EPA-600/2-77-107f
July 1977

SOURCE ASSESSMENT: HARVESTING OF GRAIN State of the Art

by

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Contract No. 68-02-1874
ROAP No. 21AXM-071
Program Element No. 1AB015

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

PREFACE

The Industrial Environmental Research Laboratory (IERL) of EPA has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act and solid waste legislation. If control technology is unavailable, inadequate, uneconomical or socially unacceptable, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. The Chemical Processes Branch of the Industrial Processes Division of IERL has the responsibility for investing tax dollars in programs to develop control technology for a large number (>500) of operations in the chemical industries.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries which represent sources of pollution in accordance with EPA's responsibility as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program entitled, "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer. Reports prepared in this program are of two types: Source Assessment Documents, and State-of-the-Art Reports.

Source Assessment Documents contain data on emissions from specific industries. Such data are gathered from the literature, government agencies and cooperating companies. Sampling and analysis are also performed by the contractor when the available information does not adequately characterize the source emissions. These documents contain all of the information necessary for IERL to decide whether a need exists to develop additional control technology for specific industries.

State-of-the-Art Reports include data on emissions from specific industries which are also gathered from the literature, government agencies and cooperating companies. However, no extensive sampling is conducted by the contractor for such industries. Sources in this category are considered by EPA to be of insufficient priority to warrant complete assessment for control technology decision making. Therefore, results from such studies are published as State-of-the-Art Reports for potentially utility by the government, industry, and others having specific needs and interests.

This study was undertaken to provide information on air emissions from harvesting of grain. In this project, Mr. D. K. Oestreich served as EPA Task Officer.

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SYMBOLS

Symbol	Definition
A, A_1, A_2, A_3, B_1, B_2, B_3, C_1, C_2	Coefficients for atmospheric stability functions
a, b, x, y	Variables of original space
A, B, C, D, E, F	Atmospheric stability classes
A, B, X, Y	Variables of transformed space
A_H	The grain field area harvested to load an average truck
A_S	The area of grain harvested per state
BGD	Background concentration
D	Representative distance to boundary from the representative source
D_T	The round trip distance traveled by a truck on the field
E	Emission factor
E_L	Emission factor for loading the harvested grain crop
E_M	Emission factor for the harvest machine activity
E_S	The emission factor for free silica from the harvest machine and transport operations
E_T	The composite emission factor for grain harvesting
E_{TR}	Emission factor for the transport of the harvested grain crop on the field
exp	Natural log base, e = 2.72
F	The hazard factor for a pollutant
F_P	National primary standard for total suspended particulates

SYMBOLS (continued)

Symbol	Definition
G_L	Amount of grain transported in a rural truck
h	Physical stack height
H	The height of the emission source (= h + ΔH)
ΔH	Plume rise
$\bar{H}_S$	The average harvest speed of a harvesting machine
K_1, K_2	Constants
LD_{50}	The dose of a test material that causes death in 50% of the rats which have ingested the material or which have been injected
M	Dispersion model used
P	The exponent of the time-averaged concentration function
P_G	Grain production
ppm	Parts per million
P_R	Production rate
P_S	Percent of free silica detected as quartz
Q	Emission rate of pollutants
Q_D	Emissions from a source per length of distance
Q_H	Emission rate for the machine harvesting activity
Q_L	Emission rate for loading of the trucks
Q_T	The composite weighted emission rate for grain harvesting
Q_{TH}	The weighted emission rate for the machine harvesting activity

SYMBOLS (continued)

Symbol	Definition
Q_{TL}	The weighted emission rate for loading of trucks
Q_{TR}	Emission rate for transport on the field
Q_{TTR}	The weighted emission rate for the transport of trucks on the field
R	Respirable particulates
S	Source severity
S'	Atmospheric stability classification
S_B	Standard error of B (intercept)
S_M	Standard error of M (slope)
S_P	Particulate severity (<7 μm)
S_R	Source severity for representative plant
$\overline{S}_W$	The average swath width of a harvesting machine
$S_{X \cdot Y}$	Standard error of estimate
t_K	The sampling time for concentration measurements
t_S	Sampling time for time averaging
T	Total mass reading
T_H	The time to harvest the harvest area required to fill the average grain truck
T_L	Time required to load an average grain truck
T_S	The time to harvest one square kilometer of grain
T_T	Total time to harvest and load an average truck full of grain

SYMBOLS (continued)

Symbol	Definition
T_{TR}	Time required to travel the round trip distance on a field
u	Arithmetic mean wind speed
veh	Vehicle
veh-m	Vehicle-meters
V_G	Volume of grain harvested per area
V_S	The speed of a truck on the field
W_G	Weight of grain harvested per volume
x_C	Crosswind distance from a source
x_i	ith threshold limit values
x, y, z	Coordinate downwind distance points from source
z	The standardized value of a random variable
$Z_{\alpha/2}$	The value of standardized variable that corresponds with a probability of $\alpha/2$
α	The probability that a random variable does not lie within a specified area
Δ	Difference between background concentration and concentration downwind of source
π	Pi, a constant 3.1416
σ_y	Standard deviation of horizontal distance
σ_z	Standard deviation of vertical distance
σ_{zI}	The instantaneous vertical standard deviation

SYMBOLS (continued)

Symbol	Definition
χ	Downwind concentration
χ_K	The concentration obtained from the sampling time, t_K
χ_S	The concentration for the sampling time, t_S
$\overline{\chi}_{max}$	Time-averaged maximum ground level concentration
$\overline{\chi}_{max,P}$	Time-averaged maximum ground level particulate concentration
ψ	The dosage of pollutants from a source

SECTION I

INTRODUCTION

Harvesting of grain refers to the physical activities of cutting, threshing, picking, screening, cleaning, shelling, loading, binding, and field transport of grain crops, all of which cause air pollution. Grain is a general term referring to wheat, rye, barley, oats, soybeans, flaxseed, corn, and sorghum.

Data and information on air pollution from the harvesting of grain are virtually nonexistent in the literature. This study provides the data and information necessary for evaluating the hazard potential of the pollutants. Evaluation criteria are quantified to establish the need for developing control technology.

This document presents the following information:

- A source definition
- Descriptions of the operations and sources of emissions
- Composition and hazard potential of the emissions
- Geographical distribution of the source
- Description of a representative source
- Severity of the source
- Trends in harvesting and present/future control technology

SECTION II

SUMMARY

Grain is harvested at over 380,000 farms in the U.S. which produce wheat, rye, oats, barley, soybeans, flaxseed, corn, and sorghum. These grains are cut, threshed, picked, cleaned, screened, baled, loaded and transported from the fields, usually by truck. The crops are harvested for use of the cereal kernels or of the plant for forage and/or silage. An average grain farm harvests 2.23 grain crops from an area of 0.98 km^2 (240 acres).

The harvesting activities produce respirable particulates (<7 μm geometric mean diameter) in the form of soil dust and plant tissue fragments (called chaff). The soil dust contains free silica. A residue of pesticides and microorganisms remains on the chaff or is released with the particulate emissions.

Emissions are generated by three harvesting operations: the harvest machine activity, loading of the harvested crop, and transport while on the field. The emission rates and factors for total respirable particulates and particulates containing free silica from these operations are presented in Table 1 along with their 95% confidence limits. The composite emission rate for the entire source was weighted for the varying durations of the operations.

A maximum concentration for pesticide residues at 100 m downwind is calculated to be four orders of magnitude less

Table 1. EMISSION RATES AND EMISSION FACTORS FOR THE HARVESTING OF GRAIN

Operation/material	Emission rate		Emission factor	
	mg/s	lb/hr	g/km^2	lb/mi^2
Machine activity	8.38 ± 7.0	0.066 ± 0.055	414	2.36
Loading	1.76 ± 0.09	0.014 ± 0.0007	14.7	0.0839
Transport	47 ± 20.7	0.37 ± 0.16	137.7	0.786
Total respirable particulates (weighted)	9.8 ± 7.4	0.077 ± 0.058	566.3	3.23
Particulates containing free silica ($\geq$1% quartz by weight)	9.54 ± 7.03	0.075 ± 0.056	551.6	3.15

than the threshold limit values (TLV®'s). Thus further analysis was not required. The potential environmental risk of microorganisms cannot be evaluated due to lack of a standard or TLV. Specific allergenic reactions have been observed in grain harvest workers, but the extent of epidemiological hazard has not been defined.

A representative emission source is defined by the harvesting of a single grain crop covering 0.44 ± 0.06 km^2 (109 ± 13 acres) at the 95% confidence level. The distance to the nearest affected population is 330 ± 122 m (1083 ± 400 ft) at the 95% confidence level. The hazard potential of this source is indicated by the severity, S, expressed by:

$$S = \frac{\bar{\chi}_{max}}{F} \qquad (1)$$

where $\bar{\chi}_{max}$ = time-averaged maximum ground level pollutant concentration from a representative source

F = hazard factor for the pollutant

For criteria pollutants the hazard factor is the primary ambient air quality standard (AAQS). For noncriteria pollutants, this factor is the threshold limit value corrected to a 24-hr exposure and including a safety factor (i.e., TLV · 8/24 · 1/100). The primary AAQS for particulate matter is 260 $\mu g/m^3$. The hazard factor for particulates containing a maximum of 10% free silica is 2.76 $\mu g/m^3$. The resulting arithmetic mean source severities are 3.5×10^{-3} for respirable particulates and ≤ 0.29 for free silica. The population affected by a time-averaged ground level concentration ($\bar{\chi}$) for which $\bar{\chi}/F \geq 0.1$ is zero for respirable particulates and 28 persons for free silica particulates.

The emissions burden for a source is the ratio of its mass respirable particulate emissions to the total respirable emissions of a state or the nation. The highest state emissions burden is 0.12% for North Dakota. The national emissions burden is 0.008%.

Industry growth in terms of area harvested is expected to be 13% higher than the 1972 figure by 1978, which will result in a comparable growth of emissions. Specific air pollution control technology for grain harvesting is presently nonexistent.

SECTION III

SOURCE DESCRIPTION

A. PROCESS DESCRIPTION

1. Source Definition

This source includes the grains listed in the U.S. Department of Agriculture Official Standards for Grain: wheat, rye, oats, barley, flaxseed, soybeans, corn, and sorghum.[1] Harvesting of these crops refers to the activities performed to obtain the cereal kernels of the plant for grain or the entire plant for forage and/or silage uses. These activities are accomplished by machines that cut, thresh, screen, clean, bind, pick, and shell these crops in the field. Harvesting also includes the loading of the harvested crops into trucks and transport of the crops on the grain field.

2. Source Characteristics

Grain crops are harvested for use of the cereal kernels or the remainder of the grain plant. The various machines and methods employed for harvesting depend on the use of the crop.

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[1]The Official United States Standards for Grain. U.S. Department of Agriculture, Agricultural Marketing Service, Grain Division. U.S. Government Printing Office. Washington. Stock No. 0116-00094. June 2, 1974. 66 p.

Crops harvested for the cereal kernels are cut as close as possible to the inflorescence (the flowering portion containing the kernels).[2] This portion is threshed, screened, and cleaned to separate the kernels from the plant. The grain is then stored in the harvest machine while the remainder of the plant is discharged back onto the field.

Combines perform all of the above activities in one operation. Binder machines are used just to cut the grain plants and tie them into bundles or leave them in a row (called a windrow) in the field.[3,4] The crop is then allowed to dry for threshing at a later date by a combine with a pickup attachment.

Corn is the only exception to the above procedures. It is harvested by mechanical pickers, picker-shellers, and combines with corn head attachments. These machines cut and husk the ears from the standing stalk. The sheller unit also removes the kernels from the ear. A binder is sometimes used to cut and bind the entire corn plant. These bundles are placed into piles (called shocks) to dry for husking at a later date.[4]

Mowers, crushers, windrowers, field choppers, binders, and similar cutting machines are used for harvesting the grasses, stalks, and cereal kernels for forage and/or silage.[5] These machines cut the plants as close to the ground as possible

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[2]Private communication. Mr. H. B. Drake. Montgomery County Agricultural Extension Agency (Ohio). July 8, 1975.

[3]Wilson, H. K. Grain Crops, 2nd Edition. New York, McGraw-Hill Book Co., 1955. 396 p.

[4]Kipps, M. S. Production of Field Crops, 6th Edition. New York, McGraw-Hill Book Co., 1970. 790 p.

[5]Encyclopaedia Brittanica, 1974 Edition. Volume 1 - Technology of Agriculture. Chicago, Encyclopaedia Brittanica, Inc., 1974. p. 357-361.

and leave them in a windrow. The plants are later picked up by a baler which ties them into bundles. Pickup balers are also used on previously threshed crops that were left in the field.[4]

Harvested crops are loaded into trucks on the field. Grain kernels are loaded through a spout from the combine. Forage and silage bales are manually or mechanically placed in the trucks. The harvested crop is then transported on the field to a storage facility.

3. Emission Sources

Emissions are generated by three grain harvesting operations: (1) crop handling by the harvest machine, (2) loading of the harvested crop into trucks, and (3) transport by trucks on the field.

Machines create particulates at the various areas where the harvesting actions take place. Emissions occur at the points where these activities are open, or material is discharged, to the atmosphere. Wind then entrains particulate matter which is composed of soil dust and plant tissue fragments (chaff). This particulate matter has a respirable fraction that contains free silica.

Particulate matter may also contain a residue of pesticides that were applied to the crop prior to harvest.[6] The proportion of pesticide in the plant, increased by three orders of magnitude, is assumed to represent the proportion present in the dust. This results in a concentration (at

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[6]Spear, R. C., and W. J. Popendorf. Preliminary Survey of Factors Affecting the Exposure of Harvesters to Pesticide Residues. American Industrial Hygiene Journal. 35:374-380, June 1974.

100 m downwind) which is four orders of magnitude less than the threshold limit value (see Appendices A and B). Thus further consideration of pesticides is not necessary.

Particulates from harvesting operations also contain various microorganisms, such as bacteria and fungal growths.[7] There are 236 common types of microorganisms associated with grain plants.[8] These growths are present on the dust and release spores when agitated by the vibration of the harvesting machine.[9] A standard for grain handling dust exposure has not been promulgated due to lack of specifically identified hazards other than the free silica in the particles.

Particulate emissions are generated in two other operations which are not as complex as the harvest machine activities. The loading of the harvested grain crop generates particulates that are subject to wind entrainment during the free fall of the harvested crop into the truck. Particulates containing free silica are emitted during transport of the material by trucks from the action of the truck tires on the field.

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[7]Harris, L. H. Allergy to Grain Dusts and Smuts. Journal of Allergy and Clinical Immunology. 10:327-336, 1939.

[8]Dickson, J. G. Diseases of Field Crops, 2nd Edition. New York, McGraw-Hill Book Co., 1956.

[9]Hirst, J. M. Chapter 47 - Spore Liberation and Dispersal. In: Plant Pathology - Problems and Progress, 1908-1958, Hotton, C. S. et al. (ed.). Madison, The University of Wisconsin Press, 1959. p. 529-538.

B. GEOGRAPHICAL DISTRIBUTION

There were 380,596 farms in the U.S. in 1969 harvesting 804,850 square kilometers of grain.[10] Five states, Illinois, Iowa, Kansas, Minnesota, and North Dakota (in descending order), accounted for 40.7% of the total area harvested.[11]

The harvested land area per state (A_S) is illustrated in Figure 1 and listed in Table 2.

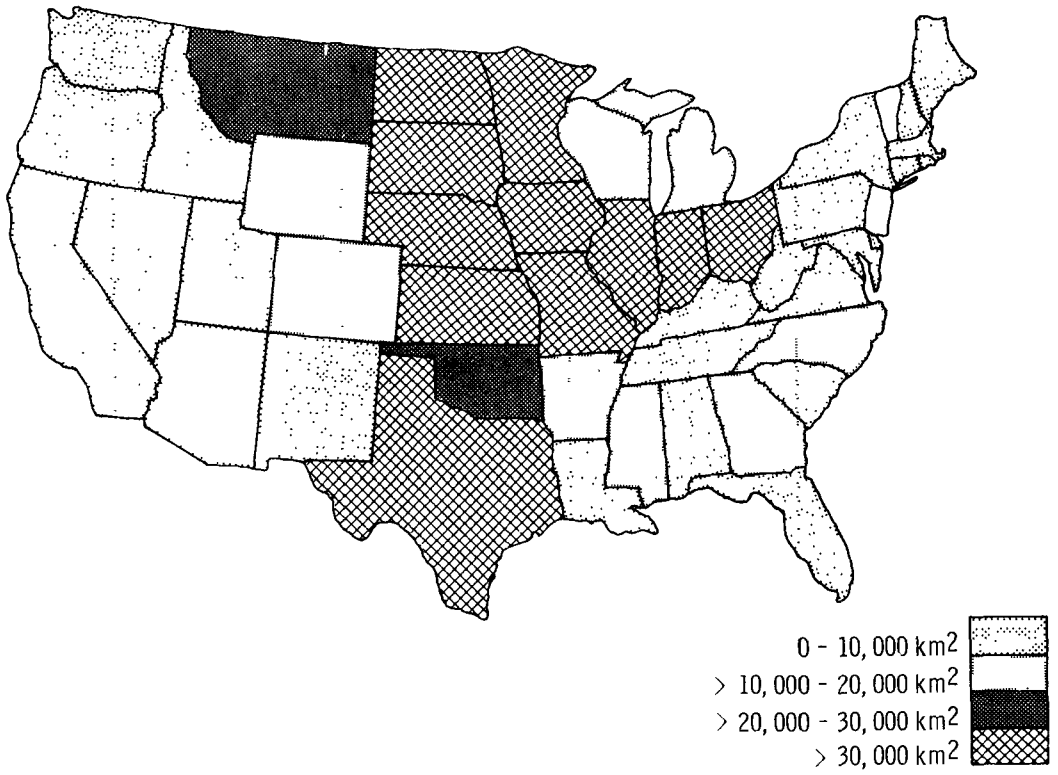

Figure 1. Area of grain harvested per state

[10] 1969 Census of Agriculture; Volume II, General Reports; Chapter 8, Type of Farm. U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census. U.S. Government Printing Office. Washington. June 1973. 287 p.

[11] 1969 Census of Agriculture; Volume V, Special Reports; Part 1, Grains, Soybeans, Dry Beans, and Dry Peas. U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census. U.S. Government Printing Office. Washington. Stock No. 0324-00244. November 1973. 711 p.

Table 2. AREA OF GRAIN HARVESTED PER STATE, 1969[11]

State	Total area harvested (A_S), km^2
Alabama	6,100
Arizona	1,830
Arkansas	18,880
California	8,770
Colorado	14,690
Connecticut	190
Delaware	1,660
Florida	2,450
Georgia	10,470
Idaho	7,520
Illinois	75,410
Indiana	39,660
Iowa	74,610
Kansas	66,260
Kentucky	9,530
Louisiana	7,510
Maine	280
Maryland	4,250
Massachusetts	130
Michigan	14,050
Minnesota	56,330
Mississippi	11,910
Missouri	32,970
Montana	23,250
Nebraska	38,220
Nevada	140
New Hampshire	70
New Mexico	2,390
New York	5,350
North Carolina	12,380
North Dakota	55,110

Table 2 (continued). AREA OF GRAIN HARVESTED PER STATE

State	Total area harvested (A_S), km^2
Ohio	31,180
Oklahoma	23,110
Oregon	5,160
Pennsylvania	9,070
Rhode Island	20
South Carolina	7,420
South Dakota	36,240
Tennessee	9,250
Texas	39,940
Utah	1,790
Vermont	340
Virginia	5,880
Washington	12,220
West Virginia	520
Wisconsin	18,350
Wyoming	1,990
Nationwide	804,850

SECTION IV

EMISSIONS

A. SELECTED POLLUTANTS

The emissions from grain harvesting which possess a hazard potential to public health are respirable (<7 μm) particulates which contain a free silica fraction.

Particulate matter is one of the criteria pollutants for which air quality standards exist.[12] Those particles with less than 1% (by weight) free silica are also termed "inert." The American Conference of Governmental Industrial Hygienists (ACGIH) has published a threshold limit value (TLV) of 10 mg/m^3 for these particles.[13] In addition, inhalation of grain dusts causes a granulomatous reaction in the lungs with associated interstitial fibrosis. Progressive pulmonary fibrosis results from repeated exposure.[14] This type of

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[12]Code of Federal Regulations, Title 42 - Public Health, Chapter IV - Environmental Protection Agency, Part 410 - National Primary and Secondary Ambient Air Quality Standards, April 28, 1971. 16 p.

[13]TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1973. American Conference of Governmental Industrial Hygienists. Cincinnati. 1973. 94 p.

[14]Frank, R. C. Farmer's Lung - A Form of Pneumoconiosis Due to Organic Dusts. The American Journal of Roentgenology. 79:189-215, February 1958.

reaction is termed farmer's and/or thresher's lung.[15] Grain smuts have been cited as possible causes for the production of these grain dusts.[16] Farmer's lung has been associated with the long-term inhalation of these smuts.[17]

Free silica particulate matter has long been associated with silicosis. This disease results from the prolonged inhalation of these particulates, which produces a pulmonary fibrosis. Symptoms of the condition may appear after several years of exposure or after exposure is terminated. Death has resulted in some cases due to extensive damage to the lung tissues.[18] The TLV for particulates with a free silica content greater than 1% varies with the percent of free silica detected.

B. MASS EMISSIONS

The total respirable particulate emission factor for grain harvesting is a combination of the emission factors from the following three sources: (1) harvest machine activity, (2) loading of trucks, and (3) transport on the field. Emissions data were determined following established procedures (see Appendix C) for each of these activities. The results of this study are presented in Appendix D.

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[15]Fuller, C. J. Farmer's Lung: A Review of Present Knowledge. Thorax (London). 8:59-64, 1953.

[16]Harris, L. H. The Nature of the Grain Dust Antigen. Journal of Allergy and Clinical Immunology. 10:433-442, 1939.

[17]Blaknikova, D., M. Tumova, and A. Valisova. A Syndrome Resembling Farmer's Lung in Workers Inhaling Spores of Aspergillus and Penicillin Moulds. Thorax (London). 15:212-217, 1960.

[18]Sax, N. I. Dangerous Properties of Industrial Materials, 3rd Edition. New York, Reinhold Book Corp., 1968. p. 1088-1089.

The emission factors (@ 95% confidence level) for respirable particulates from each of the harvesting operations and the entire source are listed in Table 3.

Table 3. EMISSION FACTORS FOR RESPIRABLE PARTICULATES FROM GRAIN HARVESTING

Operation	Emission factor (@ 95% level)	
	Symbol	Value, g/km^2
Machine activity	E_M	414
Loading	E_L	14.7
Transport	E_{TR}	137.7
Total respirable particulate emission factor	E_T	566.3

Free silica particulates are emitted from the soil during the harvest machine activity and transport on the field. The emission factor for free silica (E_S) is 551.6 ± 406.6 g/km^2 at the 95% confidence level. (These data are the result of sampling emissions from the harvesting of two grain crops.)

The total respirable particulate emission factor is used in computing statewide emission levels. These levels are the products of the area of grain harvested per state (A_S; Table 2) and this emission factor. The results are presented in Table 4 which also lists the state emission burdens.[19] These values are the ratio of each state's respirable particulate emissions from grain harvesting to the total respirable emissions of that state as reported in the National Emission Data System, NEDS.[19] Respirable emissions are assumed to be about 1/3 of the total reported in NEDS.

[19]1972 National Emissions Report. Environmental Protection Agency. Research Triangle Park. Publication No. EPA-450/2-74-012. June 1974. 422 p.

Table 4. STATE AND NATIONAL PARTICULATE EMISSIONS BURDENS FROM THE HARVESTING OF GRAIN[19]

State	Total particulates, metric ton[a]	Respirable particulates due to harvesting of grain, metric ton[a]	Contribution of[b] harvesting of grain to overall state emissions, %
Alabama	1,178,643	3.45	<0.001
Arizona	72,685	1.04	0.004
Arkansas	137,817	10.69	0.023
California	1,006,452	4.97	0.001
Colorado	201,166	8.32	0.012
Connecticut	40,074	0.11	0.001
Delaware	36,808	0.94	0.008
Florida	226,460	1.39	0.002
Georgia	404,574	5.93	0.004
Idaho	55,499	4.26	0.023
Illinois	1,143,027	42.70	0.011
Indiana	748,405	22.5	0.009
Iowa	216,493	42.3	0.058
Kansas	348,351	37.5	0.032
Kentucky	546,214	5.4	0.003
Louisiana	380,551	4.25	0.003
Maine	49,155	0.16	<0.001
Maryland	494,221	2.41	0.001
Massachusetts	96,160	0.07	<0.001
Michigan	705,921	7.96	0.003
Minnesota	266,230	31.9	0.036
Mississippi	168,355	6.74	0.012
Missouri	202,435	18.7	0.028
Montana	272,688	13.2	0.014
Nebraska	95,338	21.6	0.068

[a] 1 metric ton = 1 x 10^6 g = 2,204 lb.

[b] This value is estimated by taking 1/3 of the state total emissions as respirable.

Table 4 (continued). STATE AND NATIONAL PARTICULATE EMISSIONS BURDENS FROM THE HARVESTING OF GRAIN[19]

State	Total particulates, metric ton[a]	Respirable particulates due to harvesting of grain, metric ton[a]	Contribution of harvesting of grain to overall state emissions,[b] %
Nevada	94,040	0.08	<0.001
New Hampshire	14,920	0.04	<0.001
New Mexico	102,785	1.35	0.004
New York	160,044	3.03	0.006
North Carolina	481,017	7.01	0.004
North Dakota	78,778	31.2	0.12
Ohio	1,766,056	17.7	0.003
Oklahoma	93,595	13.1	0.042
Oregon	169,449	2.92	0.005
Pennsylvania	1,810,598	5.14	<0.001
Rhode Island	13,073	0.01	<0.001
South Carolina	198,767	4.2	0.006
South Dakota	52,336	20.5	0.12
Tennessee	409,704	5.24	0.004
Texas	549,399	22.6	0.012
Utah	71,692	1.0	0.004
Vermont	14,587	0.2	0.004
Virginia	477,494	3.33	0.002
Washington	161,934	6.92	0.012
West Virginia	213,715	0.29	<0.001
Wisconsin	411,558	10.39	0.008
Wyoming	75,427	1.13	0.004
TOTAL	17,872,000[c]	455.8	

[a] 1 metric ton = 1 x 10^6 g = 2,204 lb.

[b] This value is estimated by taking 1/3 of the state total emissions as respirable.

[c] This total includes five sources not listed by state.

The particulate emissions due to harvesting of grain account for no more than 0.12% in any of the states. The national emissions burden is 0.008%.

C. DEFINITION OF THE REPRESENTATIVE SOURCE

Emissions due to the harvesting of wheat and sorghum were chosen to represent those of all grains. These two grains were reported to have the highest emission factors for a grain handling activity that generated the greatest amount of dust.[20] In addition, this dust was described as being primarily composed of particles <5 μm in diameter.[21] Using this basis, the range of emissions due to grain type is viewed from a "worst case" condition. Therefore, analysis of different grains is not necessary. This hypothesis was tested in presurvey, and the results are presented in Appendix D.

The representative source is derived in Appendix E. It is defined by arithmetic mean emission parameters for a single grain crop harvested on a farm. The area of the field harvested is 0.44 km^2. The distance to the boundary and average travel distance is 330 m. The population density in the area surrounding the field is 39.9 persons/km^2. This is the arithmetic mean of the population densities per state.

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[20] Gorman, P. G. Potential Dust Emissions from a Grain Elevator in Kansas City, Missouri. Midwest Research Institute. Kansas City. Fianl report, Environmental Protection Agency, EPA Contract 68-02-0228, Task 24. May 1974. p. xv, 52, and 70.

[21] Epp, D., and M. Schrag. Potential Impact of Emission Controls on Country Elevators. Midwest Research Institute. Kansas City, Missouri. MRI Project No. 3866-C. July 24, 1974. p. 43.

D. SOURCE SEVERITY

Source severity means and ranges for grain harvesting were calculated (see Appendix F) for the parameters of the defined representative source. For criteria pollutants the source severity was calculated as the time-averaged maximum ground level concentration ($\overline{\chi}_{max}$) divided by the national primary air quality standard. For noncriteria pollutants $\overline{\chi}_{max}$ was divided by a corrected threshold limit value.

Mean severity for respirable particulates was calculated for the representative grain field. The severities for each operation and the entire source are listed in Table 5.

Table 5. MEAN SEVERITIES FOR RESPIRABLE PARTICULATES

Operation	Mean severity
Machine activity	11.2×10^{-4}
Loading	3.0×10^{-5}
Transport	1.7×10^{-2}
Time-weighted total severity	3.5×10^{-3}

The mean severity for free silica particles generated from the machine activity and transport was calculated as being ≤ 0.29 (based on maximum free silica content). Using the representative source and distance, the affected population for respirable particles is zero and for free silica particles is 28 persons.

The distribution of source severity is not computed for respirable particulates since the mean value is three orders of magnitude less than one. For free silica the severity

distribution is presented in Figure 2. The distribution is near normal, with a maximum of 0.32 and a mean (for 50% of the grain fields) at 0.28, which is within 4% of the value (0.29) calculated for the representative source. The derivation of this distribution is presented in Appendix F.

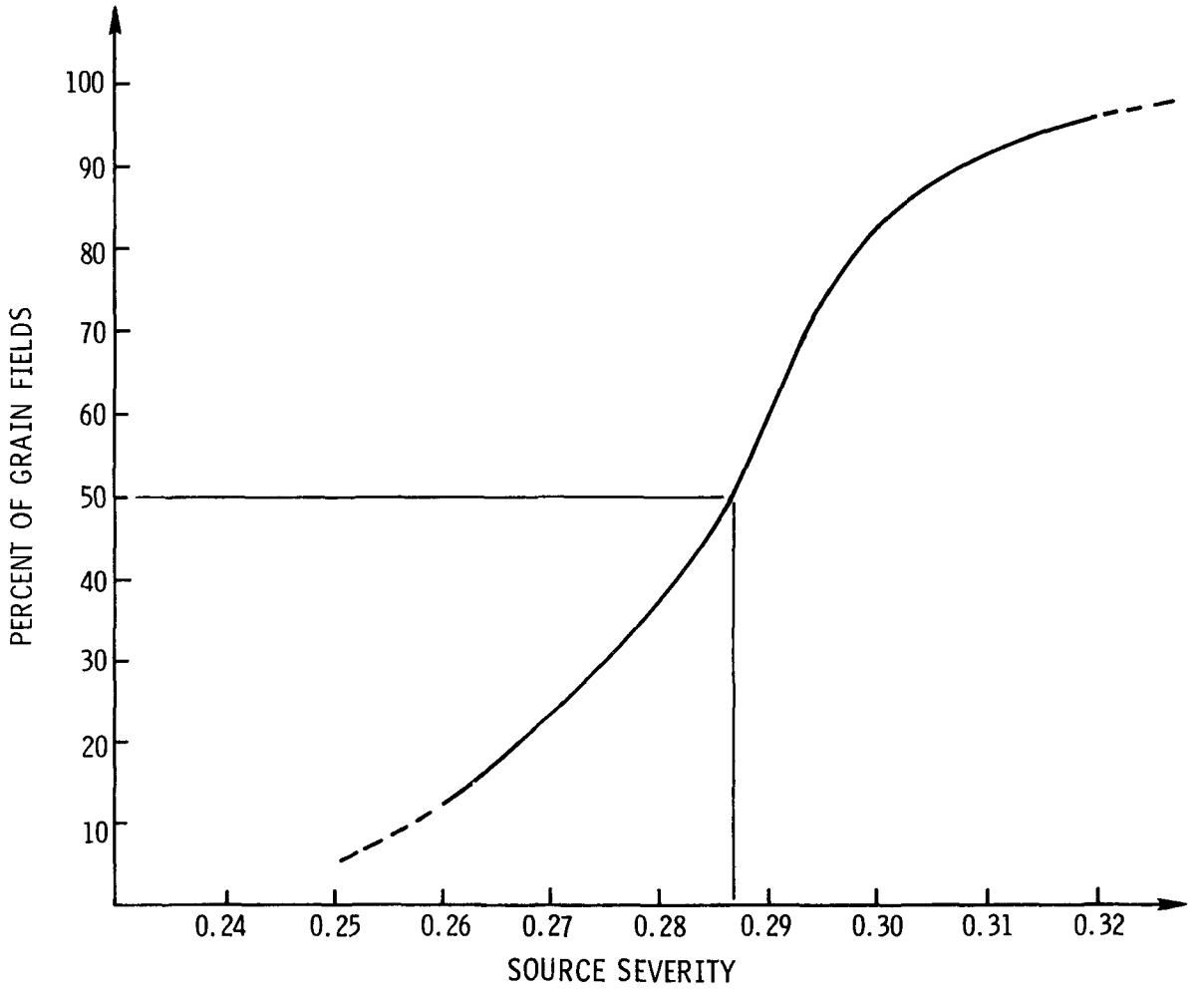

Figure 2. Source severity distribution for free silica

SECTION V

CONTROL TECHNOLOGY

A. STATE OF THE ART

There are no control techniques specifically implemented for the reduction of air pollution emissions from grain harvesting. However, several practices and occurrences inadvertently affect emission rates and concentrations.

The use of terraces, contouring, and stripcropping to inhibit soil erosion[22] also suppresses the entrainment of harvested crop fragments in the wind. Shelterbelts, positioned perpendicular to the prevailing wind, also lower emissions by reducing the wind velocity across the field. An average shelterbelt can reduce the wind velocity by more than 10% up to a distance of 20 times the tree height on the downwind side and three times on the upwind side of the field.[5] Lower wind speeds and stable atmospheres reduce emission rates but increase concentrations as evidenced by dispersion equations.[23] In addition, by minimizing tillaging

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[22]Allaway, W. H. Systems - Cropping Systems and Soil. In: The Yearbook of Agriculture 1957. U.S. Government Printing Office. Washington, 1957. p. 393.

[23]Turner, D. B. Workbook of Atmospheric Dispersion Estimates. U.S. Department of Health, Education, and Welfare. Cincinnati. Public Health Service Publication No. 999-AP-26. May 1970. 65 p.

and avoiding residue burning, the soil will remain consolidated and less prone to emission from transport activities.

Sexual sterility can be induced in insects and weeds by the use of attractants and pathogens, thereby eliminating the need for pesticides and thus the pesticide residues on crop fragments.[24]

B. FUTURE CONSIDERATIONS

Control of atmospheric emissions centers around two areas: (1) modification of the harvesting machine activity, and (2) alteration of the crop characteristics.

In the machine harvest of grain crops, kernel breakage is a factor in the creation of dust and the reduction of grain quality. Breakage is greatest at low temperatures and moisture contents. Harvesting the crops at higher temperatures and moisture contents will therefore reduce the dust levels and enhance the quality of the grain. This approach, however, contradicts the recommendations for storing grain.[25] Water application at the time of harvest is a possibility for curtailing dust generation, but the feasibility of maintaining a water supply on the harvest machine is questionable. Application of water prior to or during the harvest also presents a problem termed "weathering" which refers to the

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[24] New Approaches to Pest Control and Eradication. Advances in Chemistry Series, No. 41. Washington, American Chemical Society, 1963. 74 p.

[25] Fiscus, D. E., G. H. Foster, and H. H. Kaufmann. Physical Damage of Grain Caused by Various Handling Techniques. Presented at the 1969 Winter Meeting of the American Society of Agricultural Engineers, Sherman House, Chicago. Paper No. 69-853. St. Joseph, Michigan, American Society of Agricultural Engineers, December 1969. 25 p.

partial digestion of the starch and increase of mold growth caused by the higher moisture levels. In addition, farmers are penalized if the moisture content of grain is too high.

Reduction of the free fall (drop height) and abrasiveness of contacted surfaces within the harvest machine will reduce the fragmentation of the grain crop. Addition of a baghouse/screening type of collector, as an integral component of the harvest machine, could collect particulate emissions. An aspiration system would be required to entrain dust at the points of emission.

All of the above techniques require design modifications of the harvest machines.

Covering the entire crop field in a controlled environment has been suggested as a possible means of control. The confidence in this approach for vegetables and fruits is greater than for large areas of grain. However, a controlled environment requires only 2% of the water used for open cultivation. Since the enclosure keeps out pests and the soil is easily sterilized, there is little or no requirement for pesticides. Soil erosion problems are also eliminated, and the area required for grain plant production could be reduced by a factor greater than 10.[26] However, the feasibility and practicality of such crop alteration from an economic and technical standpoint are highly uncertain.

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[26]Taylor, T. B., et al. A Systems Approach to Problem Oriented Research Planning: A Case Study of Food Production Wastes. International Research and Technology Corp. IRT No. 244-R (PB 228 114). June 1973. 105 p.

SECTION VI

GROWTH AND NATURE OF THE INDUSTRY

A. PRESENT TECHNOLOGY

An increase in the use and efficiency of mechanical equipment in harvesting grain crops has brought about many changes in recent years. This machinery has enabled production of grain to keep up with demand and has allowed a profitable return in the face of rising farming costs. The number of each type of machine utilized is listed in Table 6.[27]

Table 6. HARVESTING MACHINES UTILIZED[27]

Type	Number	Percent of total
Pickup balers	708,044	39.1
Cornpickers, cornheads, and picker-shellers	634,592	35.1
Grain and bean combines	467,226	25.8

The combine is the most widely accepted machine in all sections of the U.S.[28] Combines are often used for the

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[27] 1969 Census of Agriculture; Volume V, Special Reports; Part 15, Graphic Summary. U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census. U.S. Government Printing Office. Washington. Stock No. 0324-00252. December 1973. 145 p.

[28] Encyclopaedia Brittanica, 1974 Edition. Volume 5 - Cereals and Other Starches. Chicago, Encyclopaedia Brittanica, Inc., 1974. p. 1161.

"windrow and pickup" method which facilitates the harvesting of weedy, moist, and/or unevenly ripening crops. However, this method is more expensive than direct combining.[4]

Most farms are equipped with mechanical pickers for harvesting corn. These machines, available in the one or two row variety, pick and husk the crop. Manual picking and/or husking is performed in some areas, but the cost is much higher. Therefore, an increasing area of corn is mechanically harvested.

The rapid growth of this mechanization has increased the production of grain crops in the Western States where the combine has been especially popular. The development of the windrow method has also caused growing use of the combine in the East.[4]

B. EMERGING TECHNOLOGY

No specific technological breakthroughs are anticipated in the grain harvesting industry, although the future promises a steady improvement in harvest machine design and adaptability. Better cultivation practices, improved crop varieties, control of pests, maintenance of soil productivity, and economical labor will further accelerate grain production.

C. TRENDS

The number of persons supported by the production of one farm worker has grown from four in 1820 to 39 in 1966.[29] Mechanization has made this increase possible. With the

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[29] Kendall, J. R., et al. Agricultural Statistics. U.S. Department of Agriculture. U.S. Government Printing Office. Washington, 1967. p. 526, 528, 539, and 549.

increased use of machinery comes a decrease in the number and an increase in the size of farms.

The population of the U.S. will continue to increase, and improvements in current cropland harvested and yields per square kilometer will be necessary. This will require rising efficiency, specialization, and heavy capital outlay for farm operations. Greater demands for grain exports will further advance the area of land harvested. Production will grow at the rate of 2% per year; by 1978 the total area harvested is expected to reach 909,480 km^2.[30]

[30]Shannon, Y. J., R. W. Gerstle, P. G. Gorman, D. M. Epp, T. W. Devitt and R. Amick. Emissions Control in the Grain and Feed Industry, Volume I - Engineering and Cost Study. Midwest Research Institute, Kansas City, Missouri. Environmental Protection Agency, EPA-450/3-73-003a (PB229-996). December 1973. p. 4-14.

SECTION VII

UNUSUAL RESULTS

The fact that the free silica content of the particulate collected originated from the soil was unexpected. The silica content of the soil is three orders of magnitude greater than that of the grain. By visual observation, the harvesting machine was not in contact with the ground except for the tires. The source of the free silica had to be either the soil from the ground or soil particles that adhered to the grain plant. It had rained prior to the day on which the airborne particulate was collected, thereby suppressing the ground soil. It is therefore believed that the free silica emanated from soil particles adhering to the grain plant.

Appendix G presents the maximum pollutant concentration values from the source.

SECTION VIII

APPENDIXES

A. Calculation of Pesticide Residue Concentration Downwind of Harvesting Activity

B. A Method for Estimating TLV Values for Compounds where None Exist

C. Sampling Methodology - Analysis and Procedures

D. Sampling Results

E. Derivation of the Representative Source

F. Calculation of Source Severity

G. Determination of Maximum Pollutant Concentrations

APPENDIX A

CALCULATION OF PESTICIDE RESIDUE CONCENTRATION DOWNWIND OF HARVESTING ACTIVITY

The pesticide levels downwind of the machine harvesting activity were calculated for two selected pesticide residues. These residues were detected on grain plants just prior to harvest. One has the lowest TLV and the other the highest concentration in the plant (see Table A-1) (some pesticides in Table A-1 are no longer used, but do not deteriorate easily in the environment and are included here for calculation purposes).[31,32]

The lowest TLV for the pesticide residues detected is that of Endrin, 0.1 mg/m^3. The concentration of this residue detected on the grain plants is <0.01 ppm. This is equated to 0.01 ppm. Applying an increase of three orders of magnitude, this becomes a concentration of 10 ppm (by weight) in the dust. The weighted mean emission rate for harvesting is 9.8 ± 7.4 mg/s at the 95% confidence level (Appendix D). Using the point source model[23] for average U.S. conditions

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[31]Crockett, A. B., G. B. Wiersana, H. Tai, W. G. Mitchell, P. F. Sand, and A. E. Carey. Pesticide Residue Levels in Soils and Crops, FY-70 - National Soils Monitoring Program. Pesticides Monitoring Journal. 8(2):96-97, September 1974.

[32]Carey, A. E., G. B. Wiersana, H. Tai, and W. G. Mitchell. Organochlorine Pesticide Residues in Soils and Crops of the Corn Belt Region, United States - 1970. Pesticides Monitoring Journal. 6(4):375, March 1973.

Table A-1. LIST OF TLV'S AND CONCENTRATION OF PESTICIDE RESIDUES ON GRAIN PLANTS[31,32]

Pesticide	TLV, mg/m^3	Mean concentration, ppm (by weight)				
		Group A	Group B			
		Soybean beans	Corn kernels	Corn stalks	Grain sorghum	Sorghum forage
Dieldrin	0.25[a]	0.01	<0.01	<0.01	ND[c]	0.01
Endrin	0.10[a]	<0.01	<0.01	-[d]	-	-
Ethion	0.14[b]	-	<0.01	-	-	-
Chlordane	0.50[a]	<0.01	-	0.01	-	-
o, p' - DDE[f]	N.A.[e]	-	-	<0.01	-	-
p, p' - DDE	N.A.	-	-	<0.01	ND	ND
o, p' - DDT[g]	1.0	0.012	-	0.01	ND	ND
p, p' - DDT	1.0	0.015	-	0.03	ND	ND
DDTR[h]	N.A.	-	-	0.04	ND	ND
Heptachlor	0.5[a]	<0.01	-	<0.01	-	-
Heptachlor Epoxide	0.64[b]	<0.01	-	<0.01	ND	ND
p, p' - TDE[i]	N.A.	-	-	<0.01	ND	ND
Toxaphene	0.5[a]	0.02	-	0.02	-	-
Malathion	10[a]	-	-	<0.01	-	-
Ethyl Parathion	N.A.	-	-	<0.01	ND	ND
PCB's[j]	0.5	-	-	2.8	ND	ND
Ramrod	5.92[b]	<0.01	-	-	-	-
Trifluralin	N.A.	<0.01	-	-	-	-
Lindane	0.5	0.005	-	-	-	-
Aldrin	0.25[a]	0.001	-	-	-	-

[a] Skin TLV.

[b] Converted from LD_{50} to TLV (see Appendix B); TLV = 0.0198 $(LD_{50})^{0.774}$.

[c] None detected.

[d] Dashes indicate that analyses were not completed for the specific pesticide shown.

[e] N.A. = not available.

[f] DDE = Dichlorodiphenyl dichloroethylene.

[g] DDT = 1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane.

[h] DDTR = DDE + TDE.

[i] TDE = 1,1-Dichloro-2,2-bis(p-chlorophenyl)ethane.

[j] PCB = Polychlorinated biphenyls.

(stability C, wind speed 4.5 m/s), the concentration for a ground level source at 10 m downwind is 443 $\mu g/m^3$. With the pesticide residue constituting 0.001% by weight (10 ppm of the dust), the concentration is 0.0044 $\mu g/m^3$. This is five orders of magnitude less than the TLV value of 0.1 mg/m^3.

The same process was followed for the highest concentration of pesticide residue detected (Table A-1), 2.8 ppm for PCB's. Applying an increase of three orders of magnitude, the concentration is 2,800 ppm (by weight) in the dust. Using the ground level point source model at average U.S. conditions, the downwind concentration at 100 m is four orders of magnitude less than the TLV of 0.5 mg/m^3 for PCB's. Therefore, for the lowest TLV and highest concentrations of pesticide residues found on grain plants, the downwind concentrations are at least four orders of magnitude less than their TLV's at 100 m from the source.

APPENDIX B

A METHOD FOR ESTIMATING TLV VALUES FOR COMPOUNDS WHERE NONE EXIST

by J. A. Peters
Monsanto Research Corporation

In assessing health hazards associated with the application of agricultural chemicals, many of the emitted compounds to be assessed have no TLV assigned by the ACGIH. The TLV of air pollutants is utilized as an integral part of Industrial Environmental Research Laboratory's first decision criteria for future control technology development.

Thirty agricultural chemicals selected from those listed in Reference 13 with their TLV values are shown in Table B-1. Seven of the 30 chemicals are herbicides, one is a fungicide, and 22 are insecticides; no distinction is made between inhalation and skin TLV. The most common toxicity value published for chemical substances is the acute oral LD_{50} dose for male rats.[33,34] These LD_{50} values are tabulated with the TLV's and curve-fitting is attempted to correlate LD_{50} with TLV to obtain a relationship whereby compounds of unknown TLV can be assigned functional TLV's for decision criteria use. The results of the best curve-fit are presented below.

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[33]1969 Farm Chemicals Handbook. Willoughby, Ohio, Meister Publishing Co., 1968. 472 p.

[34]Toxic Substances List, 1972 Edition. John J. Thompson and Co. Rockville, Maryland. June 1972. 563 p.

Table B-1. SELECTED AGRICULTURAL CHEMICALS[13]

Chemical (primary use)	TLV, mg/m^3	LD_{50}, mg/kg (acute oral rat dose)
Abate (insecticide)	10	2000
Aldrin (insecticide)	0.25	55
Allyl Alcohol (herbicide)	3	95
Ammate (herbicide)	10	3900
Arsenic Acid (herbicide)	0.5	48
Carbaryl (Sevin®) (insecticide)	5	500
Chlordane (insecticide)	0.5	570
Toxaphene (insecticide)	0.5	69
2,4-D (herbicide)[a]	10	1200
DDT (insecticide)[b]	1	113
DDVP (insecticide)[c]	1	56
Demeton (insecticide)	0.1	9
Diazinon (insecticide)	0.1	134
Dibrom (insecticide)	3	430
Dieldrin (insecticide)	0.25	60
Dinitro-*o*-cresol (insecticide)	0.2	50
Diquat (herbicide)	0.5	300
Endrin (insecticide)	0.1	5
EPN (insecticide)[d]	0.5	50
Heptachlor (insecticide)	0.5	90
Malathion (insecticide)	10	1375
Methoxychlor (insecticide)	10	5000
Methylparathion (insecticide)	0.2	25
Paraquat (herbicide)	0.5	145
Parathion (insecticide)	0.1	15
Phosdrin (insecticide)	0.1	7
Ronnel (insecticide)	10	1740
2,4,5-T (herbicide)[e]	10	500
TEPP (insecticide)[f]	0.05	1.2
Thiram (fungicide)	5	860

[a] 2,4-D = 2,4-Dichlorophenoxyacetic acid.

[b] DDT = 1,1,1-Trichloro-2,2-bis(*p*-chlorophenyl)ethane.

[c] DDVP = Dimethyl 2,2-dichlorovinyl phosphate.

[d] EPN = O-Ethyl O-*p*-Nitrophenyl phenylphosphonothioate.

[e] 2,4,5-T = 2,4,5-Trichlorophenoxyacetic acid.

[f] TEPP = Tetraethyl pyrophosphate.

The best APL[a] regression fit is an equation of the type:

$$y = ax^b \qquad \text{(B-1)}$$

Logarithmic transformation of Equation B-1 yields:

$$\ln y = \ln a + b \ln x \qquad \text{(B-2)}$$

Equation B-2 is further transformed to resemble the familiar straight-line slope-intercept equation form:

$$Y = MX + B \qquad \text{(B-3)}$$

if $Y = \ln y$
$B = \ln a$
$M = b$
$X = \ln x$

The indicators of goodness-of-fit for this regression show that $R^2 = 0.7951$ and the F-value = 108.6.

The fitted values for the slope-intercept form are:

$$B = -3.921$$
$$M = 0.774$$

Standard errors are computed and result in:

S_M = 0.07426 = standard error of M (slope)
$S_{Y \cdot X}$ = 0.821 = standard error of estimate
S_B = 0.3936 = standard error of B (intercept)

[a]Programming language.

S_B is calculated separately where

$$S_B = S_{X \cdot Y} \sqrt{\frac{\Sigma \text{ (Transformed } x_i)^2}{n \Sigma \text{ (Transformed } x_i - \text{mean transformed } x_i)^2}}$$

Using the above calculated values, 95% confidence level intervals are obtained about the slope and intercept of the equation $y = ax^b$:

Slope

b (or M) $\pm$ $Z_{\alpha/2}$ S_M gives the upper and lower bound limits for the confidence interval. Given n = 30, α = 0.05 so $Z_{\alpha/2}$ = 1.96; then 0.774 $\pm$ (1.96)(0.07426) will be (0.6285 $\leq$ slope $\leq$ 0.9195) = 95%. The slope confidence interval is the same in transformed space as in the original space.

Intercept

In transformed space the 95% confidence interval is B $\pm$ $Z_{\alpha/2}$ S_B; but in the original space:

$$\frac{\text{anti ln a}}{\text{anti ln}(Z_{\alpha/2} S_B)} \leq \text{intercept} \leq \text{anti ln a[anti ln}(Z_{\alpha/2} S_B)]$$

which is $\frac{0.01982}{2.1629} \leq$ intercept $\leq$ (0.01982)(2.1629)

or (0.00916 $\leq$ 0.0198 $\leq$ 0.04287) = 95%

In the Y = MX + B equation form, the 95% confidence limits for B are $\pm$ 19.7% of B, and for M are $\pm$ 18.8% of M. In original space, the exponential equation form $y = ax^b$, the limits for b are the same as those for M, but the confidence limits for a become + 216.5% and -46.3%. Dividing the maximum value by the minimum value for the 95% confidence interval yields 4.68 for a and 1.46 for b.

The final form of the regressed equation relating LD_{50} to TLV, given the original (LD_{50}, TLV) pairs, is:

$$TLV = 0.0198(LD_{50})^{0.774} \qquad \text{(B-4)}$$

where LD_{50} = acute oral dose, mg/kg, for male rat
TLV = threshold limit value, mg/m^3

The TLV values for the pesticides listed in Table A-1 (Appendix A) were calculated using Equation B-4.

APPENDIX C

SAMPLING METHODOLOGY - ANALYSIS AND PROCEDURES

1. INSTRUMENTATION

The GCA® Model RDM 101-4 respirable dust monitor[a] was used to sample the downwind concentration of respirable particulates from the harvesting of wheat and sorghum. This is an advanced instrument designed for on-the-spot measurements of mass concentrations of the respirable fraction or the total mass loading of particulates. It is a portable and fully self-contained monitor with automatic and direct digital readout of the mass concentration of airborne particulates. Readings can be taken for from 4 minutes to 30 minutes sampling time, and a traverse of points around a source of interest can be accomplished quickly.

Results are obtained by electronic measurement of the beta absorption of the collected sample. A cyclone collection system is used as a first stage for respirable (<10 μm) measurements. Using the respirable concentration values obtained with the GCA, the emission rate of particulates can be obtained through use of the appropriate model.[35]

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[a]GCA Corporation
GCA/Technology Division
Bedford, Massachusetts 01730

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[35]Lilienfeld, P., and J. Dulchinos. Portable Instantaneous Mass Monitor for Coal Mine Dust. American Industrial Hygiene Association Journal. 33:136, March 1972.

2. MODELS

Open source sampling uses diffusion models in reverse. Normal use is to predict concentrations surrounding a point source of known strength. Several concentration readings are taken to calculate the source strength of an open source.

Models applicable to the sampling arrangement and source characteristics are chosen and utilized for each source of emissions. For grain harvesting there are three sources; (1) harvest machine activity, (2) loading the truck, and (3) truck transport on the field.

Two models are used in this study. The first represents emissions from machine activity and loading operations. This is the point source model[2 3] where:

$$\chi\ (x,\ y,\ z;\ H) = \frac{Q}{2\pi\sigma_y\sigma_z u}\ \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \cdot \cdot$$

$$\cdot \cdot \cdot \left\{ \exp\left[-\frac{1}{2}\left(\frac{z - H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z + H}{\sigma_z}\right)^2\right] \right\} \qquad \text{(C-1)}$$

The notation used to depict the concentration is $\chi(x,y,z;H)$. H, the height of the plume centerline from the ground level when it becomes essentially level, is the sum of the physical stack height, h, and the plume rise, ΔH. The following assumptions are made: the plume spread has a Gaussian distribution in both the horizontal and vertical planes, with standard deviations of plume concentration distribution in the horizontal and vertical of σ_y and σ_z, respectively; the mean wind speed affecting the plume is u; the uniform emission rate of pollutants is Q; and total reflection of the plume takes place at the earth's surface, i.e., there is no deposition or reaction at the surface. Any consistent set of units may be used. The most common is χ in g/m^3, Q in g/s, u in m/s, and σ_y, σ_z, H, x, y, and z in meters. The

concentration χ is a mean over the same time interval as the time interval for which the σ's and u are representative. The values of both σ_y and σ_z are evaluated in terms of the downwind distance, x, and stability class. Stability classes are determined conveniently by graphical methods, Figure C-1.[36] Continuous functions are then used to calculate values for σ_y, and σ_z, Tables C-1[37] and C-2,[38] given the downwind distance, x. In open source sampling the sampler is maintained in the center of the plume at a constant distance; the plume has no effective height (H=0); and the concentrations are calculated at ground level. Equation C-1 thus reduces to:[23]

$$\chi\ (x,\ 0,\ 0;\ 0) = \frac{Q}{\pi\sigma_y\sigma_z u} \qquad \text{(C-2)}$$

The second model is used to describe emissions from transport on the field. In this equation instantaneous puff concentrations are represented by Equation C-3:[39]

$$\psi = \left(\frac{2}{\pi}\right)^{1/2} \frac{Q_D}{\sigma_{zI} u} \qquad \text{(C-3)}$$

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[36]Blackwood, T. R., T. F. Boyle, T. L. Peltier, E. C. Eimutis, and D. L. Zanders. Fugitive Dust from Mining Operations. Monsanto Research Corporation. Dayton. Report No. MRC-DA-442. (EPA Contract 68-02-1320, Task 6.) May 1975. p. 34.

[37]Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions for the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment. 6:859-863, March 1972.

[38]Martin, D. O., and Tikvart, J. A. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. (Presented at the 61st Annual Meeting of the Air Pollution Control Association. St. Paul. June 23-27, 1968.) 18 p.

[39]Gifford, F. A., Jr. Chapter 3 - An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Slade, D. A. (ed.). Oak Ridge, Tennessee, U.S. Atomic Energy Commission Technical Information Center. Publication No. TID-24190. July 1968. p. 445.

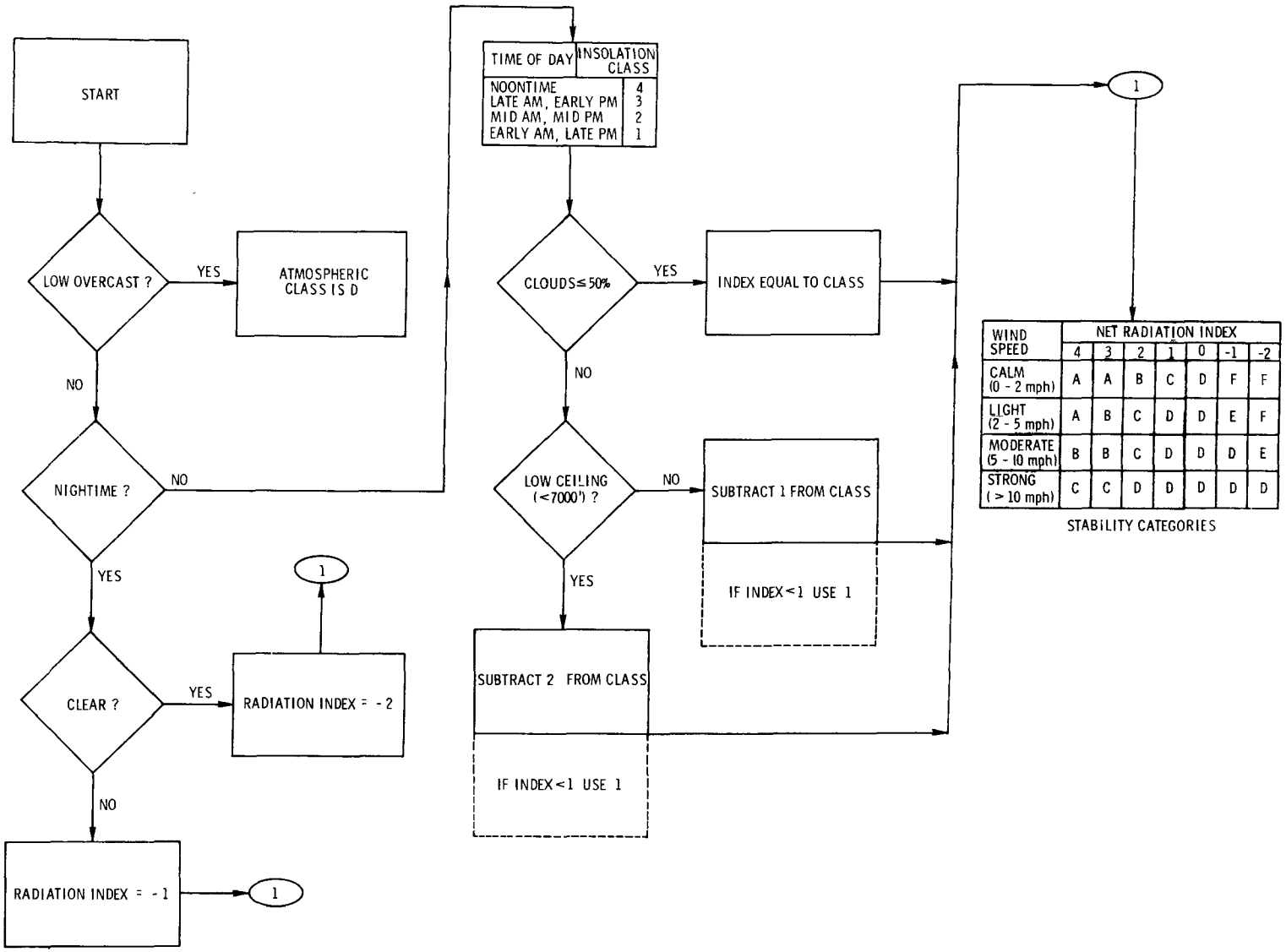

Figure C-1. Flow chart of atmospheric stability class determination[36]

Table C-1. CONTINUOUS FUNCTION FOR LATERAL ATMOSPHERIC DIFFUSION COEFFICIENT σ_y [37]

$$\sigma_y = AX^{0.9031}$$

Stability class	A
A	0.3658
B	0.2751
C	0.2089
D	0.1471
E	0.1046
F	0.0722

Table C-2. CONTINUOUS FUNCTION FOR VERTICAL ATMOSPHERIC DIFFUSION COEFFICIENT σ_z [38]

$$\sigma_z = AX^B + C$$

Usable range	Stability class	Coefficient		
		A_1	B_1	C_1
>1000 m	A	0.00024	2.094	-9.6
	B	0.055	1.098	2.0
	C	0.113	0.911	0.0
	D	1.26	0.516	-13
	E	6.73	0.305	-34
	F	18.05	0.18	-48.6
		A_2	B_2	C_2
100 - 1000 m	A	0.0015	1.941	9.27
	B	0.028	1.149	3.3
	C	0.113	0.911	0.0
	D	0.222	0.725	-1.7
	E	0.211	0.678	-1.3
	F	0.086	0.74	-0.35
		A_3	B_3	
<100 m	A	0.192	0.936	
	B	0.156	0.922	
	C	0.116	0.905	
	D	0.079	0.881	
	E	0.063	0.871	
	F	0.053	0.814	

where ψ = dose, g-s/m^3

Q_D = line source emissions per length of line, g/m

σ_{zI} = instantaneous vertical dispersion parameter, m

u = mean wind speed, m/s

For neutral stability:

$$\sigma_{zI} = 0.15\ x_C^{0.7} \qquad \text{(C-4)}$$

where x_C = crosswind distance from the line source, m

Equation C-3 is a line source diffusion model and is used to find the mass emissions per length of road. The value of the dose, ψ, is determined by multiplying the concentration by the actual sampling time.

3. DATA COLLECTION

Each variable for these models was determined in the field by use of the sampling arrangement shown in Figure C-2. For each concentration reading, displayed by direct digital readout, the mean wind speed was determined by averaging 15-s readings (a stopwatch was used) of the wind meter. This meter is connected to the anemometer which sits atop a 3.05-m (10-ft) pole. Distance x was measured by visual observation of the number of combine swaths downwind of the source. The 6.1-m (20-ft) wide swaths could be counted by the rows of threshed grain stalks left on the field.

All these data were recorded for each sampling run on the form shown in Figure C-3 while in the field. The time of day and atmospheric stability (determined following Figure C-1) were recorded periodically on the bottom of the form.

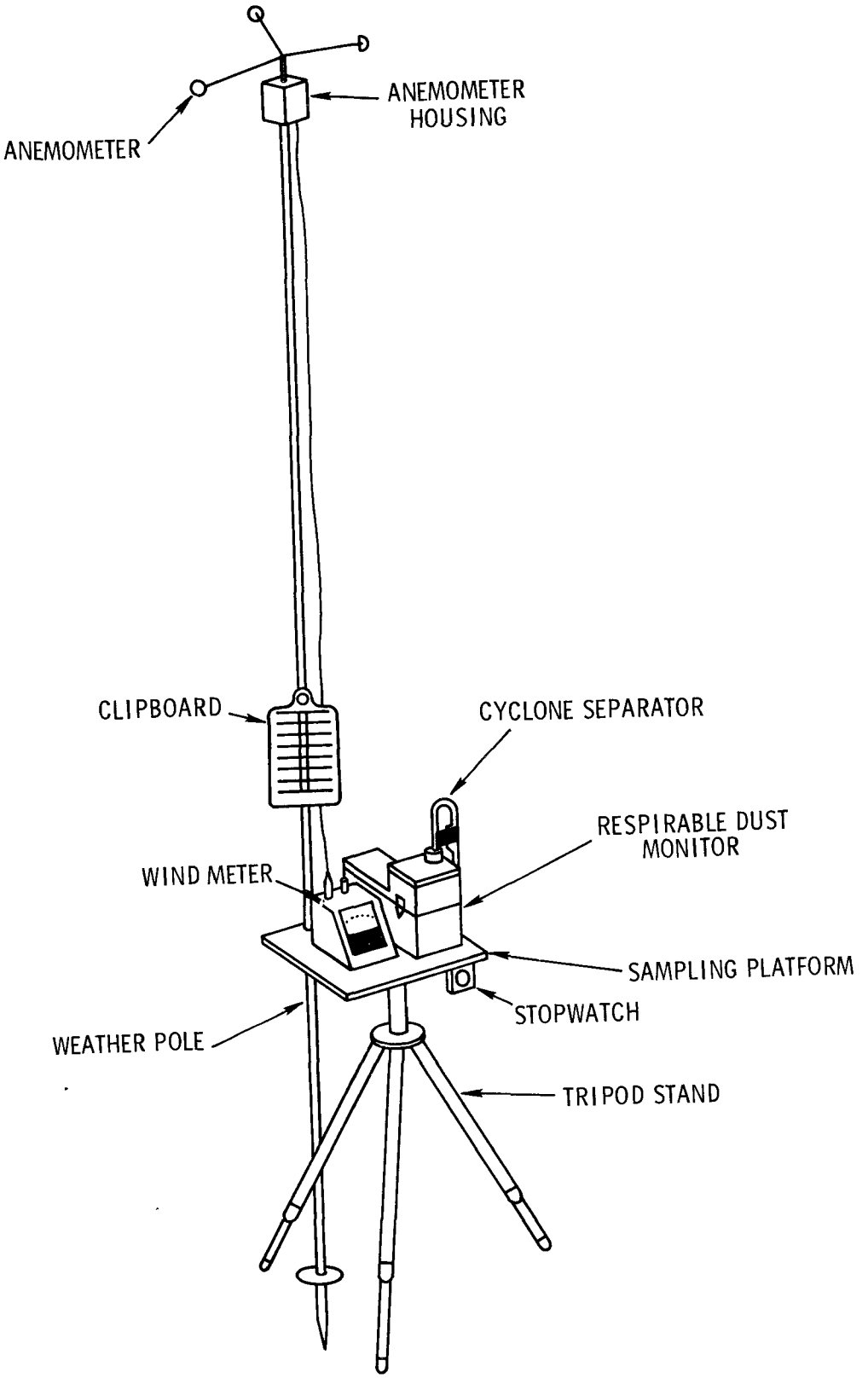

Figure C-2. Sampling apparatus

DATE _____

MODEL: POINT = 1
LINE = 2
DOSE = 3

SOURCE TYPE _____

BY _____

UNIT OPERATION	WIND SPEED, MPH	DISTANCE, FT. X	Y	Z	TIME, MIN.	READ., mg/m^3	CONC. $\mu g/m^3$	R/T	BGD, $\mu g/m^3$	Δ, $\mu g/m^3$	Q, g	S'	M	COMMENTS
											-			

TIME OF DAY ____ ____ ____ ____ ____

ATM. STABILITY ____ ____ ____ ____ ____

TOTAL SAMPLING TIME	MULTIPLY READING BY
4 MINUTES	1
8 MINUTES	0.46
16 MINUTES	0.23
20 MINUTES	0.184
30 MINUTES	0.122
37 MINUTES	0.1

Figure C-3. Field data form

The terms used on the field data form are explained below.

Table C-3. EXPLANATION OF FIELD DATA FORM TERMS

Term (units)	Meaning
Read (mg/m^3)	Concentration reading
Conc. ($\mu g/m^3$)	Converted concentration for sampling times greater than 4 minutes (lower right hand corner).
R/T	R = respirable reading T = total mass reading
BGD ($\mu g/m^3$)	Background concentration
Δ ($\mu g/m^3$)	The difference between the converted concentration and the background
Q (g or g/sec)	Calculated emission rate
S'	Stability for the time of day the unit operation was sampled
M	The model used referenced as 1, 2, or 3 (point, line, or dose, respectively)

Any factors that might have affected concentration or emission rate were mentioned in the column labeled "Comments." When this form was completed the data were programmed into a computer and the emission rate, Q, calculated in accordance with the model specified in the column labeled "M."

4. PROCEDURES

a. Harvest Machine Activity

The harvest machine is a mobile source which travels along a line. The original intent was to sample this source from a stationary position (using the arrangement in Figure C-1) and apply a line source model. However, while sampling in the field the concentration was undetectable with this method. The speed of the combine (9.65 km/hr) and length of

the field (∿3.2 km) caused the instrument to remain in the plume for only 10 s to 15 s. The actual sampling time of the GCA is 3 minutes 40 seconds for a 4-minute run. The remaining 20 seconds is devoted to initial and final beta counts.[35] The instrument was thus in the plume only 4.5% to 6.8% of the time. The remaining time was spent sampling background concentration levels. This caused dilution of the 10-s to 15-s sample and resulted in undetectable concentrations.

The solution to the problem was to keep the monitor in the plume centerline by carrying it alongside the combine. This was possible because the instrument was portable and the plume was visible. The sampling platform (Figure C-2) was removed from the tripod and the anemometer connected, minus pole, to the platform. In this manner wind speed was determined while walking alongside the combine.

Concentration readings were immediately obtained using this technique, and they were all within the same order of magnitude. The combine thus became a continuous point source, and the model represented by Equation C-1 was used to calculate the emission rate.

b. Loading the Truck

The sampling platform was returned to the tripod for measurement of the emissions from the loading of trucks with grain kernels. It was possible to stay at a fixed downwind position and remain in the centerline of the plume from this operation. The point source model, Equation C-2, was therefore used to describe the emissions, and sampling procedures described above were followed.

c. Transport on the Field

The platform had to be left on the tripod for sampling the emissions from transport on unpaved roads. This is a mobile line source similar to the combine, but the faster truck speed (16.1 to 32.2 km/hr) did not allow walking alongside the source. After a few undetectable readings were obtained at a stationary position, it became evident that the monitor was not in the plume long enough to capture a measureable amount of particulate, given the 4-minute sampling time. In order to provide a sufficient capture time, the truck was driven back and forth upwind of the sampler. The number of passes and speed of the truck were recorded on the sampling form (Figure C-3). Markers were placed along the road to assure travel of a constant back and forth distance.

This procedure involved starting the sampler, walking to the truck, and driving back and forth between the markers for 4 to 5 minutes. The time it took to walk to the truck did not dilute the sampling results because the initial beta count was occurring during this time. Using this method the instrument periodically received short-term releases of particulates. The Equation C-2 model was therefore used. Emission rates from this model are divided by the number of passes of the vehicle to yield the emission rate per vehicle pass.

5. ANALYSIS

The composition of the particulate was determined using the Bendix Model 150 Telmatic Air Sampler. This unit consists of a pump, charcoal filter, and tubing connected to a cassette encasing a Millipore® filter.[a] The sampler is

[a]Millipore Corp., Bedford, Massachusetts.

battery operated, portable, and can be preset to run up to an hour, or continuously (depending on battery-life). During sampling the unit is set to run continuously while the GCA sampling of the source proceeds. The starting time and flow rate of the unit are recorded on the form shown in Figure C-4. Pertinent data are obtained and recorded in the same manner as with the GCA instrument. At the end of the sampling period, time and flow rate are again recorded. An average flow rate is then determined, along with estimates of the mean wind speed and distance from the source. The filter is then weighed and ashed in the laboratory. Analysis is performed by infrared spectrophotometry to determine the free silica content.[40] It is assumed that this free silica is all respirable dust.

A sampling time of 3 hr to 5 hr is required to obtain an adequate particulate collection for analysis. A sample was taken downwind of the combine activity in the field. Samples could not be taken of the loading or transport activities due to their short operating durations. In addition, if the magnitude of free silica emissions from the combine activity were found to be low there would be no need to sample the grain loading activity. Therefore, this initial analysis did not require sampling these operations.

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[40] Cares, J. W., A. S. Goldin, J. J. Lynch, and W. A. Burgers. The Determination of Quartz in Airborne Respirable Granite Dust by Infrared Spectrophotometry. American Industrial Hygiene Association Journal. 34:298-305, July 1973.

SITE SAMPLED	WIND SPEED, MPH	DISTANCE, FT X	Y	Z	ATM. STAB	START TIME	FLOW, LPM	STOP TIME	FLOW, LPM	SAMPLE TIME	AVG. FLOW LPM	SAMPLE NO.	DATE	MODEL	COMMENTS

DATE _____ _____ _____ _____ _____

TIME OF DAY _____ _____ _____ _____ _____

ATM. STABILITY _____ _____ _____ _____ _____

Figure C-4. Cassette sampling worksheet

APPENDIX D

SAMPLING RESULTS

1. EMISSION RATES

The total emission rate from grain harvesting is a composite of the emission rates from each of the harvesting activities. However, each of these activities takes a different length of time. This fact will be reflected in the total emission rate by weighting each of the emission rates by its duration. The reference or common denominator time used is the time required to harvest and load a truck-full of grain.

The average amount of grain loaded onto a truck, $\overline{G}_L$, is 8,691 kg.[41] In Table D-1 it can be seen that grain has an average weight per volume, $\overline{W}_G$, of 664 kg/m^3 and an average volume per area, $\overline{V}_G$, of 303 m^3/km^2.[42] Therefore, a truck carrying a load of 8,691 kg represents the harvest of an area, A_H, calculated in Equations D-1 and D-2:

$$A_H = \frac{(\overline{G}_L)}{(\overline{W}_G)(\overline{V}_G)} \qquad \text{(D-1)}$$

$$= \frac{8{,}691 \text{ kg}}{(664 \text{ kg/m}^3)(303 \text{ m}^3/\text{km}^2)} = 0.043 \text{ km}^2 \qquad \text{(D-2)}$$

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[41] 1972 Highway Statistics. U.S. Department of Transportation, Federal Highway Administration. U.S. Government Printing Office. Washington. Stock No. 5001-00066. 216 p.

[42] Agricultural Statistics 1973. U.S. Department of Agriculture. U.S. Government Printing Office. Washington. Stock No. 0100-02841. 617 p.

Table D-1. AVERAGE GRAIN WEIGHT PER VOLUME AND VOLUME PER AREA

Grain	W_G, kg/m^3	V_G, m^3/km^2
Wheat	773	216
Rye	683	164
Oats	399	381
Corn	657	623
Barley	580	329
Grain sorghum	722	415
Soybeans	773	208
Flaxseed	722	86
Arithmetic mean	664	303

The time required to harvest this area (A_H) is calculated from the speed and swath width of the harvest machine. These machines operate at speeds up to 6.71 m/s,[43] with the mean, $\overline{H}_S$, assumed to be 3.36 m/s. The average swath width, $\overline{S}_W$, of a combine is 6.07 m. Using Equation D-3:

$$T_S = \left(\frac{1 \times 10^6 \text{ m}^2}{\text{km}}\right)\left(\frac{\text{km}}{(S_W)(H_S)}\right)\left(\frac{\text{hr}}{3{,}600 \text{ sec}}\right) \qquad \text{(D-3)}$$

the time to harvest 1 km^2, T_S, is calculated in Equation D-3 as 13.62 hr/km^2. The time required to harvest the 0.043 km^2 area, T_H, is then calculated from Equation D-4 as 0.59.

$$T_H = T_S \cdot A_H \qquad \text{(D-4)}$$

In addition, the time required to load this grain onto the truck, T_L, is approximately 6 minutes. The composite time

[43] Zimmerman, M. D. Field-Going Factories: Agricultures' Amazing Monster Machines. Machine Design. 47(20):16-22, August 1975.

required to harvest and load a truck full of grain, T_T, is calculated in Equation D-5:

$$T_T = T_H + T_L = 0.69 \text{ hr} \qquad \text{(D-5)}$$

The weighted emission rates can thus be calculated for each of the harvesting activities using this time reference.

The emission rate for the machine harvesting activity, Q_H, is calculated from the sampling results for wheat and sorghum harvesting presented in Tables D-2 and D-3. (The original data sheets and computer printouts are located in Appendix H). Combining these tables, the arithmetic mean emission rate is 8.38 ± 7.0 mg/s at the 95% confidence level. However, an F-test of these tables shows that the ratio of the variances for emission rates for wheat and sorghum harvesting are non-homogeneous. This illustrates the fact that the grain type is not a critical factor.

Table D-2. EMISSION RATES FROM WHEAT HARVESTING MACHINE ACTIVITY

Emission rates, g/s	
3.969×10^{-3}	3.696×10^{-3}
8.353×10^{-3}	4.859×10^{-3}
6.776×10^{-3}	3.031×10^{-3}
2.582×10^{-3}	3.689×10^{-3}
2.129×10^{-3}	2.578×10^{-3}
2.346×10^{-3}	4.653×10^{-3}
2.460×10^{-3}	1.801×10^{-3}
3.760×10^{-3}	1.091×10^{-3}
1.620×10^{-3}	2.082×10^{-3}

The emission rate for loading of the trucks, Q_L, is the arithmetic mean of two values obtained during sampling,

Table D-3. EMISSION RATES FROM SORGHUM HARVESTING MACHINE ACTIVITY

Emission rates, g/s	
4.552×10^{-3}	3.571×10^{-3}
6.411×10^{-3}	2.162×10^{-2}
1.941×10^{-2}	8.406×10^{-2}

1.692×10^{-3} g/s and 1.819×10^{-3} g/s. This value is 1.76 ± 0.8 mg/s at the 95% confidence level.

The emission rate for the transport of the harvested crop on a field was determined with the results presented in Table D-4. These values were all obtained at a downwind distance of 18 m. Four values were obtained at vehicle speeds of 4.47 m/s and four values at 8.94 m/s. Thus the arithmetic mean emission rate of 0.009 ± 0.004 g/veh-m at the 95% confidence level, used to calculate the emission rate per time period was obtained over these two values of vehicle speed. At 4.47 m/s, the rate was 0.005 ± 0.001 g/veh-m, and at 8.94 m/s, it was 0.012 ± 0.005 g/veh-m, illustrating that emission rate varies with vehicle speed.

Table D-4. EMISSION RATES, TRANSPORT ON THE FIELD

Vehicle speed, m/s	Wind speed, m/s	Concentration, $\mu g/m^3$	Travel distance, m	Emission rate, g/veh-m
4.47	4.1	30	293	0.005
8.94	6.3	40	475	0.006
4.47	3.6	30	293	0.004
8.94	4.5	90	439	0.011
4.47	5.9	20	329	0.004
8.94	4.5	160	439	0.019
4.47	5.9	40	402	0.007
8.94	7.2	50	329	0.012

During the harvesting of the 0.043 km^2 reference ares, the distance traveled, D_T, is twice (round trip) the representative distance, D, calculated in Appendix E, or 660 m. The vehicle travels this distance during the 0.69 hr (T_T) required to harvest and load the next truck. The mean speed a truck travels on the field lies between 2.4 m/s and 6/71 m/s, with a mean speed, $\bar{V}_S$, of 4.48 m/s chosen. The time required to transport (T_{TR}) the grain the distance on the field (D_T) is calculated from Equation D-6.

$$T_{TR} = \frac{D_T}{\bar{V}_S} \qquad \text{(D-6)}$$

$$= 660 \text{ m}/(4.48 \text{ m/s}) = 125 \text{ s} = 0.035 \text{ hr}$$

The time-based emission rate for transport is calculated in Equation D-7.

$$Q_{TR} = (0.009 \text{ g/veh-m})(660 \text{ m}) \left(\frac{\text{hr}}{3{,}600 \text{ s}}\right)\left(\frac{\text{veh}}{0.035 \text{ hr}}\right)\left(\frac{1{,}000 \text{ mg}}{\text{g}}\right) \qquad \text{(D-7)}$$

$$= 47 \pm 20.7 \text{ mg/s at the 95\% confidence level}$$

The weighted emission rate for each of the harvesting activities is calculated from the product of each emission rate and the ratio of time required to perform the activity and composite time, T_T. These values are tabulated and calculated in Table D-5. The composite emission rate, Q_T, is thus the sum of the composite ratio for each activity and is calculated in Equation D-8.

$$Q_T = Q_{TH} + Q_{TL} + Q_{TTR} \qquad \text{(D-8)}$$

$$= 9.8 \pm 14.5 \text{ mg/s at the 95\% confidence level}$$

Table D-5. TIME-AVERAGED EMISSION RATES

Activity	$\frac{\text{Time of activity}}{\text{Composite time}}$ hr	x	Emission rate mg/s	=	Weighted emission rate mg/s
Machine activity	$\left(\frac{T_H}{T_T}\right)$ $\frac{0.59}{0.69}$		(Q_H) 8.38		(Q_{TH}) 7.16
Loading	$\left(\frac{T_L}{T_T}\right)$ $\frac{0.10}{0.69}$		(Q_L) 1.76		(Q_{TL}) 0.26
Transport	$\left(\frac{T_{TR}}{T_T}\right)$ $\frac{0.035}{0.69}$		(Q_{TR}) 47.0		(Q_{TTR}) 2.38

Free silica was detected by sampling the harvest machine activity. For a sample of 0.6 mg collected, 0.014 mg of free silica (detected as quartz) was present. This constitutes 2.3% (by weight) of the particulate from the machine activity. The grain harvested contained 0.012% silicon[44] whereas the soil contained 62.1% silica in the upper 38 mm.[45] Assuming these figures reflect the proportion of free silica in the dust, it is concluded that the free silica originates from the soil.

[44]Kent, N. L. Technology of Cereals with Special Reference to Wheat. The Commonwealth and International Library of Science, Technology, Engineering, and Liberal Studies Research Association of British Flour Millers, 1966. 262 p.

[45]Soil Classification - a Comprehensive System - 7th Approximation. U.S. Department of Agriculture, Soil Survey Staff, Soil Conservation Service. U.S. Government Printing Office. Washington. August 1960. 265 p.

Free silica contents of soils where grains are harvested have a maximum respirable free silica content somewhere between 5% and 10%.[46] The free silica content of a soil is basically equal to the free silica content in the dust.[47] Emissions of free silica, Q_S, are therefore generated by the machine activity and transport on the field. The weighted emission rate for these two operations is 9.54 ± 7.03 mg/s at the 95% confidence level.

2. EMISSION FACTORS

The emission factor for the machine activity, E_M, is obtained from the emission rate and the time required to harvest 0.043 km^2. This is calculated in Equation D-9 as:

$$E_M = \left(\frac{8.38 \text{ mg}}{\text{s}}\right)\left(\frac{\text{g}}{1{,}000 \text{ mg}}\right)\left(\frac{0.59 \text{ hr}}{0.043 \text{ km}^2}\right)\left(\frac{3{,}600 \text{ s}}{\text{hr}}\right) \qquad \text{(D-9)}$$

$$= 413.91 \pm 834.8 \text{ g/km}^2$$

The emission factor for loading the harvested crop, E_L, is the product of the emission rate and the time it takes to load the truck divided by 0.043 km^2, as shown in Equation D-10:

$$E_L = \left(\frac{1.76 \text{ mg}}{\text{s}}\right)\left(\frac{\text{g}}{1{,}000 \text{ mg}}\right)\left(\frac{360 \text{ s}}{0.043 \text{ km}^2}\right) \qquad \text{(D-10)}$$

$$= 14.71 \pm 0.75 \text{ g/km}^2$$

For transporting the grain crop, the emission factor, E_{TR}, is the emission rate multiplied by the time of transport

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[46] Personal communication. Dr. Warren Lynn and Dr. Steven Holzhey. National Soil Survey Laboratory, Lincoln, Nebraska. September 4, 1975.

[47] Sheinbaum, M. Comparative Concentration of Silica in Parent Material and in Airborne Particulate Matter. American Industrial Hygiene Association Journal. 22(4):313-317, August 1961.

associated with the harvesting of 0.043 km^2 divided by the harvest area. This is calculated in Equation D-11:

$$E_{TR} = \left(\frac{47\ mg}{s}\right)\left(\frac{g}{1{,}000\ mg}\right)\left(\frac{126\ s}{0.043\ km^2}\right) \qquad (D\text{-}11)$$

$$= 137.7 \pm 76.2\ g/km^2$$

The composite emission factor, E_T, for the harvesting of grain is the summation of the emission factors for each of the grain activities. This factor is calculated in Equation D-12:

$$E_T = E_H + E_L + E_{TR} \qquad (D\text{-}12)$$

$$= 413.9 + 14.7 + 137.7$$

$$= 566.3 \pm 838.3\ g/km^2$$

In Equation D-13, the emission factor for free silica, E_S, is computed from the emission factors for machine activity and transport of the harvest of 0.043 km^2.

$$E_S = E_H + E_{TR} \qquad (D\text{-}13)$$

$$= 551.6 \pm 838.3\ g/km^2$$

The variation of these emission factors represents the deviation at the source sampled; however, these variations do not apply to all sources. Confidence limits are not used since this was a preliminary sampling of one source, two grain types.

APPENDIX E

DERIVATION OF THE REPRESENTATIVE SOURCE

The individual emission sources from the harvesting of grain are the fields and farms upon which these activities occur. A representative source is the arithmetic mean size of a grain field harvested per farm. There are 380,596 farms harvesting grain in the United States.[10] Table E-1[11] lists the number of farms harvesting each crop. Dividing the total from Table E-1 (850,347) by the total number of grain farms (380,596) yields the arithmetic mean number of grain crops harvested per farm, 2.23. The size of each grain field is taken as the arithmetic mean of the average size of each grain farm per state (Table E-2).[10,11] This field is 0.44 km^2 ± 0.06 km^2 at the 95% confidence level. The average grain farm harvests (2.33)(0.44) or 0.98 km^2 of land. However, the crops are seasonal, harvested at different periods during the year. The release of particulates or maximum concentration thus occurs only when a single crop is harvested, and the representative source occurs when the arithmetic mean grain field area of 0.44 km^2 is harvested. It takes (13.62 hr/km^2)(0.44 km^2) or 6.0 hr to harvest this crop. Assuming the field is square, 660 m x 660 m, the average transport distance (and therein distance to the boundary) is 1/2(660 m), or 330 ± 122 m at the 95% confidence level. The state population densities are listed in

Table E-1. NUMBER OF FARMS HARVESTING EACH GRAIN[11]

Crop	Number of farms
Corn	220,465
Sorghum	51,156
Wheat	205,562
Oats	102,573
Barley	43,015
Rye	10,291
Soybeans	205,641
Flaxseed	11,644
TOTAL	850,347

Table E-2. AVERAGE SIZE OF EACH GRAIN FARM PER STATE[10,11]

State	Farm size, km^2
Alabama	0.34
Arizona	0.72
Arkansas	0.39
California	0.87
Colorado	0.71
Connecticut	0.38
Delaware	0.29
Florida	0.55
Georgia	0.41
Idaho	0.52
Illinois	0.23
Indiana	0.26
Iowa	0.22
Kansas	0.43
Kentucky	0.29
Louisiana	0.54
Maine	0.66
Maryland	0.24

Table E-2 (continued). AVERAGE SIZE OF EACH GRAIN FARM PER STATE

State	Farm size, km^2
Massachusetts	N.A.[a]
Michigan	0.15
Minnesota	0.36
Mississippi	0.49
Missouri	0.32
Montana	0.91
Nebraska	0.36
Nevada	0.65
New Hampshire	0.27
New Mexico	0.65
New York	0.19
North Carolina	0.25
North Dakota	0.53
Ohio	0.18
Oklahoma	0.53
Oregon	0.70
Pennsylvania	0.17
Rhode Island	N.A.
South Carolina	0.34
South Dakota	0.53
Tennessee	0.29
Texas	0.55
Utah	0.47
Vermont	N.A.
Virginia	0.24
Washington	1.09
West Virginia	0.22
Wisconsin	0.22
Wyoming	0.57

[a]N.A. = not available.

Table E-3.[48] The arithmetic mean population density of all the states (Table E-3) is 39.9 persons/km^2.

The respirable free silica content of soil ranges from 0 to 10%. Soil upon which wheat harvesting is performed has a high silt content (maximum 10%).[46] Therefore, sampling of this soil illustrated that the free silica found in the dust (2.33%) was within the same order of magnitude as the free silica content of the soil.

Table E-3. POPULATION DENSITY PER GRAIN HARVESTING STATE (persons/km^2)[47]

State	Population density
Alabama	27
Arizona	7
Arkansas	15
California	50
Colorado	9
Connecticut	240
Delaware	106
Florida	48
Georgia	31
Idaho	4
Illinois	76
Indiana	57
Iowa	20
Kansas	11
Kentucky	31
Louisiana	30
Maine	12

[48] Statistical Abstracts of the United States, 1973. U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census. U.S. Government Printing Office. Washington. Stock No. 0324-00113/ 0324-00108. 1014 p.

Table E-3 (continued). POPULATION DENSITY PER GRAIN HARVESTING STATE (persons/km^2)

State	Population density
Maryland	177
Massachusetts	-[a]
Michigan	60
Minnesota	18
Mississippi	18
Missouri	27
Montana	2
Nebraska	7
Nevada	2
New Hampshire	32
New Mexico	3
New York	145
North Carolina	39
North Dakota	2
Ohio	102
Oklahoma	15
Oregon	9
Pennsylvania	103
Rhode Island	-
South Carolina	34
South Dakota	2
Tennessee	38
Texas	17
Utah	5
Vermont	-
Virginia	46
Washington	20
West Virginia	27
Wisconsin	31
Wyoming	1

[a]Dashes indicate not applicable.

APPENDIX F

CALCULATION OF SOURCE SEVERITY

Mean severity is calculated for each of the three operations: harvest machine activity, loading, and transport. For criteria pollutants, severity is defined as the time-averaged maximum ground level concentration ($\bar{\chi}_{max}$, Equation G-2, Appendix G) divided by the national primary ambient air quality standard. Noncriteria pollutants are divided by an exposure time-corrected TLV.

For average U.S. conditions (Class C stability, wind speed 4.5 m/s) the severity for respirable particulates is:

$$S_P = \frac{\bar{\chi}_{max,P}}{F_P} \qquad \text{(F-1)}$$

where S_P = particulate (<7 μm) severity

$\bar{\chi}_{max,P}$ = time average of maximum ground level particulate concentration, g/m^3

F_P = national primary standard for total suspended particulates, 2.6×10^{-4} g/m^3

The representative distance is the same as the average field transport distance of 330 m for the representative source (see Appendix E) of 0.44 km^2.

For the harvest machine activity the point source model (Equation C-2, Appendix C) is applied to Equation F-1 to yield a mean source severity of 11.2×10^{-4}. Loading of the harvested grain crop has a severity of 3×10^{-5}. Transport of the crop while on the field has a severity of 0.017. With all these activities occurring, the total severity is 3.5×10^{-3}.

For noncriteria pollutants, the severity is calculated by Equation F-2:

$$S = \frac{\bar{\chi}_{max}}{F} \qquad \text{(F-2)}$$

where S = severity

F = corrected TLV (i.e., TLV · 8/24 · 1/100), g/m^3

$\bar{\chi}_{max}$ = time-averaged maximum ground level concentration, g/m^3

TLV = threshold limit value for the pollutant, g/m^3

The TLV for particulates (containing >1% free silica) is based on the maximum free silia content of soils, 10%. The TLV is calculated[13] as 10 mg/m^3 (% quartz + 2) where % quartz represents the free silica detected as quartz. The TLV is thus calculated to be 0.83 mg/m^3 and the hazard factor $F = 0.0028$ mg/m^3. Using Equation 1, the mean source severity for free silica particles is ≤ 0.29.

The affected population for respirable particulate severities greater than 0.1 is zero persons since the severity is 0.0035 at the representative source. Free silica, however, has a source severity of ≤ 0.29. A severity of 0.1 is achieved when in Equation F-3:

$$0.1 = \frac{\bar{\chi}_{max}}{F} \qquad \text{(F-3)}$$

The value of F is 0.0028 mg/m^3, or in Equation F-2, 0.00028 $mg/m^3 = \bar{\chi}_{max}$. Solving Equation C-2, the value of x for severity S = 0.1 occurs at 576 m. Assuming a circular source, the area of the circle at 576-m radius (S = 0.1) minus the area of the circle at 330-m radius (the plant boundary severity level) will yield the area affected; hence:

$$\begin{aligned} \text{Area affected} &= \pi(576^2 - 330^2) \\ &= 699{,}830 m^2 \\ &= 0.7\ km^2 \end{aligned} \qquad \text{(F-4)}$$

As the representative population density of 39.9 persons/km^2, the affected population for free silica is:

$$\left(\frac{39.9 \text{ persons}}{km^2}\right)(0.7\ km^2) = 28 \text{ persons}$$

The source severity distribution for respirable particulates is not developed since the severity for the representative source is three orders of magnitude less than 1. However, the free silica severity distribution is derived from Equation F-2.

The value of $\bar{\chi}_{max}$ for free silica emissions is computed from Equation C-2, Appendix C. Using C-2 in Equation F-2 results in:

$$S = \frac{Q/\pi\sigma_y\sigma_z u}{F} \qquad \text{(F-5)}$$

where $F = TLV \times \frac{8}{24} \times \frac{1}{100}\ g/m^3$

At Class C stability and U.S. average wind speed (Appendix C), Equation F-5 yields:

$$S = \frac{316Q}{x^{1.814}TLV} \qquad \text{(F-6)}$$

The value of TLV for free silica from grain harvesting is 0.83 mg/m^3. Therefore Equation F-6 yields:

$$S = \frac{380Q}{x^{1.814}} \qquad \text{(F-7)}$$

Assuming grain production (P_G) is proportional to the area of the field:

$$P_G = K_1 x^2 \qquad \text{(F-8)}$$

where x equals distance to the plant boundary and K is a constant.

Therefore, distance x is:

$$x = K_2 (P_G)^{1/2} \qquad \text{(F-9)}$$

In Equation F-7, emission rate (Q) equals the production, P_G, multiplied by an emission factor, E. Substituting $Q = P_G \cdot E$ and Equation F-9 into Equation F-6 yields:

$$S = \frac{380P_G \cdot E}{x^{1.814}} \qquad \text{(F-10)}$$

Severity for the representative plant, S_R, and production rate, P_R, is thus:

$$S_R = \frac{380P_R \cdot E}{x^{1.814}} \qquad \text{(F-11)}$$

Dividing Equation F-10 by F-11 yields:

$$S = S_R \left(\frac{P}{P_R}\right)^{0.093} \qquad \text{(F-12)}$$

Therefore the distribution of grain production (P_G) per farm with the known representative production rate (P_R) and severity (S_R) will yield severities (S) for other sources.

The distribution of harvested grain land is listed in Table F-1.[10]

Table F-1. DISTRIBUTION OF HARVESTED GRAIN LAND[10]

Average farm size, acres	Percent
803	9
409	19.4
259	25.9
146	24.3
83	21.4

The severity distribution, computed using Equation F-11 and Table F-1, at $S_R = 0.29$ and $P_R = 0.98$ km^2 = 242 acres, is presented in Table F-2.

Table F-2. FREE SILICA SEVERITY DISTRIBUTION

Severity	Percent
0.32	9
0.30	19.4
0.29	25.9
0.28	24.3
0.26	21.4

Cumulative distribution is plotted in the text in Figure 2.

APPENDIX G

DETERMINATION OF MAXIMUM POLLUTANT CONCENTRATIONS

The four categories of pollutants emitted from this source are: (1) respirable particulates (less than 7-μm geometric mean diameter) which are termed "inert" and nuisance," (2) respirable particles that contain free silica (detected as quartz), (3) particulates which contain pesticide residue, and (4) microorganisms on the particulates or detached from them. These pollutants will be analyzed for comparison with the evaluation criteria.

The downwind concentration of these pollutants is calculated from Equation G-1:[23]

$$\chi_{max} = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad \text{(G-1)}$$

where χ_{max} = the maximum concentration at a downwind distance (x), g/m^3

Q = emission rate, g/s

u = average wind speed, m/s

σ_y, σ_z = dispersion standard deviations in horizontal and vertical planes respectively

A "maximized" concentration is computed from the upper confidence limit of the weighted emission rate and lower confidence limits of the dispersion standard deviations. This concentration is then compared to the hazard potential of each emission. However, this concentration must be corrected

for time-averaged wind direction variations not reflected in σ_y. The 24-hr concentration is thus calculated from Equation G-2:

$$\chi_S = \chi_K \left(\frac{t_K}{t_S}\right)^P \qquad \text{(G-2)}$$

where χ_S = the concentration for sampling time, t_S
χ_K = the concentration for the sampling time, t_K
P = 0.17 to 0.20 (mean 0.185)

The sampling time, t_K, for concentrations obtained from Equation G-1 is equivalent to the operation time of the harvesting activity. For all pollutants considered, the average U.S. wind speed is 4.5 m/s and the stability class approximates C. The dispersion standard deviations (under C stability) are calculated from Equations G-3 and G-4:

$$\sigma_y = 0.2089(x^{0.9031}) \qquad \text{(G-3)}$$

$$\sigma_y = 0.113(x^{0.911}) \qquad \text{(G-4)}$$

where x = downwind distance, m

The average grain field is harvested with a distance to the boundary of 330 ± 122 m at the 95% confidence level. Therefore, using Equations G-3 and G-4. the values of σ_y and σ_z at the lower confidence level are 25.9 m and 14.6 m, respectively.

The inert (nuisance) respirable particulates are emitted at a weighted rate of 9.8 ± 7.4 mg/s (@ 95% confidence level) from all grain harvesting operations (machine activity, loading, and transport). Using Equation G-1, the maximum concentration is corrected to a 24-hr exposure, using

Equation G-2, to 1.17 $\mu g/m^3$. The primary air quality standard for these particulates is 260 $\mu g/m^3$. This is two orders of magnitude greater than the maximum concentration obtained when all grain harvesting operations are considered.

Particulates containing free silica are emitted at a weighted rate of 9.54 ± 7.03 mg/s (at 95% confidence level) from the harvest machine activity and the transport on field roads. Using Equations G-1 and G-2, the maximum concentration is 1.13 $\mu g/m^3$. The threshold limit value for particulates containing 10% free silica is 0.83 mg/m^3 (Appendix F). This TLV is corrected to the hazard factor, F, through Equation G-5:

$$F = (TLV)(8/24)(1/100) \qquad (G-5)$$

Therefore, F = 2.76 $\mu g/m^3$. This is over twice the maximum concentration obtained when the machine activity and transport of the crop occur simultaneously.

In Appendix A, pesticide residue concentration levels found on plants were increased by three orders of magnitude to a dust concentration level. For the pesticide with the lowest TLV (Endrin), the hazard factor using Equation G-5 is 0.33 $\mu g/m^3$. The maximum downwind concentration (Equations G-1 and G-2) is 7.9×10^{-3} $\mu g/m^3$. This is two orders of magnitude less than the hazard factor. For the pesticide with the highest concentration (polychlorinated biphenyls), the hazard factor is 1.66 $\mu g/m^3$. The maximum concentration level is 0.035 $\mu g/m^3$. The hazard factor is two orders of magnitude greater than this concentration.

The ranges of source severity are determined from the confidence limits at the 95% level. For criteria pollutants (respirable particulates) the emission rate is 9.8 ± 7.4 mg/s

at a distance of 330 ± 122 m at the 95% level. The source severity therfore ranges from 1.7×10^{-3} to 1.2×10^{-2}. For noncriteria pollutants the emission rate is 9.54 ± 7.03 mg/s at a distance of 330 ± 122 m (at the 95% level). The source severity thus ranges between 0.17 and 1.12 (with the TLV constant at 0.83 mg/m^3 based on maximum respirable free silica soil content).

The population affected for free silica at severity of 0.1 to the maximum 1.12 is calculated from the differences in downwind distance, x. As computed in Appendix F, S = 0.1 at 576 m, as S = 1.12,

$$1.12 = \frac{\bar{\chi}_{max}}{F} \qquad \text{(G-6)}$$

and using Equation G-1, the value of x is 155 m. The area affected is thus:

$$\begin{aligned} \text{Area affected} &= \pi(576^2 - 155^2) \qquad \text{(G-7)} \\ &= 966{,}338 \text{ m}^2 \\ &= 0.97 \text{ km}^2 \end{aligned}$$

The maximum population affected is thus:

$$(0.97 \text{ km}^2) \quad \frac{39.9 \text{ persons}}{\text{km}^2} = 39 \text{ persons}$$

The maximum national and state emissions burdens, calculated from the upper limit (@ 95% level) of emission factor, are 0.014% and 0.206%, respectively.

The data in this appendix are maximized values calculated from confidence limits. These data are summarized and tabulated in Table G-1. From inspection, the maximum severity for free silica particulates (1.12) exceeds the evaluation criteria. This value is calculated from the upper confidence

Table G-1. MAXIMIZED EVALUATION CRITERIA VALUES

Pollutant	Source	Hazard factor, $\mu g/m^3$	Concentration, $\mu g/m^3$	Evaluation criteria			
				Severity	Population affected for S>0.1	National emission burden, % of total	State emission burden, % of total
Respirable particulates	Entire source	260	1.83	1.2×10^{-2}	0	0.014	0.206 [d]
Free silica particulates	Entire source	2.76	1.76	1.12	39	_[b]	_[b]
Pesticide residues							
Highest conc.	Machine activity	1.66	0.035	_[a]	_[a]	_[b]	_[b]
Lowest TLV	Machine activity	0.33	7.9×10^{-3}	_[a]	_[a]	_[b]	_[b]
Microorganisms	Machine activity	N.A.[c]	N.A.	N.A.	N.A.	_[b]	_[b]

[a] Not calculated since $\bar{\chi}_{max}$ is four orders of magnitude less than TLV.

[b] Not applicable.

[c] N.A. = not available.

[d] North Dakota.

limit of emission rate, and the maximum possible respirable free silica soil percentage. However, this affects only 39 persons, not accounting for the fact that this is based on state population densities. Farm fields are located in rural areas where population densities are lower than state population densities. In addition, the harvesting of the representative field is accompoished in 6 hr as shown below:

$$\frac{13.62 \text{ hr}}{\text{km}^2} (0.44 \text{ km}^2) = 6 \text{ hr}$$

The corrected threshold limit values are based on a 24-hr annual exposure for a 5-day work week. Using the logic applied in calculating the corrected TLV, the TLV for dose exposure to free silica could be corrected by the multiplier:

$$\frac{6 \text{ hr}}{\left(\frac{24 \text{ hr}}{\text{day}}\right)\left(\frac{260 \text{ day}}{\text{yr}}\right)} = 9.6 \times 10^{-4}$$

Given the above levels, coupled with the fact that grain harvesting is a basic and highly necessary function of the economy, further consideration of the source via sampling was not deemed necessary.

SECTION IX

GLOSSARY

ANEMOMETER - A rotating cup device used at a meteorological station for measuring wind speed.

ATMOSPHERIC STABILITY CLASS - A categorization used to describe the turbulent structure and wind speed of the atmosphere.

ATTRACTANTS - Chemicals used to lure pests away from cultivated crops.

BALER - A mechanical device used to tie the grain crop into bundles.

BETA ABSORPTION - The degree of attenuation of beta rays passing through a medium.

BINDER - A machine that cuts and binds a crop into bundles.

CHAFF - Plant tissue fragments from threshed grain.

COMBINE - A machine that cuts, screens, and threshes grain in one operation.

CONFIDENCE LEVEL - The probability that a random variable lies within a given range with a normal distribution.

CONFIDENCE LIMITS - The upper and lower boundaries of a range in which a random variable can exist at a given probability.

CONTOURING - Creating furrows along natural elevation lines so as to avoid erosion.

CRITERIA POLLUTANTS - Particulate matter, carbon monoxide sulfur dioxide, and hydrocarbons.

EMISSIONS BURDEN - The ratio of a pollutant from a source category to the state and national level of that pollutant.

ENTRAINMENT RATE - The rate of wind capture of dust particles.

FORAGE - Vegetable matter, fresh or preserved, utilized as feed for animals.

FREE SILICA - Silicon dioxide molecules oriented in a fixed pattern.

GRANULOMATOUS - Containing chronically inflamed tissue marked by the formation of granulations.

INFLORESCENCE - The flowering portion of the plant.

INSOLATION CLASS - Factor expressing the radiation received by the earth's surface.

NONCRITERIA POLLUTANT - Any pollutant for which ambient air quality standards have not been established.

PICKER/PICKER-SHELLER - Machines that mechanically pick and husk the cobs from the corn plant. The sheller unit also removes the kernels.

PULMONARY FIBROSIS - An abnormal increase in the amount of fibrous connective tissue in the lungs.

QUARTZ - SiO_2; a brilliant, crystalline mineral.

RADIATION INDEX - Relative categorization used to describe incoming solar waves.

SEVERITY - The ratio of the maximum concentration of a pollutant to the hazard factor of that pollutant.

SHELTERBELT - A row of trees or bushes planted perpendicular to the prevailing wind direction to shield a field from wind erosion.

SHOCK - A group of grain sheaves stacked together.

SILAGE - Forage that has been stored and preserved in a succulent condition by partial fermentation.

SILICOSIS - A chronic disease of the lungs caused by the continued inhalation of silica dust.

SMUT - Plant disease characterized by the appearance of masses of spores which break up into a find powder.

SPECTROPHOTOMETRY - The analytical technique for comparing the color intensities of different spectra.

STRIPCROPPING - Crop planting in which strips of heavy rooted and loose rooted plants are alternated to lessen wind erosion.

SWATH - A strip of cut herbage lying on the stubble.

TERRACES - Flat platforms of earth with sloping sides, rising one above the other to lessen wind erosion.

WEATHERING - The partial digestion of the starch and increase of mold growth on the grain kernel.

WINDROW - A row of grain plants raked together to dry before being baled or put into shocks.

SECTION X

CONVERSION FACTORS AND METRIC PREFIXES[49]

CONVERSION FACTORS

To convert from	to	Multiply by
grams/kilometer^2 (g/km^2)	pounds/acre	9.124×10^{-6}
grams/meter^3 (g/m^3)	pounds/bushel	7.770×10^{-5}
grams/sec (g/sec)	grains/sec	1.543×10^{1}
kilogram (kg)	grains	1.543×10^{4}
kilogram (kg)	pound (mass)	2.205
kilogram (kg)	ton	1.102×10^{-3}
kilometer/hour (km/hr)	miles/hr	6.215×10^{-1}
kilogram/meter^3 (kg/m^3)	pounds/ft^3	6.242×10^{-1}
kilometer^2 (km^2)	acres	2.471×10^{2}
meter (m)	feet	3.281
meter (m)	mil	3.937×10^{4}
meter (m)	mile	6.215×10^{-4}
meter/second (m/sec)	feet/sec	3.281
meter^2 (m^2)	acres	2.471×10^{-4}
meter^2 (m^2)	feet^2	1.076×10^{1}
meter^3 (m^3)	bushels (U.S.)	2.838×10^{1}
meter^3 (m^3)	feet^3	3.531×10^{1}
meter^3/kilometer^2 (m^3/km^2)	bushels/acre	1.150×10^{-1}
metric ton	pound (mass)	2.205×10^{3}
micrograms/meter^3 (μg/m^3)	grains/yard^3	1.180×10^{-5}
milligrams/kilogram (mg/kg)	grains/ton	1.400×10^{1}

[49]Metric Practice Guide. American Society for Testing and Materials. Philadelphia, ASTM Designation: E380-74, November 1974. 34 p.

CONVERSION FACTORS (continued)

To convert from	to	Multiply by
milligrams/second (mg/s)	grains/sec	1.543
milligrams/meter^3 (mg/m^3)	grains/feet^3	4.371×10^{-4}
persons/kilometer^2 (persons/km^2)	persons/acre	4.047

PREFIXES

Prefix	Symbol	Multiplication factor	Example
kilo	k	10^3	1 kg = 1 x 10^3 g; 1 km^2 = $(10^3$ m$)^2$ = 10^6 m^2
milli	m	10^{-3}	1 mg = 1 x 10^{-3} g
micro	μ	10^{-6}	1 μm = 1 x 10^{-6} m

SECTION XI

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TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
1. REPORT NO. EPA-600/2-77-107f	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE SOURCE ASSESSMENT: HARVESTING OF GRAIN, State of the Art		5. REPORT DATE July 1977 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R.A. Wachter and T.R. Blackwood		8. PERFORMING ORGANIZATION REPORT NO. MRC-DA-698
9. PERFORMING ORGANIZATION NAME AND ADDRESS Monsanto Research Corporation 1515 Nicholas Road Dayton, Ohio 45407		10. PROGRAM ELEMENT NO. 1AB015; ROAP 21AXM-071 11. CONTRACT/GRANT NO. 68-02-1874
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Task Final; 5-12/75 14. SPONSORING AGENCY CODE EPA/600/13
15. SUPPLEMENTARY NOTES IERL-RTP task officer for this report is David K. Oestreich, Mail Drop 62, 919/541-2547.		

16. ABSTRACT The report describes a study of air pollutants generated by the harvesting of grain. Grain harvesting produces respirable particulates in the form of soil dust and plant tissue fragments. The former contains free silica, while the latter contains pesticide residues and microorganisms. Emissions are generated by the harvest machine activity, loading of the harvested crop, and transport while on the field. The source severity was 0.0012 for respirable particulates and < or =0.11 for free silica. Grain harvesting contributes 0.006% of the national particulate emissions burden. (Source severity is a measure of the hazard potential of a representative emission source; for this source type, it was defined as the ratio of the time-averaged maximum ground level concentration of a species emitted, to a hazard factor which is the primary AAQS for particulate and a time-adjusted TLV for silica.) Specific air pollution control technology for grain harvesting is presently nonexistent.

17. KEY WORDS AND DOCUMENT ANALYSIS				
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Plant Tissues	Air Pollution Control	13B	06C
Grain Crops	Silicon Dioxide	Particulates	02D	07B
Harvesting	Pesticides	Source Severity		06F
Agricultural Machinery	Microorganisms		02C	06M
Dust			11G	
Soils			08G,08M	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Unlimited	Unclassified	96
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)