a. Characterization of Emission Sources

Table 16-16 and Figure 16-6 present the emission source characteristics of a 16,000-m^3/day (100,000-B/D) coal liquefaction plant employing the H-Coal process. The emission rates are taken from the process and control descriptions of Section B of this chapter. These rates are for a highly controlled plant, one employing the best available control technology (Section B). Stack characteristics (Table 16-16) were estimated on the basis of reasonable combustion conditions and other process requirements, as well as by analogy to the Colony plans for an oil shale plant. The stack configuration shown in Figure 16-6 was chosen to occupy an area of about 1 million m^2 (250 acres)* and to reflect likely capacities of various process units and their associated stacks. Radical changes in the assumed configuration could result in concentrations somewhat different from those calculated here.

b. Characterization of Powder River Coal Region

(1) Topography.† The strippable coal reserves of the Powder River Basin are concentrated along a north-south line through Gillette, Wyoming. The eastern Powder River Coal Basin lies within the Missouri Plateau in the drainage basin of the Missouri River. The landscape consists primarily of plains and tablelands and low-lying hills. Some areas feature entrenched river valleys, isolated uplands, flat-topped buttes and mesas, long narrow divides, and ridges 30 to 150 m (100 to 500 ft) high.

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*This area for the conversion process units is consistent with the land requirement scaling factor given in Chapter 4 and with a published design for an SRC coal liquefaction facility.[17]

†The information contained in this section was extracted from Reference 18.

Table 16-16

STACK PARAMETERS AND EMISSION RATES FOR A 16,000-m^3/day
(100,000-B/D) H-COAL PLANT USING POWDER RIVER COAL

Stack No.*	Description of Unit	Flow Rate† (all stacks) (m^3/s)	Temp. (°C)	No. of Stacks	Stack Height (m)	Stack Diameter (m)	Gas Exit Velocity (m/s)	Emissions (all stacks) (g/s)			
								Particulates	SO_2	NO_x	HC
1	Coal dryer--process	1200	63	10	30	4.	9.6	44	--	--	--
2	Coal dryer--combustion	277	55	2	75	3.	19.6	6.6	27.1	257	4.3
3	Steam reformer	603	260	5	30	3.	17.1	5.8	0.19	74	1.0
4	Plant (gas fuel)	135	260	1	30	3.	19.1	1.3	0.04	17	0.2
5	Plant (coal fuel)	489	55	4	75	3.	17.3	11.7	47.9	454	7.6
6	Sulfur plant	27	38	1	75	1.3	20.3	--	16.	--	--

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*Stack locations are shown in Figure 16-6.

†At pressure of 87.4 kPa (25.8 inches of mercury) corresponding to an elevation of 1230 m (4000 ft).

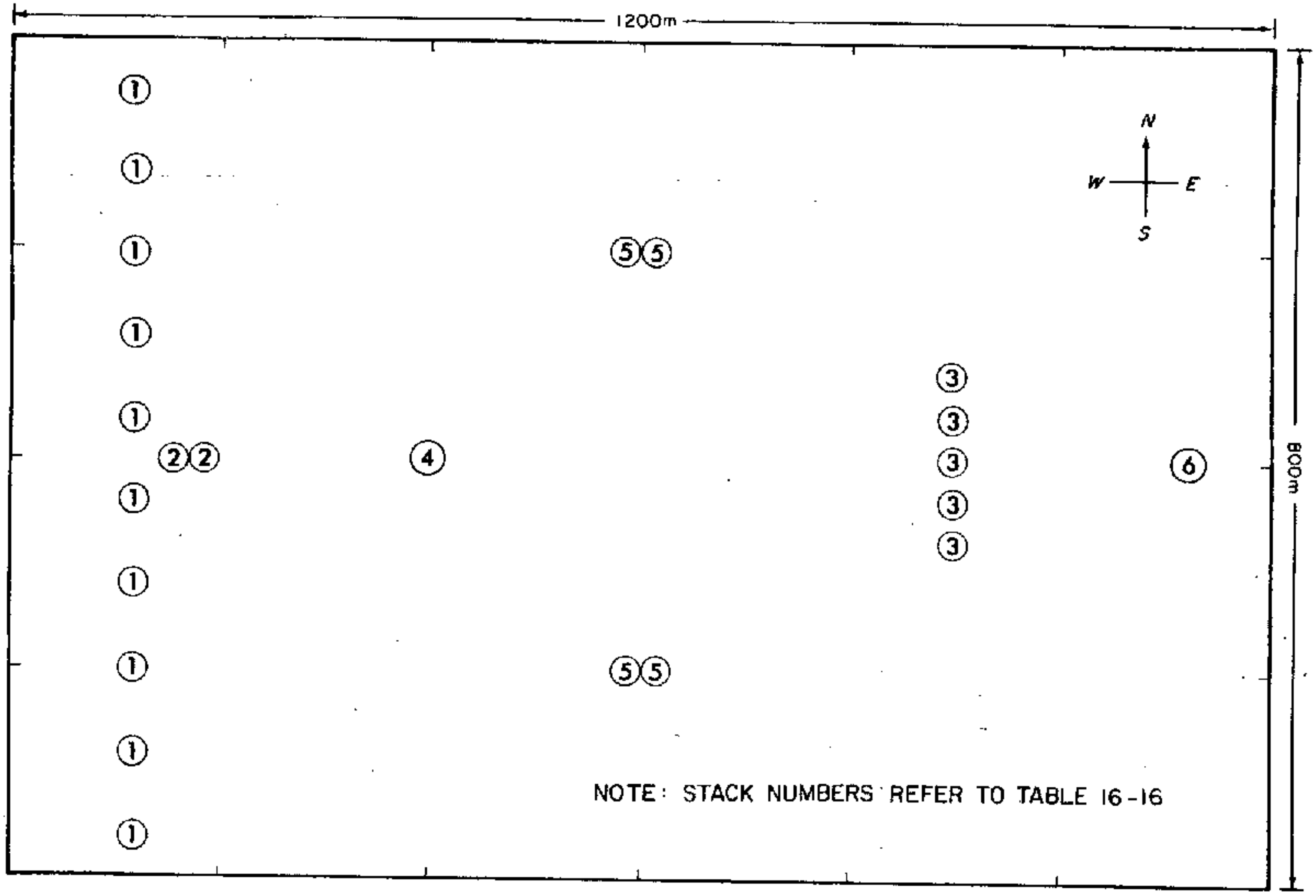

FIGURE 16-6. STACK CONFIGURATION FOR COAL LIQUEFACTION PLANT

The coal basin is part of a topographic depression that lies between the Black Hills and the Bighorn Mountains. The central part of the basin consists of a broad plateau, with the strippable coal near the eastern edge of the rolling, grass-covered upland. Irregular, rough, broken terrain borders the shallow coal deposits. To the east, erosion has reduced the terrain to knobs and ridges.

In the northern part of the topographic basin, there are high open hills north of Gillette and tablelands south of Gillette. The open hills have a local relief of 120 to 240 m (400 to 800 ft) and the gently sloping plains and tablelands have local relief of 60 to 120 m (200 to 400 ft). The southern part of the basin is characterized by rolling grass-covered prairie cut by broad steam valleys.

(2) Meteorology. Sufficient meteorological data for application of the CDM are not available for potential coal liquefaction plant sites within the boundaries of the coal reserve region. However, a complete weather station is located at Moorcroft, Wyoming, about 25 km (15 miles) east of Gillette, and from frequency distributions of meteorological conditions observed there the CDM was used to calculate annual averages. Considering the topography of the region and the proximity of Moorcroft to possible plant sites, the meteorology of Moorcroft is a good approximation of the meteorology of future coal plant sites. The same type of argument that applied to Grand Junction for the oil shale region applies here, but with the advantage that the topography of the Wyoming coal reserves is far less rugged and varied than that found in the oil shale bearing portions of Colorado.

SRI has recently developed a computer program (WRSCASE) to determine the days on which worst-case pollutant concentrations occur. The program takes as input the stack characteristics and emission rates of a simplified version of a plant and hourly meteorological data for a period considered statistically representative (e.g., 3 years). It then calculates the hourly pollutant concentrations at several locations, computes 24-hour (or 3-hour) average concentrations at each location, and for each pollutant, selects the sequence of meteorological conditions that produces the greatest concentration 1 km or farther from the plant. This program was used with Moorcroft, Wyoming, meteorological data to determine the worst-case sequence for each pollutant over the appropriate averaging time (24 hours or 3 hours). Table 16-17 lists these worst-case meteorological sequences determined by the program and used in the 24-hour and 3-hour average coal liquefaction plant calculations. When the wind is calm, the wind direction of the previous hour and a wind speed of 1 m/s are used in model calculations since the Gaussian plume formulation does not allow for calm winds.

c. Results of Dispersion Modeling

Dispersion of pollutants from a syncrude plant was calculated using the stack characteristics and emission rates listed in Table 16-16 and the plant configuration illustrated in Figure 16-6. Figures 16-7 and 16-8 show isopleths of concentrations for various pollutants and averaging times. Tables 16-18 and 16-19 summarize dispersion model results for a single coal liquefaction plant. Measured values of background concentrations of particulates in the coal region range from 13 to 21 $\mu g/m^3$ (see Reference 16-18). Background levels of SO_2, NO_x, and HC have not been measured in the basin. However, 24-hour maximum and annual average values of SO_2 background concentrations have been measured in nearby Casper,[19] and these values are included for reference in Tables 16-18 and 16-19. Since it can be expected that background levels in the basin will be less than those measured in the Casper urban area, it seems safe to assume that no additional controls will be required for SO_2 due to background levels. The method of calculating the

Table 16-17

WORST-CASE METEOROLOGICAL SEQUENCES FOR MOORCROFT, WYOMING

	SO_2 (24-hr sequence)			Particulates and NO_x (24-hr sequence)			HC (3-hr sequence)		
Hour	Wind Direction*	Wind Speed (m/s)	Atmospheric Stability†	Wind Direction*	Wind Speed (m/s)	Atmospheric Stability†	Wind Direction*	Wind Speed (m/s)	Atmospheric Stability
0100	10	11.8	4	8	10.8	4			
0200	10	8.2	4	8	13.4	4			
0300	10	3.6	5	8	11.8	4			
0400	6	2.1	6	8	15.9	4			
0500	10	1.5	6	8	14.4	4			
0600	10	6.2	4	8	15.9	4			
0700	10	6.7	4	8	18.0	4	11	1.0	6
0800	10	10.8	4	8	13.4	4	11	1.0	3
0900	10	12.3	4	8	9.8	4	calm	calm	3
1000	10	11.8	4	8	18.0	4			
1100	10	9.8	4	8	21.6	4			
1200	10	10.8	4	8	18.5	4			
1300	10	12.3	4	8	20.0	4			
1400	10	10.3	4	8	18.5	4			
1500	10	7.2	4	8	20.0	4			
1600	10	8.2	4	8	17.5	4			
1700	10	8.7	4	7	16.4	4			
1800	10	11.8	4	8	17.5	4			
1900	10	8.7	4	8	15.4	4			
2000	10	12.3	4	8	14.9	4			
2100	10	8.7	4	8	9.3	4			
2200	10	14.4	4	8	7.7	4			
2300	10	13.4	4	8	7.7	4			
2400	12	9.3	4	9	5.1	5			

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*Wind direction sector. The compass is divided into sixteen 22.5° sectors; sector 1 is from 348.75° to 11.24°; succeeding sectors are in a clockwise direction from sector 1.

†Pasquill-Gifford stability categories.

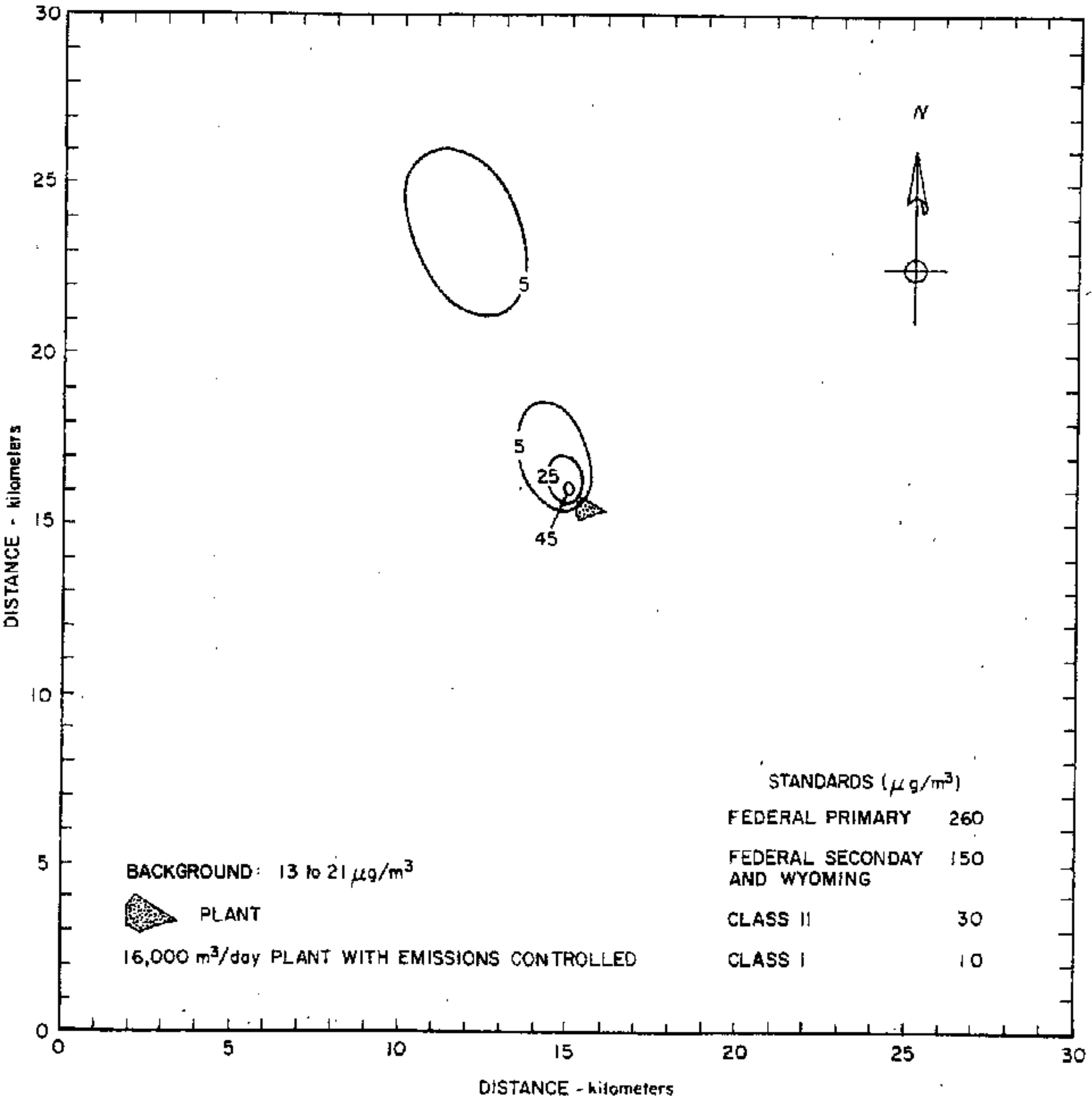

FIGURE 16-7. WORST CASE 24-HOUR AVERAGE PARTICULATE CONCENTRATIONS ($\mu g/m^3$) FOR A COAL LIQUEFACTION PLANT

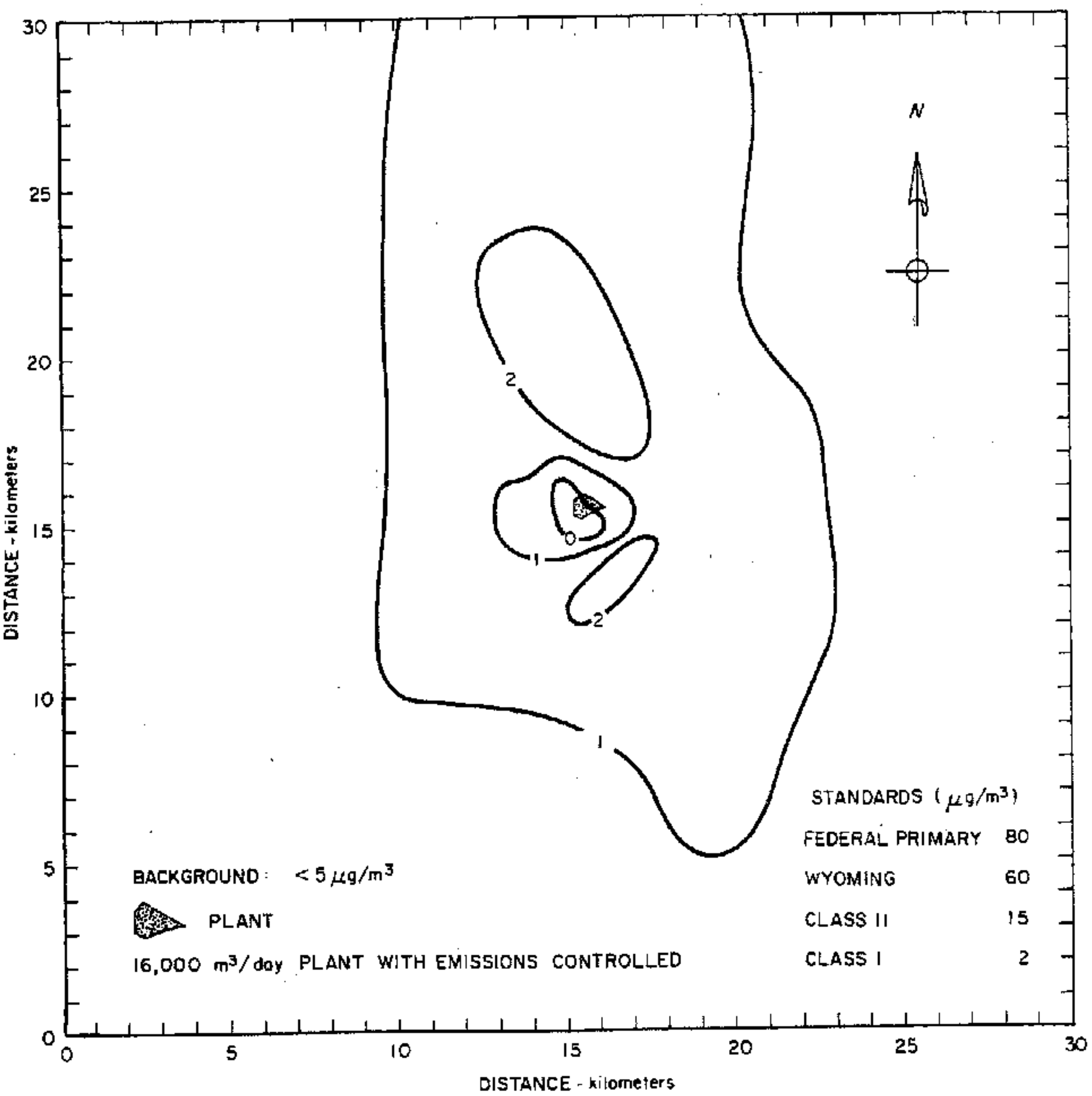

FIGURE 16-8. ANNUAL AVERAGE SO_2 CONCENTRATIONS ($\mu g/m^3$) FOR A COAL LIQUEFACTION PLANT

Table 16-18

CONTROL REQUIREMENTS BASED ON FEDERAL PRIMARY AND WYOMING AIR QUALITY STANDARDS AND EMISSIONS FROM A 16,000-m^3/DAY (100,000-B/D) COAL SYNCRUDE PLANT

Pollutant	Averaging Period	Maximum Calculated ($\mu g/m^3$)	Background ($\mu g/m^3$)	Standard ($\mu g/m^3$) Federal Primary	Standard ($\mu g/m^3$) Wyoming	Control Required* (%) Federal Primary	Control Required* (%) Wyoming
Particulates	1 yr	4	13 to 21†	75	60	None	None
	24 hr	25	13 to 21†	260	150*	None	None
SO_2	1 hr	2	5‡	80	60	None	None
	24 hr	7	16‡	365	260§	None	None
	3 hr	38	--	1300	1300§	None	None
NO_x	1 yr	15	--	160**	100**	None	None
HC	3 hr (6-9 a.m.)	4	--	100	160*	None	None

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*Control required in addition to the best available as specified in Section B of this chapter.

†Measured in the Powder River Basin (Reference 18).

‡Measured at Casper, Wyoming (Reference 19).

§Not to be exceeded more than once per year.

**NO_2 standard.

Table 16-19

CONTROL REQUIREMENTS BASED ON FEDERAL SECONDARY, CLASS I AND CLASS II AIR QUALITY STANDARDS AND EMISSIONS FROM A 16,000-m^3/DAY (100,000-B/D) COAL SYNCRUDE PLANT

				Standard ($\mu g/m^3$)			Control Required* (%)		
Pollutant	Averaging Period	Maximum Calculated ($\mu g/m^3$)	Background ($\mu g/m^3$)	Federal Class I	Federal Class II	Federal Secondary	Federal Class I	Federal Class II	Federal Secondary
Particulates	1 yr	4	13 to 21†	5	10	60	None	None	None
	24 hr	25	13 to 21†	10	30	150	60	None	None
SO_2	1 yr	2	< 5‡	2	15	--	None	None	--
	24 hr	7	< 16‡	5	100	--	29	None	--

---

*Control required in addition to the best available as specified in Section B of this chapter.

†Measured in the Powder River Basin (Reference 18).

‡Measured at Casper, Wyoming (Reference 19).

control requirements shown in Tables 16-18 and 16-19 is the same as that described for oil shale.

The dispersion calculations (Figures 16-7 and 16-8; Tables 16-18 and 16-19) indicate that no additional controls are required to meet any of the standards except the 24-hour Class I particulate and SO_2 standards. To meet the federal "nondegradation" standard for particulates, emissions must be controlled by an additional 60 percent, and to meet the "non-degradation" standard for SO_2, emissions must be controlled by an additional 29 percent.

4. Effects of Multiple Plants in a Region

a. Assumptions for Modeling

Lack of definite meteorological data and plant site information makes it necessary to base the modeling of air pollution from a complex of plants on a possible, but hypothetical, situation. In the modeling process, a simplified worst-case situation was devised. Four plants, identical to the single coal liquefaction plant first modeled, were sited 6 km apart on a north-south line. The 6-km separation is about the minimum separation possible for plants using a 20-year supply of coal from a 9 m (30 ft) seam of Powder River coal. Annual average pollutant concentrations from the plant complex were calculated using the Moorcroft annual frequency distribution. In the actual 24-hour average worst-case, the meteorological sequence was a wind from the south-southeast for 22 hours with one hour periods with the wind blowing from adjacent sectors.* For this calculation, the sequence was rotated clockwise by one sector so that for 22 hours the wind blew from the south. Such a sequence, although hypothetical, was judged to be possible and would represent the worst-case for the complex of plants

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*There are 16 wind direction sectors.

assumed. Thus, for the most part, the wind is assumed to be blowing along the string of plants, causing superposition of plumes. This synthesized sequence of meteorological conditions is likely to occur and represent a worst-case wind direction.

b. Results for Complex of Coal Syncrude Plants

Figures 16-9 and 16-10 show the complex of four plants and illustrate results of the dispersion modeling for the two cases that lead to maximum control requirements. Similar calculations for comparison with the complete set of ambient standards have been made. The results for all of the pollutants and averaging times are summarized in Tables 16-20 and 16-21. Background concentrations are treated as they were for oil shale (Tables 16-14 and 16-15).

As shown in Tables 16-20 and 16-21, no additional control is required to meet the federal primary or secondary standards nor the Wyoming standards for any of the pollutants modeled. However, Table 16-21 indicates some additional control requirements based on Class I and II standards. For particulates, 17 percent control is required to meet the annual Class I standard; 75 percent is required to meet the 24-hour Class I standards; and 25 percent is needed to satisfy the 24-hour Class II standard. The annual Class II standard for particulates can be met with no additional controls.

Again referring to Table 16-21, no additional controls are needed to comply with the Class II SO_2 standards. For the annual Class I standard for SO_2, an additional 67 percent control is needed, and for the 24-hour Class I SO_2 standard, an additional 77 percent control is needed.

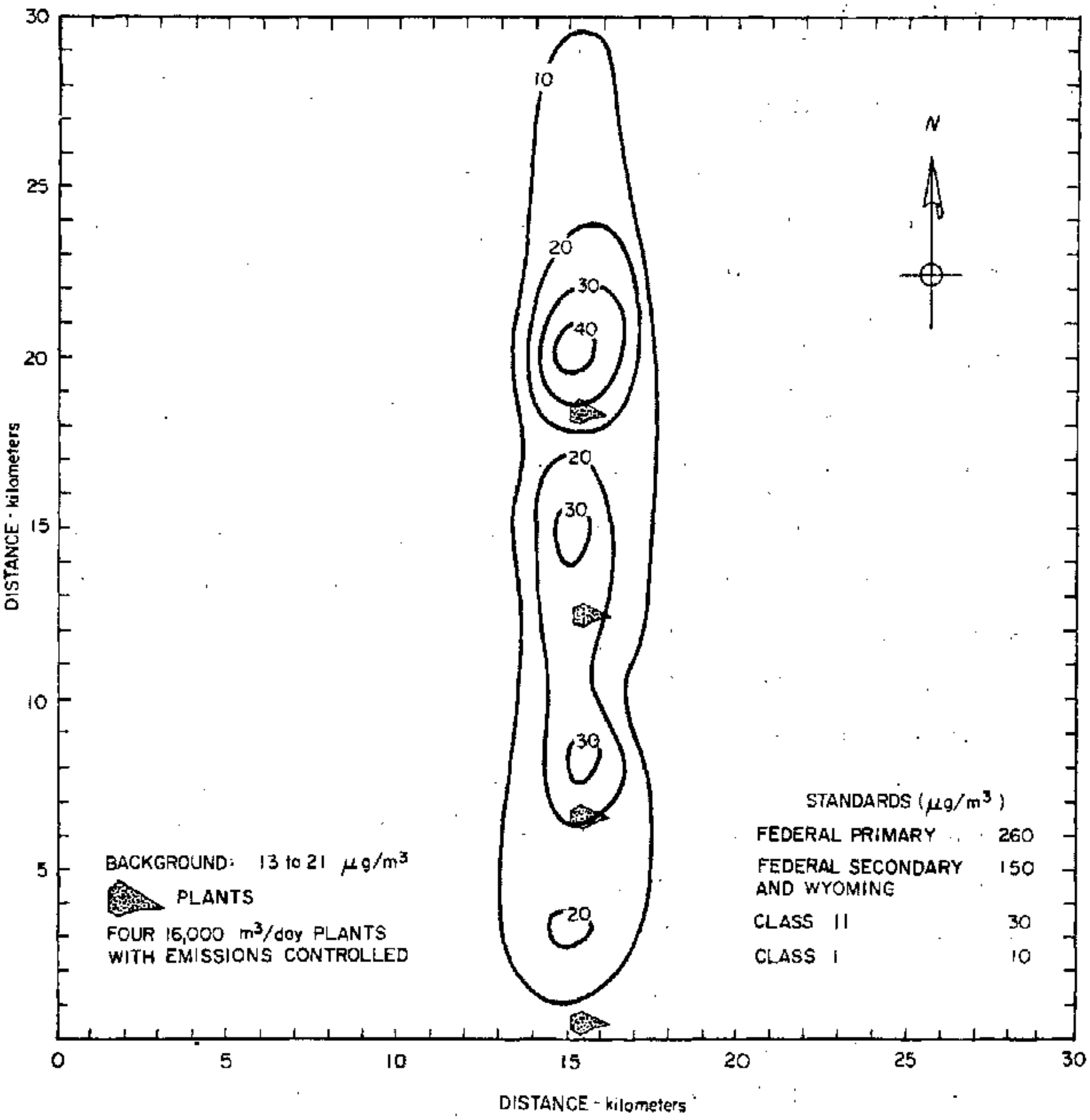

FIGURE 16-9. WORST CASE 24-HOUR AVERAGE PARTICULATE CONCENTRATIONS ($\mu g/m^3$) FOR A COMPLEX OF COAL LIQUEFACTION PLANTS

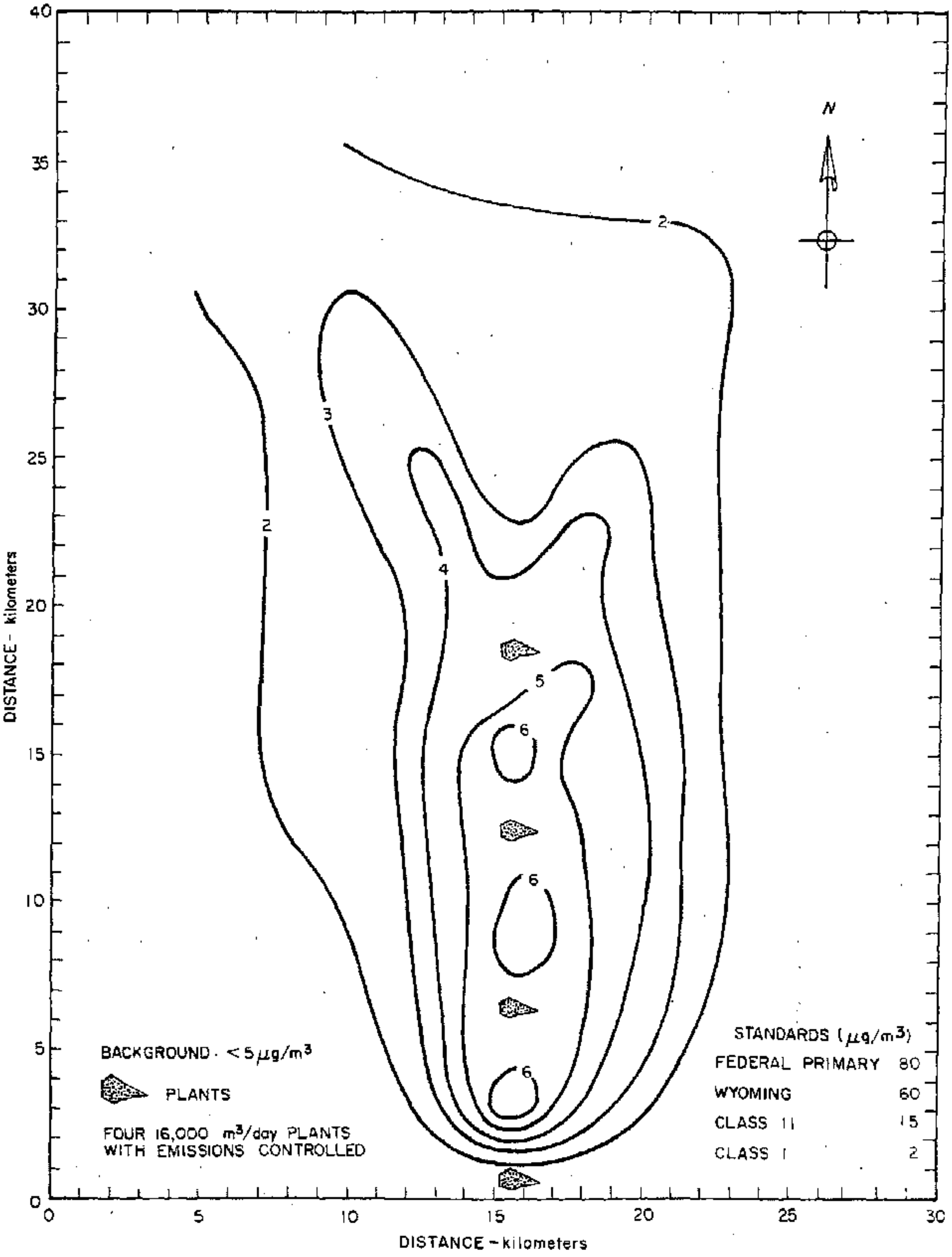

FIGURE 16-10. ANNUAL AVERAGE SO_2 CONCENTRATIONS (μg/m³) FOR A COMPLEX OF COAL LIQUEFACTION PLANTS

Table 16-20

CONTROL REQUIREMENTS BASED ON FEDERAL PRIMARY AND WYOMING AIR QUALITY STANDARDS AND EMISSIONS FROM A COMPLEX OF FOUR 16,000-m^3/DAY COAL SYNCRUDE PLANTS

Pollutant	Averaging Period	Maximum Calculated ($\mu g/m^3$)	Background ($\mu g/m^3$)	Standard ($\mu g/m^3$)		Control Required[*] (%)	
				Federal Primary	Wyoming	Federal Primary	Wyoming
Particulates	1 yr	6	13 to 21[†]	75	60	None	None
	24 hr	40	13 to 21[†]	260	150[*]	None	None
SO_2	1 yr	6	5[‡]	80	60	None	None
	24 hr	22	16[‡]	365	260[§]	None	None
	3 hr	38	--	1300	1300[§]	None	None
NO_x	1 yr	40	--	160[§]	100[**]	None	None
HC	3 hrs (6-9 a.m.)	4	--	100	160[*]	None	None

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[*] Control required in addition to the best available as specified in Section B of this chapter.

[†] Measured in the Powder River Basin (Reference 19).

[‡] Measured at Casper, Wyoming (Reference 19).

[§] Not to be exceeded more than once per year.

[**] NO_2 standard.

Table 16-21

CONTROL REQUIREMENTS BASED ON FEDERAL SECONDARY, CLASS I, AND CLASS II AIR QUALITY STANDARDS AND EMISSIONS FROM A COMPLEX OF FOUR 16,000-m^3/DAY COAL SYNCRUDE PLANTS

				Standard ($\mu g/m^3$)			Control Required* (%)		
Pollutant	Averaging Period	Maximum Calculated ($\mu g/m^3$)	Background ($\mu g/m^3$)	Federal Class I	Federal Class II	Federal Secondary	Federal Class I	Federal Class II	Federal Secondary
Particulates	1 yr	6	13 to 21†	5	10	60	17	None	None
	24 hr	40	13 to 21†	10	30	150	75	25	None
SO_2	1 yr	6	5‡	2	15	--	67	None	--
	24 hr	22	16‡	5	100	--	77	None	--

---

*Control required in addition to the best available as specified in Section B of this chapter.

†Measured in the Powder River Basin (Reference 18).

‡Measured at Casper, Wyoming (Reference 19).

5. Sensitivity Analysis

a. Variation of Stack Parameters

The Gaussian plume formulae used in the CDM assume that air pollutants originate from a point located along the vertical axis of the physical stack. The distance of the effective source point above ground level is called the effective stack height, H. The effective height is a sum of two terms, the physical stack height, h, plus the plume rise, Δh, i.e., $H = h + \Delta h$.

The plume rise is a function of stack characteristics, wind speed, and distance from the source. Physically, the plume rise is caused by both the upward velocity of the gas emerging from the stack and the buoyancy of the hot stack gas in the cooler ambient air. The buoyancy effect generally dominates. The combined effect is described by a buoyancy flux parameter, F, whose value can be calculated from the ambient air temperature and the stack parameters, namely, gas exit velocity, gas temperature, and stack diameter. The value of F is a measure of the flow (or flux) of heat energy from the stack, with the reference or zero level of heat energy being set by the ambient temperature in accordance with the formula[21]

$$F = gVR^2 \frac{(T-T_a)}{T}$$

where g is the acceleration of gravity, V is the gas exit velocity, R is the inner radius of the stack, and T and T_a are the absolute temperatures of the gas and the ambient air, respectively. The plume rise itself, Δh, is proportional to the one-third power of F and is inversely proportional to the wind speed. The proportionality constant is different for different distances from the source and ranges of F.

By using the derived parameter F as the indicator of plume rise it is possible to reduce the number of possible stack parameters that must be considered as individual cases in determining how changes in stack parameters can affect the control requirements presented here. Quantity F was calculated for all of the stacks used in modeling the oil shale and coal liquefaction plants, and six nonzero values of F were identified that could be taken to be typical of six groups encompassing the range of reasonable stack parameters. Table 16-22 lists the six F values chosen and indicates several sets of stack parameters that would lead to each of the F values.

Table 16-23 shows how different combinations of buoyancy flux, F, and physical stack height, h, yield different values of the calculated maximum concentration of air pollutants emitted by a single stack. The maximum concentration used to normalize the values shown in the fourth column of Table 16-23 is that of Case 1, i.e., at a distance of 1 km from a low (15.2 m or 50 ft) stack with no buoyancy flux. Higher concentrations less than 1 km from the source are not included for consideration in the table for the reasons given above in Section C-2, namely, the fact that unacceptably high concentrations close to a low stack will almost certainly be reduced by using higher stacks rather than by employing more stringent emission control systems.

Some meteorological assumptions are indicated explicitly in Tables 16-22 and 16-23. In both of these, an ambient temperature of 5°C (41°F) was used for the calculations. In Table 16-23 the meteorological assumptions are those appropriate for a worst-case situation, namely, neutral stability and a wind constant in direction and speed at 1.5 m/s.

If the ambient concentration of an air pollutant can be attributed entirely to a single stack within a plant, results like those

Table 16-22

STACK CHARACTERISTICS THAT RESULT IN VARIOUS BUOYANCY FLUX VALUES (F VALUES)

$\frac{m^4}{s^3}$ F*	Exit Velocity (m/s)	Gas Temperature (°C)	Stack Diameter (m)
0	Any velocity	Ambient	Any diameter
9	20.4	38	1.3
9	9.6	38	1.9
9	3.9	38	3.0
9	22.5	100	0.8
60	17.8	55	3.0
60	9.3	60	4.0
60	11.9	300	2.0
60	17.0	500	1.5
68	8.6	751	2.1
68	14.9	751	1.6
68	10.8	500	2.0
68	6.8	100	4.0
104	7.9	145	4.0
104	7.4	500	3.0
104	20.6	300	2.0
104	19.0	50	4.0
190	18.0	260	3.0
190	10.0	100	5.5
190	7.6	500	4.0
190	17.4	700	2.5
302	21.7	481	3.0
302	14.9	700	3.4
302	10.0	300	4.9
302	14.9	500	3.6

---

*For ambient temperature equal to 5°C.

Table 16-23

SINGLE STACK SENSITIVITY ANALYSIS RESULTS[*]

Case	F $\frac{m^4}{s^3}$	Stack Height (m)	Normalized Value	Distance from Source (km)
1	0	15.2	1.000	1[†]
2	0	30.5	0.786	1[†]
3	0	61.0	0.164	2
4	0	121.9	0.027	5
5	9	15.2	0.252	1[†]
6	9	30.5	0.118	2[†]
7	9	45.7	0.066	3
8	9	76.2	0.031	5
9	68	15.2	0.0042	15[†]
10	68	24.4	0.0042	15[†]
11	68	45.7	0.0042	15
12	68	76.2	0.0038	15
13	104	38.1	0.0025	20
14	104	45.7	0.0025	20
15	104	76.2	0.0021	20
16	104	121.9	0.0017	20
17	302	15.2	0.0001	--
18	302	30.5	0.0002	--
19	302	61.0	0.0002	--
20	302	121.9	0.0002	--

---

[*] A constant wind direction and neutral stability were used in this analysis. Results will vary for other stabilities and a nonconstant wind direction. Wind speed used here is 1.5 m/s.

[†] A value greater than that used as the maximum occurred < 1 km from source.

displayed in Tables 16-22 and 16-23 are adequate for assessing the impact of a change in stack parameters. For instance, a stack 76-m high by 1.3 m in diameter emitting a fixed rate of some pollutant with an exit velocity of 20.3 m/s and a temperature of 38°C has an F value of 9, as given in Table 16-22, and would be Case 8 of Table 16-23. Replacement of this by a Case 3 stack, one releasing the pollutant at the same rate but at a height of 61 m and at ambient temperature, would lead to a factor of 5.3 (i.e., 0.164/0.031) increase in the maximum concentration and would result in the new maximum occurring at a distance of 2 km from the stack instead of the previous 5 km.

To better understand the sensitivity of the dispersion pattern of an entire plant, in which emissions from a single stack do not dominate, a two-stack sensitivity analysis was performed, based on two sets of stack parameters that are fairly characteristic of the many stacks listed in Table 16-16 for a coal liquefaction plant. A listing of the buoyancy flux values and stack heights for the coal liquefaction plant reveals that a stack having an F value of 9 accounts for 18 percent of the SO_2 emissions and that stacks having F values near 60 account for the other 82 percent. We used the CDM to calculate dispersion patterns resulting from the combination of two stacks having these F values on an 82/18 ratio of emission rates. The calculations were made for a variety of assumed stack heights. Results are presented as the first nine cases shown in Table 16-24. Similar listing and grouping based on the emissions of the other pollutants from the coal liquefaction plant leads to a two-stack model that has 90 percent of the emissions from stacks having an F value of about 60 and 10 percent of the emissions from stacks having an F value near 190. Cases 9 through 18 in Table 16-24 show how the calculated maximum concentration changes with various combinations of physical stack heights for the two stacks.

Table 16-24

TWO-STACK SENSITIVITY ANALYSIS RESULTS*

Case	F_1 $\frac{m^4}{s^3}$	Stack Height$_1$ (m)	F_2 $\frac{m^4}{s^3}$	Stack Height$_2$ (m)	Maximum Concentration	
					Normalized Value	Distance from Source of Maximum Concentration (km)
1	9	15	60	30	1.0	1†
2	9	15	60	75	1.0	1†
3	9	15	60	122	1.0	1†
4	9	30	60	30	0.46	2†
5	9	30	60	75	0.46	2†
6	9	30	60	122	0.46	2†
7	9	75	60	30	0.15	5
8	9	75	60	75	0.14	5
9	9	75	60	122	0.12	5

Case	F_4 $\frac{m^4}{s^3}$	Stack Height$_1$ (m)	F_4 $\frac{m^4}{s^3}$	Stack Height$_2$ (m)	Normalized Value	Distance from Source of Maximum Concentration (km)
10	60	30	190	30	1.0	10
11	60	30	190	60	1.0	10
12	60	30	190	122	1.0	10
13	60	75	190	30	0.75	10
14	60	75	190	60	0.75	10
15	60	75	190	122	0.75	10
16	60	122	190	30	0.50	14
17	60	122	190	60	0.50	14
18	60	122	190	122	0.50	14

---

*A constant wind direction and neutral stability were assumed. Results will vary for other stabilities and a nonconstant wind direction.

†Wind speed was assumed to be 1.5 m/s.

b. Roles of Other Variables

Changes in the configuration of stacks located within a plant may or may not have a significant effect on pollutant concentrations. If new stack locations do not differ appreciably from previously assumed locations, that is, stack locations are shifted within the previously defined boundaries of the plant, changes in calculated concentrations will be minimal. However, if the location of a stack is changed to a position that is removed from the confines of the plant area (or vice versa), pollutant patterns may be significantly affected, and concentrations and resulting control requirements should be recalculated. Moreover, for a stack having a small effective stack height (the sum of plume rise and physical stack height), movement of the stack from one side of the plant boundary to the other may cause an appreciable difference in concentrations at receptor locations near the plant boundary. When a significant portion of the pollutant emissions emanate from such a stack, the maximum concentration is usually close to the stack. For this study, a receptor must be located at least 1 km from the plant boundaries to qualify as the point at which the maximum concentration occurs. Therefore, if the wind direction is roughly constant (as it is for 24-hour and 3-hour averages), movement of such a stack from the downwind edge of the plant boundary to the upwind edge (or vice versa) could greatly affect the maximum concentration. In this case, concentrations and control requirements should be recomputed. However, for most stacks, maximum concentrations occur at distances sufficiently removed from the plant so that relocation of a stack within the confines of the plant will alter the shape and magnitude of pollutant concentration patterns only slightly.

Pollutant concentrations are directly proportional to emission rates. Thus, if the emission rates of all stacks within a plant are changed by the same factor, pollutant concentrations will also change by that factor. However, if the emission rates of some, but not all, stacks change, pollutant concentrations must be reassessed, unless the dispersion pattern, or at least the maximum concentration of the pattern, can be approximated as being due to a single emission source. Such an approximation will be warranted to the extent that a single stack dominates the emissions.

Finally, the meteorology assumed in a calculation obviously has a significant influence on the concentration pattern and levels calculated. While a systematic analysis of meteorological parameters similar to that just described for stack parameters was not performed, some indication of the sensitivity of the calculations to meteorological assumptions can be obtained from a comparison of two CDM results for the TOSCO II oil shale plant. Reference 2 gives annual average calculations of ambient air quality near a 16,000-m^3/day (100,000-B/D) oil shale plant based on both Salt Lake City and Grand Junction meteorology. The results presented here in Tables 16-14 and 16-15 include annual averages based on Grand Junction data. If Salt Lake City data had been used instead, the annual average maximum concentrations would change from 15 to 30 $\mu g/m^3$ for particulates, 18 to 15 $\mu g/m^3$ for SO_2, and 23 to 20 $\mu g/m^3$ for NO_2. The change for particulates leads to an estimate of additional control required that is appreciably higher than those given in Tables 16-14 and 16-15.

c. Conclusions from the Sensitivity Analysis

Because of the relatively small effort within this project that could be devoted to a sensitivity analysis of atmospheric dispersion modeling, the conclusions presented here are tentative.

The very large range of maximum concentrations associated with the various cases of stack parameters shown in Tables 16-23 and

16-24 suggests that the calculated control requirements are extremely sensitive to the choice of stack parameters. Although the range is narrowed considerably by selection of stack parameters most likely to be employed in practice (i.e., notice the reduced range of maximum concentrations in Table 16-24, compared with that in Table 16-23), the uncertainty in maximum concentrations remains substantial. A range of a factor of 3 or 4 can be found in Table 16-24, even after the low (15 m) stacks are ruled out. The interpretation of the limited sensitivity analysis performed here is derived from the summary presented in Table 16-24 and the results, described above for oil shale, that indicate the unsuitability of 15 m stacks. On this basis a range of a factor of 3 or 4 (suggested by the 0.12 to 0.46 range in Table 16-24) is probably a reasonable estimate for maximum concentrations that would be associated with likely stack parameters. Therefore, a maximum concentration calculated to be 100 units could be as low as 40 or 50 units or as high as 150 or 160 units, depending on the parameters of the stacks employed in the plants.

The suggestion that 15 m stacks are unacceptably low as sources of substantial emissions is one of several implications that emerge from this sensitivity analysis. Another implication, emphasized by the F = 0 cases of Tables 16-22 and 16-23, concerns the high potential for air pollution associated with stacks emitting pollutants at ambient temperature. The need for very substantial application of particulate emission control to the ore preparation (i.e., crushing) stages of the TOSCO II oil shale plant arises from the emission of large quantities of dust at ambient temperature. A third implication is the significant improvement in ambient air quality in the vicinity of a plant that can be achieved through use of tall stacks. This is most pronounced for the low F values shown in Table 16-23, where increasing a moderate (30 m) stack to a tall (120 m) stack cuts the maximum concentration by a factor of more than 20. A fourth implication, shown by the increase in distance of the maximum concentration point as stack height is increased, is that the lowered maximum concentration is necessarily accompanied by an increased area and distance affected by the air pollution. This fact is one of those that has led EPA to restrict the stack height that can be used to meet ambient air quality standards. (See Section E.) Finally, an implication that is directly related to the one just named, is that the overlap of plumes from two or more plants is greater when tall stacks lead to dispersion over a larger area surrounding the plant. Comparison of Cases 2 and 4 in Table 16-23 suggests that the area affected in the tall (120 m) stack case is 25 times that affected by the moderate (30 m) stack case, a factor comparable to the reduction in level of the maximum concentration in the two cases. Thus, the need for a multiple-plant, regional, air pollution analysis is greater for the tall stack cases.

D. Control Requirements

To provide a unique estimate of the control required in addition to the estimates given in Section C (Tables 16-14, 16-15, 16-18, 16-19, 16-20, and 16-21), a particular comparison ambient air quality standard must be selected. The actual setting of these standards for regions in which synthetic fuel plants may eventually be located will be one critical factor that could affect deployment of the plants. In deriving control requirements, the Class II standards proposed by EPA were selected as one of three sets of standards that the states could choose to prevent significant deterioration of air quality in regions now enjoying relatively unpolluted air.

Of the three levels of standards proposed by EPA, Class II represents those that are strict but not so strict that they preclude industrial development. The other two levels are Class I, intended for application in regions that are to remain underdeveloped, and Class III, equivalent to the existing federal secondary standards (or primary when no secondary standards exist). We have chosen Class II as the comparison standard because (1) concern over air pollution in the Colorado and Wyoming areas considered in Section C makes it unlikely that air quality there will be allowed to be degraded to the most lenient standard, and (2) the most strict standards will not be applied if a significant synthetic fuels industry is to be brought into existence.

Control requirements for an oil shale plant, based on application of Class II standards to the dispersion modeling results of the preceding section, are shown in Table 16-25. The validity of the control requirements given in Table 16-25 depend not only on the comparison standard chosen but on the particular inputs of emission and meteorological data used in the dispersion modeling. Sensitivity to these inputs was discussed in Section C-5. To compensate for local effects of unnecessarily low (about 15 m in height) stacks, only concentrations that are calculated to apply over areas more than 1 km^2 in size and more than 1 km in distance from the plant are used to derive the control requirements given in Table 16-25. Hence, the calculated maximum concentration of particulates for the 24-hour worst case is taken as 200 $\mu g/m^3$ rather than the peak concentration greater than 300 $\mu g/m^3$ shown in Figure 16-3. Figures 16-4 and 16-5 show other cases summarized in Table 16-25.

Table 16-26 presents the control requirements derived for the H-Coal plant modeled in Section C. Again, Class II standards are used for comparison. In this case, no violation of the Class II standards indicated by the calculations based on emissions from a single 16,000-m^3/day (100,000-B/D) coal liquefaction plant. Only the particulate emissions come close to exceeding the comparison ambient air quality standard. Figures 16-7 and 16-8 show the dispersion pattern of the particulate and SO_2 emissions leading to the control requirements summarized in Table 16-26.

Table 16-25

CONTROL REQUIREMENTS BASED ON A SINGLE 16,000-m^3/DAY (100,000-B/D) OIL SHALE PLANT*

Pollutant	Calculated Concentration ($\mu g/m^3$)	Averaging Time	Class II Standard ($\mu g/m^3$)	Control Requirement* (%)
Particulates	200	24 hr	30	85
SO_2	18	1 hr	15	17
NO_x	23	1 yr	100†	None
HC	11	3 hr	160‡	None

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*Plant is controlled to "best available control" level as defined in Section B. Control requirement is in addition to that level.

†Federal primary standard for NO_2; no Class II standard exists.

‡Federal primary standard for hydrocarbons, 6-9 a.m.; no Class II standard exists.

Table 16-26

CONTROL REQUIREMENTS BASED ON A SINGLE 16,000-m^3/DAY (100,000-B/D) COAL LIQUEFACTION PLANT*

Pollutant	Calculated Concentration ($\mu g/m^3$)	Averaging Time	Class II Standard ($\mu g/m^3$)	Control Requirement (%)
Particulates	25	24 hr	30	None
SO_2	2	1 yr	15	None
NO_x	15	1 yr	100†	None
HC	1	3 hr (6-9 a.m.)	160‡	None

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*Plant is controlled to "best available control" level as defined in Section B. Control requirement is in addition to that level.

†Federal primary standard for NO_2; no Class II standard exists.

‡Federal primary standard for hydrocarbons, 3 hr, 6-9 a.m.; no Class II standard exists.

Table 16-27 presents values for control requirements for coal liquefaction plants based on dispersion modeling of the complex of four plants shown in Figures 16-9 and 16-10. The combination of plant locations and meteorology used for the modeling of emissions from a complex of plants represents a worst-case situation. Comparison of Tables 16-26 and 16-27 shows that for multiple plants the maximum concentrations of pollutants are increased by a factor of approximately 3.

Table 16-27

CONTROL REQUIREMENTS BASED ON A COMPLEX OF FOUR $16,000\text{-m}^3$/DAY (100,000-B/D) COAL LIQUEFACTION PLANTS*

Pollutant	Calculated Concentration ($\mu g/m^3$)	Averaging Time	Class II Standard ($\mu g/m^3$)	Control Requirement* (%)
Particulates	40	24 hr	30	25
SO_2	6	1 yr	15	None
NO_x	40	1 yr	100†	None
HC	3	3 hr (6-9 a.m.)	160‡	None

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*Each plant is controlled to "best available control" level as defined in Section B. Control requirement is in addition to that level.

†Federal primary standard for NO_2; no Class II standard exists.

‡Federal primary standard for hydrocarbons, 6-9 a.m.; no Class II standard exists.

The increase in maximum particulate concentration is not as large because the single-plant maximum in that case is closer to the plant and, therefore, the overlap between the dispersion patterns of the different plants occurs farther out from the position of the single-plant maximum. The increases over the single-plant case are sufficient to indicate some need for additional control of particulate emissions from coal liquefaction plants.

Table 16-28 summarizes emissions, ambient concentrations, standards, and control requirements for synthetic liquid fuel plants.

1. Conclusions

A general conclusion that can be drawn from the foregoing analysis is that control beyond the best available technology will be needed for particulate and SO_2 emissions from synthetic liquid fuel plants located in relatively undeveloped regions of the United States. In the absence of nondegradation standards for NO_2 and HC, there is no apparent need for improved control of these pollutants.

Specific conclusions are as follows:

- Particulate emissions from oil shale plants may have to be reduced. The TOSCO II retorting process modeled here requires an additional 85 percent control beyond that of the best available technology to meet the Class II 24-hour standard of 30 $\mu g/m^3$. Other oil shale processes are expected to have lower particulate emission control requirements.
- Sulfur dioxide (SO_2) emissions from oil shale plants may have to be reduced by an additional 17 percent beyond that of the best available technology to meet the Class II annual standard of 15 $\mu g/m^3$
- No additional control on emissions of nitrogen oxides (NO_x) and hydrocarbons (HC) from the oil shale plant are indicated by comparisons with air quality standards for nitrogen dioxide (NO_2) and hydrocarbons. No Class II standards exist for these pollutants. Because the scope of this work did not include photochemical reactions in the dispersion modeling, the conclusion regarding NO_x and HC emissions is not based on comparisons with ambient standards for photochemical oxidant.

Table 16-28

SUMMARY OF EMISSIONS AND CONTROL REQUIREMENTS

Type	Amount (kg/hr)	Control Device or Method	Efficiency With Best Control (%)	Emissions Remaining With Best Control (kg/hr)	Ambient Air Quality Comparisons*		Additional Control Requirement (%)
					Calculated from Best Control Case ($\mu g/m^3$)	Class II Standard ($\mu g/m^3$)	
Oil shale							
Particulates	107,700	Baghouse, cyclone, scrubber	99.66	370	200	30	85
SO_2	2671	Treated fuels, tail-gas	47	1417	18	15	17
NO_x	5343	--	65	1849	23	100†	None
HC	--	Incinerator	--	272	11	160†	None
Coal liquefaction							
Particulates	28,300	Multiple cyclones, Venturi scrubber, electro-static precipitator	99.12	250	25	30	None
SO_2	2700	Scrubber	88	330	2	15	None
NO_x	2890	None		2890	15	100‡	None
HC	47.2	None		47.2	4	160‡	None

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*Based on Table 16-15 and accompanying text.

†Federal primary standard. No Class II standard exists.

‡Federal primary standard. No Class II standard exists.

- Emissions from a single large coal liquefaction plant employing best available control will not result in violation of ambient air quality standards for any of the four pollutants considered. However, particulates and SO_2 are within factors of 1.2 and 7.5, respectively, of violating Class II standards, while the other two pollutants, NO_2 and HC, are far from violation of the relevant comparison standards (federal primary).

- Dispersion modeling based on a worst-case configuration of a complex of four coal liquefaction plants indicates a need for 25 percent additional control of particulates. Ambient concentrations of SO_2 remain below Class II standards. Ambient concentrations of NO_2 and HC remain well below the federal primary standards for this complex of plants.

- A preliminary sensitivity analysis indicates that the calculated concentrations used in determining the above control requirements should be viewed as accurate to within 50 percent.

2. Recommendations

- Control of Particulate Emissions--Appreciable additional control is indicated for the TOSCO II oil shale plant. Some additional control is indicated for the coal liquefaction plant. The potential contribution of higher stacks and more perfectly maintained baghouses to the attainment of this additional control should be determined. Efforts to improve technology for removal of fine particulates from emission streams should be continued.

- Flue Gas Desulfurization--Control of SO_2 emissions from a complex of only four coal liquefaction plants must be at least 70 percent to meet Class II standards. Efforts to improve flue gas desulfurization (FGD) units capable of 90 percent control should be continued.

- Oil Shale SO_2 Control--Emissions of SO_2 from combustion sources within the oil shale plant must be controlled beyond the control considered best available according to new source performance standards for liquid fossil-fuel fired boilers. FGD and additional hydrotreating of liquid fuels burned in the plant are both options for fuels burned in the plant are both options for achieving additional control. Because hydrotreating of fuel oil is an integral part of oil shale processing and because additional hydrotreating may be needed for NO_x control, it would be premature to recommend FGD for oil shale plants. Only the continued improvement of FGD technology is recommended; the 90 percent control expected from FGD units would be adequate to meet the estimated requirement.

- Oil Shale NO_x Control--No requirement for additional control of NO_x has been established by comparison of dispersion modeling results with ambient air quality standards. However, because the achievement of emissions consistent with best available control is likely to require a reduction of the nitrogen content in raw shale oil, the feasibility of more extensive hydrotreating of plant fuels should be studied. This has significance beyond the oil shale plant because the product oil, with its high nitrogen content, is a candidate for sale as a fuel oil as well as a refinery feedstock.
- Air Quality Standards in Undeveloped Regions--Both the setting of nondegradation standards and the designation of regions within which the standards will apply are issues. The conclusions presented in this chapter based on Class II standards are not the only ones possible, and it is recommended that the tables in Section C be used by readers interested in control requirements based on other standards that could be applied.
- Tall Stacks--Use of tall stacks (higher than about 100 m) to disperse pollutants sufficiently to avoid violation of ambient air quality standards in the vicinity of industrial plants is a subject of current controversy, especially for electric power plants. The results presented in this chapter illustrate the sensitivity of control requirements to the height of stacks employed in a plant. Additional analysis of the physical, economic, and legal aspects of this issue, should be carried out if more definitive control requirements are desired.
- Control Requirements Specific to Unit Operations--Additional dispersion modeling would make it possible to assign control requirements to unit operations

within the energy conversion facilities. If more definitive control requirements are desired, additional analysis should be performed to better resolve the location within the plant in which control requirements would be most important and productive.

- Multiple Plants and Emission Sources in a Region--The most significant air pollution issue associated with synthetic liquid fuels concerns the regional impact of large-scale development of both energy facilities and population. The preliminary analysis of a complex of four liquefaction plants in the Powder River Basin has predicted a factor of 3 increase in concentrations calculated for some pollutants and averaging times. Alternative approaches to determining control requirements based on regional, multiplant considerations should be identified, developed, and compared.

- Sensitivity Analysis--The preliminary analysis of the sensitivity of the calculations used in this chapter to variations in emission parameters confirms the importance of specifying these in estimating control requirements. This limited work, reinforced by implications of the preceding recommendations on tall stacks, unit operations, and multiple plants, leads us to a recommendation for further sensitivity analysis. Such work would be especially important if dispersion modeling calculations become the basis for determining whether a plant would meet the nondegradation standards at its proposed location.

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