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ESTIMATE OF CONTRIBUTION OF JET AIRCRAFT OPERATIONS TO TRACE ELEMENT CONCENTRATION AT OR NEAR AIRPORTS

by J. Stuart Fordyce and Dean W. Sheibley

Lewis Research Center

Cleveland, Ohio 44135

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16. Abstract

Samples of ASTM type A jet fuel were analyzed for trace-element content by instrumental neutron activation techniques. Forty-nine elements were sought Only ten, aluminum, gold, indium, lanthanum, titanium, vandium, barium, dysprosium, tellurium, and uranium, were observed at levels above the detection limits encountered; of these only aluminum, titanium, and barium were present at concentrations greater than 0.1 ppm. Estimates of exhaust gas concentrations are made, and the ambient contribution at or near airports is calculated by using the Los Angeles International Airport dispersion model. It is shown that the ambient contribution is about an order of magnitude below typical urban levels for virtually all elements sought.

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SUMMARY

Samples of ASTM type A jet fuel were analyzed for trace-element content by instrumental neutron activation techniques. Forty-nine elements were sought. Only ten, aluminum, gold, indium, lanthanum, titanium, vanadium, were observed at levels above the detection limits encountered; of these only aluminum, titanium, and barium were present at concentrations greater than 0.1 ppm. Estimates of exhaust gas concentrations are made, and the ambient contribution at or near airports is calculated by using the Los Angeles International Airport dispersion model. It is shown that the ambient contribution is about an order of magnitude below typical urban levels for virtually all elements sought.

INTRODUCTION

The concern in recent years for the environmental impact of jet aircraft has amplified the need to improve the understanding of the emissions from jet engines under various operating conditions. Extensive work has been done on the gaseous emissions (carbon monoxide, hydrocarbons, nitrogen oxides, and sulfur dioxide) and on total particulates (smoke) (ref. 1). Combustion modifications are being studied to reduce the emissions (ref. 2) and to accommodate increases in air traffic while meeting the air quality standards established under the Clean Air Act of 1970 (PL88-206) and its various ammendments.

The particulate emissions are perhaps the least understood. Measurements have typically been based on the empirical "smoke number" (ref. 3), which is difficult to relate to mass concentration. The composition of the particulate matter is 96 percent carbon by weight and consists of particles in the submicron range (ref. 4).

Linden and Heywood (ref. 5) point out that the extent to which gas turbine smoke is a harmful pollutant is not presently well understood and in regard to trace carcinogenic components is apparently of negligible importance. Shabad and Smirnov (ref. 6), however, report emissions of 2 to10 milligrams of benzo (a) pyrene per minute from Soviet engines depending on power setting and aromatic content of fuel. The National Academy of Sciences has emphasized the need for further definitive work on this matter (ref. 7), and studies are currently under way at the NASA Lewis Research Center to examine gas turbine exhausts for polycyclic organic matter in the particulate.

Less attention has been directed to trace elements from the fuel, lubricating oils, and engine wear. These elements should be studied because (1) the presence of trace elements in the exhaust possibly provides a "tracer" for jet combustion products to separate them from other combustion sources, (2) their impact at ground level may be of some concern as pollutants, and (3) perhaps of more significance, their emission at flight altitudes either tropospheric or stratospheric may provide heretofore unrecognized catalytic surfaces for various chemical reactions in the upper atmosphere and possibly perturb atmospheric composition. The current interest in the impact of high flying aircraft on the atmosphere exemplified by the Climatic Impact Assessment Program of the Department of Transportation emphasizes the need for information of this kind.

This report is a preliminary attempt to obtain a measure of the trace-element content of commercial jet fuels and hence an estimate of the trace-element content of the emissions from that source. The only previous experimental data on trace elements in jet fuel appear to be the work of Bicher (ref. 8), who found copper, manganese, magnesium, and aluminum in JP-6 fuel at concentrations of 0.125, 0.004, 0.5, and 0.15 part per million (60, 1.8, 240, and 7 μg/lb), respectively, by neutron activation analysis techniques. The values for magnesium and aluminum were not reproducible, and the experiment was limited by the use of a sodium iodide detector. Eckardt (ref. 9) gives upper limits of 0.1, 0.05, 0.05, and 0.10 part per million for nickel, vanadium, lead, and copper respectively.

EXPERIMENT

Samples of ASTM type A jet fuel were obtained from two storage tanks at the NASA Lewis Research Center. The fuel was transferred to a clean glass bottle prerinsed with fuel and sent to the Lewis Research Center Plum Brook Reactor Facility for neutron activation analysis.

The methodology for multielement instrumental neutron activation analysis used by the Plum Brook facility has been described (refs. 10 and 11). Short irradiations were performed with polyethylene vials, and long irradiations were done with the sample sealed in ultrapure quartz. A cold-finger condenser in liquid nitrogen was used to cool the volatile liquid to a slushy consistency, and the quartz was sealed off rapidly by using an oxygen-acetylene flame. The samples irradiated in a thermal neutron flux of 1.5×10^{14} neutrons per square centimeter per second were counted after various decay times with a lithium-drifted germanium detector coupled to conventional energy dispersion counting equipment with 4096 channels. The gamma spectra were analyzed by an appropriate data reduction code, SPECTRA (refs. 10 and 11).

RESULTS AND DISCUSSION

The results of the analysis expressed in parts per million by weight are listed in table I. Values with the less than sign indicate the sensitivity for the particular element under the conditions of the analysis. Elements not listed were not sought. Three samples were analyzed from tank A and one from tank B; the mean value for Tank A is shown with a less than sign when two of the three samples have "less than" values. The precision of the analysis expressed as one standard deviation is typically better than ±20 percent except for sulfur, where the uncertainty is ±50 percent (refs. 10 and 11). The values obtained are generally consistent with those cited in the INTRODUCTION, and the sulfur content agrees with the fuel supplier's analysis of 0.03 percent. This value is an order of magnitude less than the maximum permitted for this grade of fuel, though in practice the maximum values found are generally less than 0.15 percent.

If one estimates the concentration of these elements in a typical exhaust gas

from a jet engine (with no dispersion), values of approximately 10 to 40 parts per billion in the exhaust per 1 part per million in the fuel are found depending on the fuel-air ratio, which typically varies from 0.01 to 0.03 at takeoff and cruise and 0.008 to 0.01 during taxiing or idling. The approximate engine exhaust concentration ranges are listed in table II for those elements measurable in the fuel by instrumental neutron activation analysis.

To relate these exhaust gas concentrations to what actually is encountered in the ambient air at ground level from jet emissions, one needs a dispersion model computation. Such a computation has been performed for Los Angeles International Airport for the major pollutants, sulfur dioxide (SO_2), carbon monoxide (CO), hydrocarbons, and particulates (ref. 1), and provides an estimate of aircraft impact. Since aircraft SO_2 originates from the oxidation of the sulfur (S) in the fuel, calculating the ratio of the ambient concentration calculated with the model to the exhaust gas concentration of SO_2 provides a dispersion factor F which can be used for the other exhaust constituents.

The dispersion factors can be obtained for the various calculated ambient concentrations from the highest estimated exhaust gas concentration from the fuel analyzed in this work, that is, 3.15×10^4 microgram per cubic meter of S as SO_2, which corresponds to the highest fuel-air ratio. These ambient concentrations and calculated dispersion factors are listed in table III for the various averaging times examined in the Los Angeles study.

The values of maximum ambient concentrations are about 2×10^{-3} times the exhaust gas concentrations for the 3-hour averaging time and an order of magnitude smaller for the longer averaging times. The annual average maximum concentration from aircraft is in virtually all cases an order of magnitude or more smaller than typical urban or rural concentrations of these elements (refs. 12 to 14 and unpublished data obtained at the Lewis Research Center for the City of Cleveland by Robert B. King et al.); the latter values are compared in table IV on the basis of the highest concentration in the fuel, the highest fuel-air ratio, and $F = 10^{-4}$. Exceptions are noted in the case of titanium and indium, where concentrations due to aircraft are comparable to urban and rural levels. Unfortunately, the analytical results for titanium vary from sample to sample, so this conclusion is subject to question. Furthermore, for cadmium, cerium, strontium, hafnium, and zirconium the sensitivity of the analysis is inadequate for conclusions to be drawn.

The use of these elements as tracers for jet aircraft combustion products is therefore shown to be impractical in or near urban areas, where airports are usually located. Since jet fuel is a refined product, it may be possible to assume that the variability of its trace element composition is not large, though variable contamination in storage and distribution facilities may occur. With this assumption and the results shown in table IV it may be concluded that trace elements originating in jet fuel and estimated in this work constitute no added public health impact over that found in urban air.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, February 15, 1974,
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TABLE I. - ACTIVATION ANALYSIS OF JET FUEL

Element	Tank A. sample 1	Tank A. sample 2	Tank A. sample 3	Tank A. mean	Tank B
	Concentration, ppm by wt.				
Aluminum	6	3	5	4.8±1	<4
Calcium	<4	<4	<5	<4	<5
Chlorine	<10	16	<10	<12	<12
Bromine	<.3	.5	<.3	<.4	<.3
Gold	.008	.004	.001	.004±.002	<.007
Indium	.006	.003	.003	.004±.001	.004
Iodine	<.07	<.06	<.06	<.06	<.1
Lanthanum	<.02	.05	.024	.037±.01	<.02
Manganese	<.05	<.05	<.05	<.05	<.05
Sodium	<7	<8	<9	<8	<9
Samarium	<.002	<.002	<.002	<.002	<.004
Scandium	<.003	<.003	<.003	<.003	<.003
Sulfur	360	334	292	329±24	332
Titanium	<2	<3	9	5	<1
Vanadium	.022	.025	.040	.029±.007	.021
Barium	.18	.12	.11	.14±.03	<.1
Dysprosium	.008	.009	.009	.0086±.0005	.0003
Tellurium	.054	<.02	.01	.032±.02	<.1
Uranium	.001	.002	.001	.001±.0003	<.0009
Antimony	<.03	<.02	<.02	<.02	<.003
Arsenic	<.01	<.003	<.006	<.006	<.02
Cadmium	<3	<3	<3	<3	<3
Cerium	<.05	<.04	<.4	<.2	<.09
Cesium	<.005	<.005	<.01	<.007	<.003
Chromium	<.05	<.05	<.02	<.04	<.08
Cobalt	<.009	<.006	<.008	<.008	<.004
Copper	<.2	<.1	<.3	<.2	<.3
Europium	<.001	<.0007	<.003	<.002	<.0004
Gallium	<.03	<.02	<.02	<.02	<.02
Hafnium	<.03	<.02	<.01	<.02	<.04
Iridium	<.002	<.08	<.02	<.03	<.03
Iron	<3	<3	<8	<5	<3
Lutetium	<.002	<.002	<.002	<.002	<.0009
Magnesium	<85	<130	<14	<76	<6
Mercury	<.006	<.007	<.03	<.014	<.007
Neodymium	<.2	<.3	<.2	<.2	<.2
Potassium	<7	<7	<5	<6	<8
Rhodium	<.006	<.01	<.02	<.012	<.02
Rubidium	<.09	<.06	<.22	<.12	<.02
Selenium	<.05	<.05	<.06	<.05	<.04
Silver	<.03	<.04	<.08	<.05	<.03
Strontium	<2	<3	<3	<3	<.07
Tantalum	<.01	<.003	<.01	<.008	<.004
Terbium	<.0002	<.0002	<.0002	<.0002	<.0001
Thorium	<.001	<.003	<.02	<.008	<.004
Tungsten	<.03	<.05	<.07	<.05	<.04
Ytterbium	<.009	<.02	<.09	<.04	<.003
Zinc	<3	<.3	<3	<2	<.7
Zirconium	<3	<8	<6	<6	<5

TABLE II. - ELEMENTAL CONCENTRATIONS IN NONDISPERSED EXHAUST GAS

Element	Concentration	
	ppb by wt.	$\mu g/m^3$ (a)
Aluminum	48-192	57.5-230
Gold	0.04-0.16	0.048-0.19
Indium	0.04-0.16	0.048-0.19
Lanthaum	0.37-1.48	0.44-1.77
Sulfur[b]	6580-26 320	7880-31 500
Titanium	50-200	60-240
Vandium	0.29-1.16	0.35-1.39
Barium	1.4-5.6	1.67-6.7
Dysprosium	0.086-0.344	0.103-0.412
Tellurium	0.32-1.28	0.383-1.53
Uranium	0.01-0.04	0.012-0.048

[a] $\mu g/m^3 = 1.198 \times$ ppb by wt.
[b] As sulfur dioxide.

TABLE III. - ESTIMATED AVERAGE AMBIENT SULFUR DIOXIDE CONCENTRATIONS AND DISPERSION FACTORS FROM LOS ANGELES AIRPORT MODEL CALCULATION

[Data from reference 1; maximum values.]

Location	Annual average		24-Hour average		3-Hour average	
	Sulfur dioxide concentration, $\mu g/m^3$	Dispersion factor, $F \times 10^4$	Sulfur dioxide concentration, $\mu g/m^3$	Dispersion factor, $F \times 10^4$	Sulfur dioxide concentration, $\mu g/m^3$	Dispersion factor, $F \times 10^3$
Outside terminal	12	3.8	10	3.2	64	2.03
Airport boundary	8	2.5	9	2.9	76	2.41
Airport neighborhood	3	.95	3	.95	68	2.2

TABLE IV. - COMPARISON OF ESTIMATED ANNUAL AVERAGE AMBIENT CONCENTRATIONS DUE TO AIRCRAFT WITH RURAL AND URBAN CONCENTRATIONS

Element	Estimated annual average due to aircraft	Ref. 12		Ref. 14. urban	Ref. 13. urban	King et al. urban
		Rural	Urban			
	Concentration, ng/m^3					
Aluminum	23	1200	2 180	--------	----	1008-3660
Calcium	<24	1000	7 000	--------	----	1160-4038
Chlorine	<58	--------	--------	--------	----	428-1914
Bromine	<1.9	32	83	--------	----	107-307
Gold	.019	--------	--------	--------	----	----------
Indium	.019	.04	.1	--------	----	0.015-0.11
Iodine	<.48	--------	--------	--------	----	1.7-6
Lanthanum	.177	1.3	5.9	--------	----	1.5-3.5
Manganese	<.24	62	255	20-170	----	64-187
Sodium	<43	170	455	--------	----	252-1128
Samarium	<.019	.24	.41	70	----	0.2-0.5
Scandium	<.014	1.2	3.1	--------	----	0.32-0.93
Titanium	24	120	190	--------	40	146-439
Vanadium	.12	5	18	30-140	50	5-14
Barium	.67	--------	--------	80	----	22-76
Dysprosium	.041	--------	--------	--------	----	0.11-0.31
Tellurium	.155	--------	--------	--------	----	----------
Uranium	.005	--------	--------	--------	----	0.3-1.3
Antimony	<.096	5.8	25	--------	1	5-228
Arsenic	<.96	4.6	12	--------	20	7.4-36
Cadmium	<14	--------	--------	10	2	1.7-6.5
Cerium	<.96	.82	13	--------	----	2.2-4.5
Cesium	<.034	--------	--------	--------	----	0.31-1.02
Chromium	<.38	9.5	113	--------	15	8.9-26
Cobalt	<.038	.95	2.6	--------	----	0.9-4.3
Copper	<1.4	290	1 070	100-400	90	24-790
Europium	<.0096	.055	.14	--------	----	0.04-0.11
Gallium	<.096	.9	1.3	--------	----	0.97-4.2
Hafnium	<.19	--------	--------	--------	----	0.18-0.54
Iridium	<.145	--------	--------	--------	----	0.8-1.6
Iron	<24	1900	13 800	600-1800	1580	1443-7460
Lutetium	<.0096	--------	--------	--------	----	0.06-0.15
Magnesium	<364	500	2 400	--------	100	380-1383
Mercury	<.067	1.9	4.8	--------	----	0.34-1.3
Neodymium	<.96	--------	--------	--------	----	----------
Potassium	<38	750	1 415	--------	----	468-1634
Rhodium	<.096	--------	--------	--------	----	----------
Rubidium	<.58	--------	--------	--------	----	3.2-11.3
Selenium	<.24	2.5	3.8	--------	----	2.4-8.7
Silver	<.24	--------	2.4	--------	----	0.56-1.5
Strontium	<14	--------	--------	--------	----	----------
Tantalum	<.038	--------	--------	--------	----	0.07-0.23
Terbium	<.001	--------	--------	--------	----	0.007-0.01
Thorium	<.038	27	113	--------	----	0.2-0.7
Tungsten	<.24	.4	5.8	--------	----	1.8-10.4
Ytterbium	<.19	--------	--------	--------	----	0.4-0.9
Zinc	<9.6	140	1 400	100-1700	670	199-481
Zirconium	<29	--------	--------	--------	----	----------

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