resource required, strip-mined coal (tons)	External resource subsidy		
		Natural gas (ft ³)	Petroleum (bbl)	Strip-mined coal (tons)
Exploration	-	0.01×10^9	3,648	311
Extraction	-	1.4×10^9	39,913	31,990
Transport I	149,757	1.1×10^9	1,480,351	17,161
Process	355,781	0.1×10^9	12,467	3,109
Transport II	449	0.002×10^9	1,345	936
Conversion	2,612,153	1.1×10^9	277,150	34,980
Distribution	128,560	0.06×10^9	4,993	1,429
Delivered resource - primary	1,299,948	-	-	-
Total	4,546,678	3.8×10^9	1,819,867	89,916

*[Compiled from data in Pigford, T. H., M. J. Keaton, B. J. Mann, P. M. Cukor, and G. L. Sessler, Teknekron, Berkeley, CA, Rept. No. EEED 103 (December 1974).]

Energy-Related Minerals Depletion

Fossil and Nuclear Fission Systems

There are 13 minerals essential to conventional energy production, storage, and distribution. These minerals are:

Aluminum	Nickel
Chromium	Platinum-group
Cobalt	Tin
Copper	Tungsten
Lead	Vanadium
Manganese	Zinc
Molybdenum	

In any energy-related program the environmental impact would be a depletion of these nonrenewable natural resources. Only molybdenum is in sufficient supply; the supply of all other minerals depends on imports.

Many calculations of resource reserves that supposedly offer years of supply are as gross reserve rather than net reserve and thus may be of much shorter duration than often stated. (Table 151.)

United States steel production currently is in the range of 150×10^6 tons/y. A very rough approximation indicates that the annual requirements of the energy industry during the late 1970's and early 1980's might be as high as 10 or 15% of this total. The demands of the energy industry will be met through economics of the marketplace or else through conscious public policy decisions.

The fabricators of large steel pressure vessels of the type used for nuclear reactors currently have a total capacity of approximately 30 vessels/y. The capacity is limited by the availability of very thick and wide steel plate. There is only one U.S. supplier of steel plate in thicknesses from 10 to 24 in. and in widths adequate for fabrication into large pressure vessels without undue numbers of welds. This company currently is running at capacity and has made no announcement of expansion plans.

Onshore drill rigs are relatively straightforward to construct and it is projected that capacity to build these units can be rapidly expanded. Off-shore drill rigs require the use of a drill ship or a drilling platform. Such facilities must be constructed in shipyards, and currently the shipyard capacity of the U.S. is near saturation.

Fusion System

About 60 mi² (160 km²) need to be disrupted over the 20-y period prior to 2020 to provide the necessary ore to get the CTR nuclear island materials for the period 2000-2020. To put this figure in perspective, it is a factor of about 70 less than the land required only to provide strip-mined coal for the equivalent electrical generating capacity.

Three of the required metals stand out as needing the largest amount of ore to be processed per plant. These are in increasing order: nickel, copper, and lead. Obviously, if all other things were equal, one would like to substitute other elements with higher ore yields for these materials. (Tables 152 and 153.)

References - Energy-Related Minerals Depletion

Szego, G. C., The U.S. Energy Problem, Intertechnology Corp., Warrenton, VA, Publ. PB-207519, Appendix Q (1971).

Table 151. Ore requirements to produce 1974 U.S. electricity by various processes [200,000 MW(e)-y at assumed 40% efficiency, that is, 500,000 MW(t)-y].*

Process	Ore (fuel ppm by weight)	Ore required (10 ⁶ metric tons)
D-D fusion	Seawater (32 ppm D)	1.4
D-T (Li) fusion	Pegmatite (6000 ppm Li)	0.06
	Silver Peak brine (300 ppm Li)	1.1
	Seawater (0.17 ppm Li)	1000
LMFBR fission	Colo. sandstone (2000 ppm U)	0.17
	Chattanooga shale (60 ppm U)	5.5
	Seawater (0.003 ppm U)	110,000
LWR fission	Colo. sandstone (2000 ppm U)	14
HTGR fission	Chattanooga shale (60 ppm U)	240
Coal-fired steam	Bituminous coal	570

*[Holdren, J. P., et al., data presented in a paper at the Conference on Energy and Environment, Georgia Institute of Technology, Atlanta, Georgia, June 31, 1975.]

Table 152. Materials requirements for 10^6 MW(e) of fusion generating capacity.*

Element	Material quantity (10^6 metric tons)		
	Inventory for 10^6 MW(e)	1970 U.S. reserves	1970 world reserves
Aluminum	0.6	13	3000
Boron	0.8	33	66
Beryllium	0.12	0.018	0.38
Carbon	2	10	large
Chromium	2	~0	370
Copper	2	74	310
Fluorine	1	9	62
Helium	0.3	1.2	1.2
Iron	10	8500	180,000
Lead	11	39	85
Lithium	1	6	180
Manganese	0.2	0	590
Molybdenum	0.2	2.5	6.5
Niobium	0.8	0.005	7.8
Nickel	1.5	0.14	24
Potassium	0.02	42	30,000
Tin	0.2	0.009	6
Titanium	0.8	23	134
Vanadium	0.5	0.1	26
Zirconium	0.002	0.06	25

*[Holdren, J. P., et al., data presented in a paper at the Conference on Energy and Environment, Georgia Institute of Technology, Atlanta, Georgia, June 27, 1975.]

Table 153. Nonfuel ore requirement for projected CTR's from 2000 to 2020.*

Element	For 1063×10^3 MW(e) (10^6 metric tons)	Approximate yield of metal from ore	Total ore requirements (10^6 metric tons)
Aluminum	0.6	10	6
Beryllium	0.1	2	5
Chromium	2	5	40
Copper	3	0.9	220
Iron	13	45	29
Molybdenum	0.2	2	10
Niobium	0.8	2	50
Nickel	1	1	150
Lead	12	1.5	800
Tin	0.2	10	2
Vanadium ^a	0.5	5	10
			1351
			To account for overburden, tunnels, etc. $\times 4$
			5404×10^6 metric tons ^b

^aSubstitute for Nb structural material.

^b 160 km^2 to a depth of 10 m, assuming $0.3 \text{ m}^3/\text{metric ton}$ of ore.

*[Kulcinski, G. L., Energy Policy 2, 104 (1974).]

Section V

Social Costs

BENEFIT VS ECOLOGICAL RISK

Almost anything we do in energy production, conversion, and use involves a risk, however small. Even producing no energy involves a risk.

In everyday life we take many risks. We instinctively balance benefit and risk. It is therefore not reasonable to demand across-the-board evidence that effluents have no environmental impact, but it is reasonable to ask whether the benefits of a pollutant are commensurate with its possible risk to environmental quality.

The quantification of social cost (risk) for either nuclear- or fossil-fueled power plants is difficult because of the lack of (1) appropriate information detailing quantitatively the pollutant transport and chemical transformation in the environment and (2) accurate impact assessment of the pollutants on the ecosystem in terms of dose (or concentration level), that is, damage relationships.

The social acceptance of risk is directly influenced by public awareness of the benefits of an activity, as determined by advertising, usefulness, and the number of people participating. The public is willing to accept "voluntary" risks roughly 1000 times greater than "involuntary" risks. As one would expect, we are loathe to let others do unto us what we happily do to ourselves.

An averaged involuntary risk may be considered "excessive" if it exceeds the incidence rate of disease, "high" if it approaches it, "moderate" if the risk is about 10 to 100 times less, "low" if it approaches the level of natural hazards, and "negligible" if it is below this. (Figure 133.)

Any risk created by a new sociotechnical system is acceptably "safe enough" if the risk level is below the curve. More accurately, when the increment of additional risk added by the new system is associated with an incremental benefit equal to or greater than that indicated by the curve, the system is "safe enough." If, as is usually the case, a new system has a range of uncertainty in its risks, a design target may be set below the curve by an equivalent amount - possibly by as much as a factor of 10 or 100.

The rate of death from disease appears to play, psychologically, a yardstick role in determining the acceptability of risk on a voluntary basis. The risk of death in most sporting activities is surprisingly close to the risk of death from disease - almost as though, in sports, the individual's subconscious computer adjusted his courage and made him take risks associated with a fatality level equaling but not exceeding the statistical mortality due to involuntary exposure to disease. Perhaps this defines the demarcation between boldness and foolhardiness.

The leveling off of motor vehicle risk at about 100 fatalities/h of exposure of the participating population may be significant. Because most of the U.S. population is involved, this rate of fatalities may have sufficient public visibility to set a level of social acceptability. (Figure 134.)

It is both interesting and disconcerting that the trend of fatalities in aviation, both commercial and general, is uniformly upward to 1965. Increased public participation in commercial aviation will undoubtedly increase the pressure to reduce the risk, because, for the general population, the benefits are much less than those associated with motor vehicles. Commercial aviation has not yet reached the point of optimum benefit-risk tradeoff. For general aviation the trends are similar. The acceptable risk is inversely related to the number of people participating in an activity.

In the application of our resources to reducing public risks, the economic principle of "marginal utility" should be used - that is, the resources should be applied where they will do the most good. There is little point in spending effort on improving the safety of a system that is already in the category of "negligible risk." The effort would be better applied to the higher risk systems that will substantially influence our public health statistics. (Table 154.)

Table 154. Estimated Health Effects in 1974
Associated with Production of Electric Power.*

Fuel	1974, ⁹ kWhe x 10	Equivalent No. 1000 MWe Plants	Estimated Deaths	Estimated Disabilities	Unknowns
Coal	830	126	2,000-20,000	20,000-40,000	Increased cancer, other chronic disease mutations
Oil	299	45	100-5,000	4,000-9,000	Increased cancer, other chronic disease mutations
Gas	320	48	6	600	Increased cancer, other chronic disease mutations
Nuclear	113	17	10-30	80-400	Increased risk of catastrophic accident
Hydro	300	45	-	-	Increased risk from failure accident
Wood, Waste, Geothermal	3	.4	-	-	-
Totals	1865	281	2,000-25,000	25,000-50,000	

* Proceedings of the Conference on Computer Support of Environmental Science and Analysis,
Lawrence Livermore Laboratory, CONF-750706 (1975), p. 49.

Fig. 133. Benefit-risk pattern for involuntary exposure. [Starr, C., et al., Nuclear News 15, 37 (October 1972).]

Fig. 134. Risk comparison. The historical trend of total fatalities per hour of transportation exposure of the population involved. [Starr, C., in Proceedings of the Symposium on Environmental Aspects of Nuclear Power Stations, New York, 1970 (IAEA, Vienna, 1970).]

MINING ACCIDENTS

Miners experience a relatively high accident risk. Men employed in coal mining operations are exposed to the hazards of long-term coal dust inhalation, which has been positively correlated with a high incidence of pneumoconiosis. Additionally, they are exposed to the risk of mining accidents. Current morbidity and mortality figures reflect past neglect of dust control and safety precautions in the mines. Such neglect has resulted in escalating health costs for medical care, disability pensions, and Black Lung benefits. (Table 155 and Figs. 135 and 136.)

Present occupational health costs amount to \$58 million/y. Projection of future health costs is difficult and will depend on the efficiency of preventive measures aimed at limiting exposure of workers to coal dust and mine safety.

Uranium workers also have a serious occupational hazard through the inhalation of radionuclides that act as carcinogens in the development of lung cancer. A statistically significant excess of respiratory cancer deaths has been found in uranium miners with long intervals between time of initial exposure and development of malignant disease.

Miners are also exposed to diesel exhaust fumes, products from the detonation of explosives, and dusts composed of silica and various metal ores. Dermatitis from abrasive hand cleaners, oils, and other primary irritants are common in uranium millers.

The major health hazards of uranium miners are comparable to those of men involved in fossil-fuel mining and processing, namely, pneumoconiosis, lung cancer, and accidents. However, on a dollar cost basis it is projected that fossil-fuel production is currently a health problem of greater magnitude because of the much larger number of workers in these industries vs those involved in nuclear-fuel production.

The uranium and coal industries have very similar injury rates per million man-h. However, the uranium industry does not compare favorably with the metal mining industry as a whole since the metal industry fatal and nonfatal injury rates per million man-h averaged approximately 0.56 and 29.8, respectively, over the 1964-1968 period. (Table 156.)

Uranium mining productivity (tons of ore per man-h) is lower than coal for a variety of reasons. Often the uranium ore bodies are relatively small

and hard to develop. Therefore, coal and uranium injury rates do not look as similar when they are based on millions of tons of output. A similar analysis gave a 1964-1968 average of approximately 11,100 man-d lost/ 10^6 tons of uranium ore or about 6100 man-d lost/ 10^6 kg of U_3O_8 . Assuming a 0.2% U_3O_8 content in ore and that 50% of the mining production is by the open-pit method, the fatality rate for all uranium mining is 0.61 deaths/ 10^6 kg of U_3O_8 mined, while the nonfatal injury rate is 23.2 deaths/ 10^6 kg of U_3O_8 . Using 6000 man-d lost/death and 55 man-d lost/nonfatal injury gives 4940 man-d lost/ 10^6 kg of U_3O_8 . (Table 157.)

Underground mining had a higher fatality and nonfatal injury rate by a considerable margin over open-pit uranium mining. These rates have been showing a downward trend as the uranium industry becomes more sophisticated. For example, the inclusion of fatalities from 1960 through 1963 raises the average underground fatality rate to 2.30 deaths/ 10^6 tons. However, 1960 was a particularly bad year; 29 underground miners died and underground mining production was less than 5.6×10^6 tons of ore. (Table 158.)

Table 155. Annual social costs from a conventional coal-fired electricity system: 1000-MW power plant, 75% load factor.*

System process	Environmental impact		
	Deaths/10 ⁶ tons mined	Injuries/10 ⁶ tons mined	Workdays lost/injury
Exploration	NA	NA	NA
Extraction			
Deep	1.67	85	12,688
Surface	0.308	13.9	499
Processing			
Deep	0.0238	2.56	99.5
Surface	0.0238	2.56	99.5
Transport			
Deep	2.30	23.4	2,340
Surface	2.30	23.4	2,340
Conversion			
Deep	0.012	1.38	152.9
Surface	0.012	1.38	152.9
Transmission	NA	NA	NA
Total			
Deep	4.00	112.3	15,280
Surface	2.64	41.2	3,091

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973).]

Table 156. Comparison of coal and uranium mining accident rates.*

Year	Injury rates/10 ⁶ man/h				Injury rates/10 ⁶ tons of output			
	Uranium		Coal		Uranium ore		Coal	
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal
1964	0.51	44.6	0.96	43.9	0.75	65.9	0.48	22.0
1965	1.61	45.4	1.04	44.7	2.28	59.4	0.49	21.2
1966	1.18	35.3	0.96	42.9	1.61	48.6	0.43	19.1
1967	0.74	46.2	0.92	41.8	0.95	59.1	0.39	18.0
1968	0.71	37.0	1.33	40.4	0.92	48.4	0.56	17.0
1969	1.54	31.4	0.85	41.8	2.03	41.5	0.36	17.4
Average	1.02	39.2	1.01	42.6	1.39	53.4	0.45	19.0

* [Argonne National Laboratory, Argonne, IL, Publ. ANL-8093, Vol. 2 (1973).]

Table 157. Uranium mining accident data.*

Year	Underground mining			Open-pit mining		
	Production 10 ³ tons ore	Fatalities	Nonfatal Injuries	Production 10 ³ tons ore	Fatalities	Nonfatal injuries
1964	3760	4	326	1537	0	23
1965	3133	10	250	1243	0	10
1966	2966	7	187	1332	0	23
1967	3678	3	291	1593	2	21
1968	4082	5	303	2366	1	9
1969 ^a	3731	12	220	2173	0	25
1964-1969 average accident rates/10 ⁶ tons of ore		1.92	73.9		0.29	10.8
Rate/10 ⁶ kg U ₃ O ₈ ^b		1.06	40.6		0.16	5.9

^aPreliminary data.

^bAssuming 0.2% U₃O₈ content in ore.

* [Argonne National Laboratory, Argonne, IL, Publ. ANL-8093, Vol. 2 (1973).]

Table 158. Annual social costs from a conventional nuclear electricity system: 1000-MW power plant, 75% load factor.*

System process	Environmental impact		
	Deaths/100 Nonfatal injuries	Injuries/total man-h worked	Workdays lost/injury
Exploration	NA	NA	NA
Extraction	0.09	3.45	208
Processing	0.048	0.568	343
Transport	0.002	0.045	2.7
Conversion	0.013	1.31	25.6
Transmission	NA	NA	NA
Total	0.153	5.37	270.6

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973).]

*Preliminary data

Fig. 135. Total U.S. coal mine deaths from accidents, 1907-1973. [Mining Enforcement and Safety Administration, Department of the Interior, Washington, DC (1974).]

Fig. 136. Total nonfatal injuries, U.S. coal mines, 1930-1973. [Mining Enforcement and Safety Administration, Department of the Interior, Washington, DC (1974).]

TRANSPORTATION ACCIDENTS

Automobiles and Trucking

Traffic accidents are a major social problem by any standard, and until recently more Americans died each year on the roads than in all the years of war in Southeast Asia. Roughly 55,000 Americans died on the roads in 1970. The number of persons injured that same year ran to 5,100,000. The annual economic loss per seriously injured person in medical expenses, property damage, and lost earnings runs into the billions of dollars. (Figure 137.)

Over the years the problem was studied and a variety of efforts were launched to correct it. Some favored the educational approach, especially driver education classes and public persuasion campaigns ("the life you save may be your own"). Others subscribed to technological cures: redesign of the automobile (Ralph Nader argued that the cars were "unsafe at any speed," not the drivers) and redesign of the roads (railings, flexible signposts, and so on). Still other appealed to the long arm of the law, asking for stiffer penalties for traffic violators and mandatory use of seat belts. And yet another set of people pointed to alcohol as the major cause of fatal accidents and called for greater use of breath analyzers to get those driving while under the influence of liquor off the road. Each approach had its proponents, detractors, supportive data, and counterclaims. The number of traffic deaths continued to rise from 38,000 in 1960 to 49,000 in 1965 to 55,000 in 1970, while injuries went from 3,078,000 to 4,100,000 to 5,100,000 in the same years.

Then came the 55-mph speed limit, introduced, oddly enough, not to save lives but to conserve energy. Since then the slaughter on the highways has been curtailed by more than 23% in the first year of enforcement.

Railroads

Relatively few employees are killed compared to the number of employees injured. This is the case in most industries. The average time lost from a nonfatal injury to an employee is 50 man-d. However, in the nonemployee category, almost half as many are killed as are injured. This category is mainly made up of people killed and injured at grade crossings. Therefore, it should not be surprising that a larger fraction of the people affected are killed.

Because of the increased severity of accidents involving nonemployees, the average time lost from a nonfatal injury to a nonemployee is 200 man-d. (Tables 159 and 160.)

Aviation

Civil aviation accidents and death rates have declined steadily since 1945, a period of rapid growth for all types of flying. (Table 161.)

References - Transportation Accidents

Argonne National Laboratory, Argonne, IL, Publ. ANL-8093, Vol. 2 (1973).

Science 185, 974 (1974).

Table 159. Selected railroad statistics for 1970.*

Freight train miles	427×10^6
Freight train car-miles	$29,900 \times 10^6$
Net ton miles/train mile (Jan.-June)	1,820
Employees killed ^a	167
Employees injured ^a	15,631
Average days lost due to a nonfatal injury to an employee	48.6
Other people killed ^a	1,678
Other people injured ^a	3,574

^aExcludes those deaths and injuries involving passenger trains only.

*[Accident Bulletin No. 139, Federal Railroad Administration; Statistical Abstract, 1971; Argonne National Laboratory, Argonne, IL, Publ. ANL-8093, Vol. 2 (1973).]

Table 160. Fatality, injury, and severity rates for freight trains.*

	Rate/train mile	Rate/car mile
Employee killed	3.9×10^{-7}	5.6×10^{-9}
Employee injured	3.7×10^{-5}	5.2×10^{-7}
Severity rate (employee) ^a	4.2×10^{-3}	6.0×10^{-5}
Other people killed	3.9×10^{-6}	5.6×10^{-8}
Other people injured	8.4×10^{-6}	1.2×10^{-7}
Severity rate (other people) ^a	2.5×10^{-2}	3.6×10^{-4}

^aSeverity rates are in man-d lost. Fatalities are charged at 6000 man-d lost/death. Employees' nonfatal injuries are charged at 50 man-d lost/incident and other peoples' nonfatal injuries are charged at 200 man-d lost/incident.

*[Accident Bulletin No. 139, Federal Railroad Administration; Statistical Abstract, 1971; Argonne National Laboratory, Argonne, IL, Publ. ANL-8093, Vol. 2 (1973).]

Table 161. Civil aviation accident deaths and death rates, 1933 to 1973.*

Year	Total deaths ^a	Passenger deaths in scheduled air transport				General aviation deaths	
		Domestic		International		Total deaths	Passenger rate ^b
		Number	Rate ^b	Number	Rate ^b		
1958	877	114	0.43	10	0.16	717	23
1959	1,163	209	0.69	59	0.80	823	26
1960	1,286	297	0.93	10	0.12	787	24
1961	1,072	124	0.38	0	0.00	761	22
1962	1,187	121	0.34	0	0.00	857	23
1963	1,157	48	0.12	73	0.59	893	23
1964	1,250	65	0.14	94	0.63	1,083	24
1965	1,279	205	0.38	21	0.12	1,029	21
1966	1,420	59	0.09	0	0.00	1,151	17
1967	1,511	226	0.29	0	0.00	1,333	18
1968	1,750	258	0.28	47	0.17	1,399	19
1969	1,570	132	0.13	0	0.00	1,495	16
1970	1,454	0	0.00	2	0.01	1,310	20 ^c
1971	1,608	174	0.16	0	0.00	1,405	21
1972	1,581	160	0.13	0	0.00	1,400	20
1973	1,627	128	0.10	69	0.19	1,340	20

Source: National Transportation Safety Board, Bureau of Aviation Safety; Federal Aviation Agency.

^aIncludes some deaths not shown separately -- crew members in scheduled operations and persons not in planes killed in airplane accidents. Excludes deaths in military plane accidents.

^bRates are the number of deaths per 100,000,000 passenger miles. General aviation rates (estimated by NSC) include deaths of general aviation passengers, pilots, and crew.

^cRates for this year and subsequent years not comparable with prior years.

*[Accident Facts, National Safety Council, 1974 Edition, p. 76.]

Deaths	55,800
Injuries (Disabling beyond the day of accident)	2,000,000
Motor-vehicle	1,306 billion
Death rate (per 100,000,000 miles of travel)	4.27
Registered vehicles in the U.S.	128,700,000
Licensed drivers in the U.S.	122,400,000
Costs	\$20.2 billion

	No. of accidents	Drivers (vehicles) involved
Accident totals		
Fatal	48,100	67,300
Nonfatal injury (Disabling)	1,300,000	2,200,000
Property damage (Including nondisabling injury accidents)	15,300,000	25,800,000
Total (rounded)	16,600,000	28,100,000

Fig. 137. Motor vehicle accidents, 1973. Between 1912 and 1973, motor vehicle deaths per 10,000 registered vehicles were reduced 85%, from 33 to about 5. (Mileage data were not available in 1912.) In 1912, there were 3100 fatalities when the number of registered vehicles totaled only 950,000. In 1973, there were 55,800 fatalities, but registrations soared to nearly 129 million. [Accident Facts, National Safety Council, 1974 Edition, p.40.]

OIL AND GAS OCCUPATIONAL ACCIDENTS

Injury data for production activities (exploration, drilling, and production proper) are not compiled separately for oil and natural gas, because to a large extent these fuels are joint products. As a method of separating natural gas injury costs from crude oil costs, we have chosen to prorate total injuries on the basis of the dollar value of production. On this basis, roughly three-fourths of the total production injuries are attributed to crude oil production. (Tables 162-164.)

Table 162. Occupational injury rates in the oil and natural gas industries.*

	Oil (per kwh)			Gas (per kwh)		
	Production	Transportation	Refining	Production	Transportation	Processing
Number of injuries	1.1×10^{-9}	0.17×10^{-9}	0.45×10^{-9}	0.38×10^{-9}	0.20×10^{-9}	0.085×10^{-9}
Number of fatal injuries	9.4×10^{-12}	4.6×10^{-12}	6.4×10^{-12}	3.2×10^{-12}	3.7×10^{-12}	0.92×10^{-12}
Man-d lost (nonfatal injuries)	55×10^{-9}	6.4×10^{-9}	25×10^{-9}	19×10^{-9}	6.7×10^{-9}	8.5×10^{-9}
Man-d lost (fatal injuries)	57×10^{-9}	27×10^{-9}	39×10^{-9}	19×10^{-9}	21×10^{-9}	5.5×10^{-9}
	(per y)			(per y)		
Number of injuries	7.5	1.100	3.0	2.5	1.3	0.56
Number of fatal injuries	0.063	0.030	0.042	0.021	0.024	0.006
Man-d lost (nonfatal injuries)	360	42	162	123	44	56
Man-d lost (fatal injuries)	375	180	254	125	140	36

*[Argonne National Laboratory, Argonne, IL, Publ. ANL-8093, Vol. 2 (1973).]

Table 163. Annual social costs from a conventional oil-fired electricity system: 1000-MW power plant, 75% load factor.*

System Process	Environmental impact		
	Deaths/100 nonfatal injuries	Injuries/total man-h worked	Workdays Lost/injury
Exploration	NA	NA	NA
Extraction			
Onshore	0.21	21	2,135
Offshore	0.21	21	2,135
Processing			
Onshore	0.08	5.6	785
Offshore	0.08	5.6	735
Transport			
Onshore	0.05	4.5	562
Offshore	0.05	4.5	562
Import	0.05	4.5	562
Conversion			
Onshore	0.01	1.2	127.2
Offshore	0.01	1.2	127.2
Import	0.01	1.2	127.2
Transmission	NA	NA	NA
Total			
Onshore	0.35	32.3	3,609
Offshore	0.35	32.3	3,609
Import	0.06	5.7	689

*[Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973).]

Table 164. Annual social costs from a conventional gas-fired electricity system: 1000-MW power plant, 75% load factor.*

System Process	Environmental impact		
	Deaths/100 nonfatal injuries	Injuries/total man-h worked	Workdays Lost/injury
Exploration	NA	NA	NA
Extraction	0.16	16.0	1,629
Processing	0.01	0.95	92
Transport	0.02	1.2	145
Conversion	0.009	1.09	120.4
Transmission	NA	NA	NA
Total	0.20	18.3	1,986

* Council on Environmental Quality, Energy and the Environment - Electric Power, USGPO, Washington, DC (1973).]

NUCLEAR ACCIDENTS

Fission Power

Potential Reactor Accidents

There have been no major reactor accidents to date. In the past 30 y, the entire industry has had only 7 accidental deaths. There have been serious reactor system malfunctions to confound the calculators of probabilities.

No cancers have been observed among plutonium-exposed workers in the U.S. and U.K. after 30 y of observation in the U.S. and 22 y in Britain.

Nonnuclear accidents, including fires, explosions, toxic chemical releases, dam failures, airplane crashes, earthquakes, hurricanes, and tornadoes, are much more likely to occur and can have consequences comparable to or larger than nuclear accidents. Nonnuclear accidents to which society is already exposed are about 10,000 times more likely to produce large numbers of injuries to people than accidents in nuclear plants.

Nuclear plants are about 100 to 1000 times less likely to cause costly large dollar-value accidents than other sources.

Figures 138 and 139 show the frequency of fatalities due to man-caused and natural events. As shown in these figures, 100 nuclear power plants would cause this consequence with a likelihood of 1 in 10,000/y. Chlorine releases are about 100 times more likely, or about 1 in 100; fires are about 1000 times more likely, or about 1 in 10; air crashes are about 5000 times more likely, or about 1/2 y. (Table 165.) Frequency of property damages due to natural and man-caused events is shown in Fig. 140.

Potential Public Health Risks

Routine operation of a nuclear plant presents a significantly smaller public health risk than the routine operation of an oil-fired plant, typically by a factor of 10 to 100. The public health risk due to accidental releases from either a nuclear or oil-fired plant are both of the same magnitude, and about 100,000 times smaller than the risk from routine operation of the plants.

The maximum hypothetical accidents associated with either plant type are not likely to be sufficiently large to have a significant public health impact when compared to the normal incidence of disease. (Table 166.)

Fusion Power

Potential Hazards

If we were to imagine the maximum possible conventional accident that a CTR plant could sustain, we might envision a rupture of the entire CTR confinement vessel that results in all of the lithium flowing out into the reactor building. Coupled with this release of lithium might be the rupture of cooling water pipes or addition of air and water into the building by means of a severe storm. If all the lithium were to burn up in a 1000-MW(e) plant (about 1000 metric tons of lithium) the energy released would be equivalent to that released by burning about 1×10^6 gal of fuel oil. This amount of energy would not be released instantaneously, and it would take perhaps hours or days for all the lithium to burn up. If it took a day, this would be the equivalent of the amount of thermal energy released inside the boilers of a 1000-MW(e) oil-fired plant in the same time period. Certainly, severe damage might be incurred inside the plant, but there is little potential for damage to the surrounding populace.

Another accident that might be envisaged is the release of the energy in the superconducting magnets operating at about 100 kG. The complete failure (transition from superconducting state to normal resistive state) of the magnets could release energy equivalent to that in about 1500 gal of fuel oil. Again, such an accident would be hard on the reactor and surrounding building, but would not pose any severe problem for the public.

Finally, if all the fuel in a 1000-MW(e) fusion reactor were to burn up instantaneously the energy equivalent of about 4000 gal of fuel oil would be released.

In the case of fusion-power technology the total fusion fuel cycle can be handled at the plant site. Thus, there will be very little movement of fuel in the transportation system and consequently almost no opportunity for hijacking the fuel. Further, it is highly doubtful that an amateur could make a weapon of deuterium, tritium, and lithium.

References - Nuclear Accidents

Meyers, D. S., Lawrence Livermore Laboratory, Rept. UCRL-76571 (1975).

Nucleonics Week 15, 8 (1974).

Table 165. Typical reactor problems in the past decade.^{a,*}

Fuel and cladding
Metallic fuel bowing -- irradiation creep (GCR's)
Magnox cladding cavitation (GCR's)
Vibration failures
Stress corrosion cracking -- stainless steel (BWR's)
Crud failures
Fuel melting (thermal and fast)
Heat exchangers, steam generators, condensers major factor in shutdowns
Vibration
Corrosion (stress corrosion, etc.)
Erosion
Turbines, generators, alternators
Blade damage and failure
Loss of oil
Steam leakage through casing
Shaft failure
Loss of lubrication
Control rod drives
Blade failures -- stress corrosion
Stuck rods
Electrical failures
On-line refueling equipment
Numerous failures due to design errors
Gas circulators and pumps
Fatigue failures of blades
Oil leakage at seals
Rotor damage
Loss of motor coolant and motor burn-up
Bearing failure
Valves
Leakage
Turbine valve malfunction
Miscellany
PCRV cable corrosion (G-2)
Excessive temperature in concrete PCRV (Chinon)
Thermal insulation detached (Peachbottom)
Thermal shield failure (Yankee, Selni, Sena, Big Rock)
Pipe failures and leakage (Connecticut Yankee, Dresden, Chinon Agesta, Gundremmingen, Dounreay Fast Reactor)
Vessel cladding cracks (JPDR)
Stress corrosion cracking of stainless steel near vessel (Elk River, LACBWR, Oyster Creek, Nine Mile Point, Tarapur)

^aCapacity factor (GCR, BWR, PWR, LMFBR) > 50%; total time - down time/
total time × 100 = capacity.

*[Parker, E. R., and U. C. Montedison, Eds., The Science of Materials Used in Advanced Technology (John Wiley and Sons, New York).]

Table 166. Magnitude of latent health effects expected in a 20-y period for an accident that produces 100 fatalities.*

Effect	Chance/plant/y		Normal Incidence rate ^a
	One in 17,000	One in 1,000,000	
Latent cancers	<1	450	64,000
Thyroid illness	4	12,000	20,000
Genetic effects	<1	450	100,000

^aThis is the normal incidence that would be expected for people in the vicinity of any one reactor.

*[Facts File: Nuclear Energy and the Environment, American Nuclear Society, Hinsdale, IL, 1973).]

Fig. 138. Frequency of fatalities due to man-caused events. [Atomic Energy Commission, Washington, DC (August 1974).]

Fig. 139. Frequency of fatalities due to natural events. [Atomic Energy Commission, Washington, DC (August 1974).]

Fig. 140. Frequency of property damages due to natural and man-caused events. [Atomic Energy Commission, Washington, DC (August 1974).]

NUCLEAR THEFT

Sources

The use of nuclear energy to generate electric power will result in very large flows of materials in various nuclear fuel cycles that can be used to make nuclear weapons. By 1980 as much as 26,000 kg of plutonium may be extracted annually in the U.S. nuclear power industry. By that time about 2000 kg of high-enriched uranium fuel will also be required every year.

Safeguards aside, possibilities vary significantly for theft of nuclear weapon materials from the fuel cycles related to each of the major types of power reactors in use or under intensive development:

1. In the light-water reactor (LWR) fuel cycle without plutonium recycle, plutonium produced in a power reactor, if reprocessed, might be stolen at the output end of a reprocessing plant, during transit from the reprocessing plant to any separate storage facility used, and from a long-term plutonium storage facility.
2. In the LWR fuel cycle with plutonium recycle, in addition to possibilities without recycle, plutonium might be stolen during transit from any separate long-term storage facility and from a fuel fabrication plant.
3. In the high-temperature gas-cooled reactor (HTGR) fuel cycle, high-enriched uranium might be stolen from the output end of an enrichment plant, during transit from an enrichment plant to a conversion plant (if at a different location), at a conversion plant, during transit from a conversion plant to a fuel fabrication plant, and during processing at a fuel fabrication plant until the material is diluted with large amounts of carbide.
4. In the liquid-metal fast-breeder reactor (LMFBR) fuel cycle, the possibilities for plutonium theft will parallel those in the LWR fuel cycle with plutonium recycle.

Trends

The effects of a nuclear weapon depend on the characteristics of the device and the target area. The effects of a crude, low-yield fission explosive can be sufficiently intense and widespread to kill tens of thousands of people and cause the loss of hundreds of millions of dollars in property damage. A plutonium dispersal device can cause radioactive contamination and a serious health hazard until costly and difficult clean-up operations are complete. (Figure 141.)

The question that arises and is difficult to answer, is how this risk differs from planting a conventional bomb; or hijacking a plane and driving it into an occupied school, hospital, stadium, or the capitol building; or putting dioxin in city water mains, a milk truck, or a baker's flour. Unfortunately risks can only be totally avoided by doing away with life.

There are four ranges of total weights that contain, if completely separated, one critical mass of uranium-235, plutonium, or uranium-233.

1. The first is from approximately 5 kg up to about 65 kg. This range corresponds to all of the indicated outputs of reprocessing plants; all stages of fuel fabrication for LMFBR; the HTGR fuel cycle stages from the output of an isotope enrichment plant through the point at which the fuel particles are coated; and plutonium nitrate or plutonium oxide used in the early stages of LWR fuel fabrication with recycled plutonium.

2. The second range of weights is from about 500 to 1000 kg. This corresponds to low-enriched uranium in various forms; HTGR fuel in the middle of the fabrication process; and complete LWR fuel assemblies with or without recycled plutonium. Of course, low-enriched uranium would require further enrichment prior to use in a fission bomb.

3. The third range is 3000 to 4000 kg, corresponding to relatively pure uranium oxide (yellowcake) or uranium hexafluoride (UF_6) before enrichment, and to complete HTGR fuel assemblies.

4. The fourth range includes weights above 100,000 kg, corresponding to raw uranium ore. (Table 167.)

Delayed radiation from the fallout of a nuclear explosion could deliver lethal doses to people who remain in the open where radioactive debris has settled long enough for them to receive a total dose of roughly 500 rem. (Table 168.)

Table 169 lists fuel-cycle materials rank ordered by increasing weights required to yield one critical mass of fission explosive material, in metallic form, without uranium enrichment. The first six items on the list could be stolen by one person by hand if the containers weighed less than a few dozen pounds. This would be the case for plutonium or uranium oxide before it is packaged for shipment, or for plutonium nitrate bottles before they are inserted into the double 55-gal drums. The last three items would

require at least several people or some kind of mechanical lifting equipment, such as cranes or fork-lift trucks, to move them to a getaway vehicle.

Costs of Safeguards

To place the cost of safeguards in perspective, the cumulative capital investment in nuclear power by 1980 is projected to be more than \$75 billion, and the cost of the electricity generated with nuclear fuel will be more than \$8 billion/y. Therefore, even if the costs of safeguards were as high as \$800 million/y in 1980, this would hardly be sufficient, by itself, to affect substantially the overall economics of nuclear power.

However, calculations indicate that the total personnel costs of a highly effective national nuclear security force might be about \$79 million in 1980. This would be less than 1% of the total projected cost of nuclear electric power at that time. Thus, it seems reasonable to conclude that a nuclear safeguards system employing the best available technology and institutional mechanisms will cost no more than a very small fraction of the total costs of nuclear electric power. Certainly, the costs of effective safeguards would not be so large as to make nuclear power economically uncompetitive in the future.

Table 167. Total masses of material that contain one fast critical mass of material, if separated from other materials and converted to metal (total mass in kg).*

Nuclear fuel-cycle step	LWR	HTGR	LMFBR
1. Uranium mining (0.2% U)	140,000	140,000	140,000
2. Uranium milling (U_3O_8)	3,300	3,300	3,300
3. UF_6 production	4,200	4,200	4,200
4. Enrichment (UF_6)	750	22.6	-
5. Conversion to uranium oxide (UO_2)	570	17	-
6. Fuel fabrication	570(UO_2) 0.26($PuNO_3$ solution) 15.7(PuO_2)	17(UO_2 or UC_2) ~550 (fuel rod material)	5.7(PuO_2) 26($PuNO_3$) 18-60 (mixed Pu-U oxide)
7. Reactor and fuel fabrication	~600 (fuel assemblies w/o PuO_2) ~900 (for Pu in fuel assemblies)	~4,000 (fuel assemblies)	~20-65 (finished fuel assemblies)
8. Fuel reprocessing	26($PuNO_3$ solution)	~20($U^{235}O_2$) ~6($U^{233}O_2$)	26($PuNO_3$ solution)

*[From Nuclear Theft: Risks and Safeguards, © 1974, The Ford Foundation. Reprinted with permission from Ballinger Publishing Company.]

Table 168. Damage radii for various effects of nuclear explosions as functions of yield.*

Yield (high explosive equivalent)	Radius for indicated effect (m)						
	500-rem prompt gamma radiation	500-rem neutrons	Fallout 500 rem total dose) ^a	Severe blast damage (10 psi)	Moderate blast damage (3 psi)	Crater radius (surface burst)	Crater radius (underground burst)
1 ton	45	120	30-100	33	65	3.4	6.7
10 tons	100	230	100-300	71	140	6.8	13.3
100 tons	300	450	300-1,000	150	300	13.6	26.5
1 kton	630	730	1,000-3,000	330	650	27	53
10 kton	1,150	1,050	3,000-10,000	710	1,400	54	104
100 kton	1,600	1,450	10,000-30,000	1,500	3,000	108	208
1 Mton	2,400	2,000	30,000-100,000	3,250	6,500	216	416

^a Assuming 1-h exposure to fallout region, for yields less than 1 kton, increasing to 12 h for 1 Mton.

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Table 169. Fuel-cycle materials rank ordered by increasing weights required to yield one critical mass of fission explosive material, in metallic form, without uranium enrichment.*

Reactor and fuel-cycle step	Material	Total mass Required (kg)
LWR (Pu recycle) and LMFBR fuel fabrication input or fuel reprocessing output	PuO_2	5.7
HTGR fuel reprocessing output ^a or storage	$\text{U}^{233}\text{F}_6(\text{U}^{233}\text{O}_2)$	8.6(6)
HTGR fuel fabrication input or uranium oxide conversion output	U(H)O_2 or U(H)C_2	17
LWR (Pu recycle) and LMFBR fuel fabrication input or LWR (with or without Pu recycle) and LMFBR fuel reprocessing output or storage	Pu nitrate solution U(H)F_6	21 22.6
LMFBR fuel fabrication -- mixed oxide pellets or output, or reactor input	$\text{PuO}_2 + \text{U(D)O}_2$	18-65
HTGR fuel fabrication -- sticks of coated fuel particles	$\text{U(H)C}_2 + \text{C} + \text{SiC}$	550
LWR (Pu recycle) fuel fabrication output and reactor input	$\text{PuO}_2 + \text{U(L)O}_2$	900
HTGR fuel fabrication output and reactor input	Coated fuel and fertile particles + graphite blocks	4,000

^aOutput may be U^{233}O_2 .

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Fig. 141. Vulnerable points of the nuclear fission fuel cycle. Stages of nuclear fuel cycle where routine radiation releases occur and where nonroutine releases or incidents could occur. Arrows indicate transportation links. U-uranium, UO_2 -uranium dioxide, U_3O_8 -uranium oxide, Pu-plutonium. [Holdren, J. P., *Bull Atomic Sci.* 30, [8] 14 (1974), copyright, 1974 by the Educational Foundation for Nuclear Science, reprinted by permission.]

INFLATION AND BALANCE OF PAYMENTS DEFICITS

One important environmental consequence of increasing the fraction of fuel and nonfuel mineral resources to get more fossil and nonfuel resources is the effect on worldwide inflation. Everything which uses resources will cost more and more as net resources decline. If the money circulating is the same or increasing, and if the quality of the resource reaching society for its general work is less because so much of the resource has to go immediately into the resource-getting process, then the real work to society per unit money circulated is less. Money buys less real work of other types and money is worth less. Because the economy and total resource utilization is still expanding, we are misled to think the total value is expanding and we allow more money to circulate which makes the money-to-work ratio even larger. Eventually, resources become so capital intensive that they are unavailable for use and the demand for them runs out. (Figures 142 and 143.)

Another environmental effect arising as a result of dependence on foreign sources for raw materials lies in the balance of payments problem created by the purchase of the ore. The effect of importing elements (beryllium, manganese, chromium, nickel, tin, titanium, niobium, and vanadium) at constant (1970) prices to provide 1063×10^3 MW(e) of CTR capacity is approximately \$36,000 million. (Table 170.)

Other elements such as aluminum, copper, fluorine, iron, and lead may also have to be imported after the year 2000 because of price considerations, even though the U.S. may have sufficient reserves to cover the demand in the event of a national emergency. If these elements are imported, the total costs are almost \$50,000 million. Certainly, some of these problems would also be encountered by building other electrical generating stations, especially with chromium, manganese, nickel, aluminum, copper, and iron, but the costs for imported elements in the fossil systems would be lower by perhaps a factor of 3 or more.

Such large balance of payments charges will require serious study for other reasons, such as international politics and national security. The switch to an energy source that requires large amounts of rare materials may be, at least from the U.S. standpoint, somewhat unattractive.

If free trade is maintained and there are no new reserve discoveries or changes in technology, the price in constant dollars of copper, lead,

tin, tungsten, and zinc will be forced upward by reserve shortages. The price in constant dollars of aluminum, chromium, cobalt, manganese, molybdenum, nickel, platinum-group metals, and vanadium will not be forced upward by reserve shortages, but will contribute to the balance of payment deficit and to dependence on foreign source of supply.

Table 170. Financial requirements of importing metals to supply projected CTR capacity in the period 2000-2020.*

Element	Required from foreign sources (10 ⁶ metric ton)	1970 cost (dollars/metric ton)	Total cost (10 ⁹ dollars)
Beryllium	0.1	132,000	13.2
Chromium	2	3,000	6
Manganese	0.2	1,320	1.3
Niobium	0.8	3,630	2.9
Nickel	1.5	2,816	4.2
Tin	0.2	3,828	0.77
Titanium	0.9	2,904	2.6
Vanadium	0.5	9,614	4.7
Aluminum	0.6	638	0.38
Copper	2	3,630	7.3
Fluorine	1	113	0.11
Iron	13	136	1.8
Lead	12	352	4.3

*[Kulcinski, G. L., Energy Policy 2, 104 (1974).]

Fig. 142. Resources. The dollar is buying fewer goods and services because it is paying for more environmental control equipment, tankers, oil rigs, engineers, and pipelines to get the resources to make the goods and services. [Schatz, J., *Energy: World Future Society*, Washington, DC (April 1974), reprinted by permission of *The Futurist*, published by The World Future Society.]

Fig. 143. Declining net resources may be one of the principal forces driving world inflation. [Schatz, J., Energy: World Future Society, Washington, DC (April 1974), reprinted by permission of The Futurist, published by the World Future Society.]

MANPOWER AVAILABILITY

There is a current shortage of experienced design personnel in the construction industries and a shortage of certain kinds of skilled craftsmen, such as welders and pipefitters. Without a detailed analysis of the construction requirements of all other segments of the economy, it is not possible to single out the energy industries as having unique labor problems.

CAPITAL AVAILABILITY

Capital investment in energy industries is growing at greatest rate. Energy production probably will be limited by capital investment.

Capital requirements are very high: \$304 billion over next 14 y. The oil and gas industry requires \$59 of capital for each \$100 of sales. General industry requires \$36 of capital for each \$100 of sales. Capital availability is probably the most important constraint on energy availability. (Tables 171 and 172 and Fig. 144.)

Table 171. Estimated capital requirements for the energy industry.*

Estimated requirements (10 ⁹ dollars)				
	1970	1985	Cumulative 1971-1985	%
<u>Oil</u>				
Exploration, development, and production	2.8	5.4	64.7	107.0 35
Transportation	?	?	~43.0	
<u>Gas</u>				
Exploration, development, and production	2.0	1.0	27.7	48.7 16
Pipelines	0.4	.	9.4	
LNG, LPG	0.2	1.1	11.6	
<u>Coal</u>				
Mines	?	?	9.3	20.0 7
Rail transportation	?	?	~10.0	
<u>Uranium</u>				
Mining	?	?	2.1	3.6 1
Enrichment, plant improvement, and construction	-	-	1.5	
<u>Electricity</u>				
Generation	5.6	14.6	124.7 41	
Transportation	2.5	4.7		
Distribution and other	3.6	8.1		
<u>Hydroelectricity</u>	?	?	?	-
Total	17.1	36.8	304.0	100

* [U.S. Energy Outlook - An Initial Appraisal 1971-1985, Vol. I, National Petroleum Council, Washington, DC (1971).]

Table 172. Net benefit of breeder reactor to nation.*

				Net benefit 1975 present worth (10 ⁹ dollars)
<hr/>				
1. Base case				
Electrical growth rate	Years 1975-2000	6%	}	76
	Years 2001-2020	4%		
Inflation rate		6%		
Discount rate, without correction for inflation		6%		
Discount rate, with correction for inflation		12.36%		
Advanced converter as % of nonbreeder capacity		25%		
Uranium price -- base				
Coal price for new fossil capacity -- base				
Increases linearly (1975 dollars)	Year 1975	90c/MBtu's		
	Year 2020	\$1.35/MBtu's		
Capital cost of coal plant	(1975 dollars)	\$340/kWe	}	
Capital cost of LWR plant		\$385/kWe		
Capital cost of LMFBR plant		1.25 LWR		
Cost of uranium enrichment		\$70/SWU		
Breeder plant efficiency		38%		
Breeder introduction date		1989		
Additional cases using alternate assumptions for the parameters noted				
2. Capital cost of breeder		1.5 LWR		60
3. Capital cost of breeder		2.0 LWR		31
4. Electrical growth rate	Years 1975-2000	7%		122
	Years 2001-2020	4.5%		
5. Electrical growth rate	Years 1975-2000	5%		48
	Years 2001-2020	3.5%		
6. Uranium resources -- twice as plentiful as presently appears probable				44
7. Coal price for new fossil capacity -- pessimistic, increases linearly (1975 dollars)	Year 1975	\$1.10/MBtu's		86
	Year 2020	\$1.60/MBtu's		
8. Breeder introduction		1984		87
9. Breeder introduction		1999		43
10. Breeder introduction		2009		19
11. Advanced converter as % of nonbreeder capacity		10%		94
12. Advanced converter as % of nonbreeder capacity		40%		59
13. Cost of uranium enrichment -- 1/2 base case		\$35/SWU		76
14. LMFBR fabrication and reprocessing costs, twice probable				60
15. LMFBR breeding ratio		1.30		89
16. LMFBR breeding ratio		1.20		65
17. LMFBR specific power		700 Wt/kg Pu fissile		41
18. LMFBR specific power		1100 Wt/kg Pu fissile		100

*[Stauffer, T. R., data presented in a paper to the Breeder Reactor Corporation, March 7, 1975.]

Fig. 144. Projected capital investment in the U.S. [Energy Policy Issues for the United States during the Seventies (Arthur D. Little, Inc., Cambridge, MA, 1971).].

INDUSTRIALIZATION

Food energy consumption per capita in the U.S. has grown because people eat better and we feed domesticated animals. Home and commerce energy consumption has grown because people have warmer homes in winter and air conditioning in summer. Agricultural energy consumption has grown first because people used animals and then because of mechanization. Industrial energy consumption has grown primarily because energy is used as process heat in chemical, steel, cement, and petroleum manufacture. Transportation energy consumption has grown because of mechanization.

As the technology has developed, the U.S. has added new forms of energy. Each new form of energy is "cleaner" than the previous one. Fossil fuels - coal, oil, and gas - supply the energy people use today.

Gross national product (GNP) and energy consumption growth rates "track," which implies close interdependence. (Real GNP is measured in 1958 dollars.)

Disposable income growth rate also "tracks," implying that the availability of more dollars for goods and services requires, in turn, more energy for production. (Disposable income is defined as what people actually have left for saving or spending on consumables after all taxes, corporate savings of undistributed profits, transfer adjustments, and adjustments for consumer interest.) (Figures 145-147.)

References - Industrialization

Samuelson, P. A., Economics, 7th edition (McCraw-Hill Book Co., New York, 1967).

Fig. 145. Energy consumption per capita. [Compiled from data in Cook E., Sci. Amer. 225, 134 (September, 1971).]

Fig. 146. Growth of U.S. energy consumption. [Compiled from data in Starr, C., Sci. Amer. 225, 37 (September, 1971).]

Fig. 147. Energy consumption vs growth patterns in the U.S. [U.S. Statistical Abstracts, 1971 (92nd edition), Department of Commerce, Washington.]

BASIC HUMAN NEEDS

Energy production and use impacts in a positive way basic human needs such as, shelter, recreation, food, communications, physical protection, apparel and grooming, curiosity and knowledge, spiritual, life cycle, national defense, and the defense of the free world.

There will be minimum useful technology transfer to benefit developing countries to the extent that rich countries focus their own research and development on technologies that are heavily capital intensive, technologically sophisticated, unforgiving of errors in operation and maintenance, and attractive economically only in large units. However, if the rich countries devote some effort to development of durable labor intensive energy technologies that make sense in small packages, a social benefit of a tangible contribution could occur toward narrowing the demoralizing and destabilizing rich-poor gap that divides the world today.

References - Basic Human Needs

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