AIR EMISSIONS FROM MULTIPLE HEARTH SLUDGE INCINERATION: A PROCESS APPROACH

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ABSTRACT

The draft regulations (40 CFR Part 503) proposed by EPA for sludge incineration and the increasing scrutiny in NPDES permit renewal activities of the emissions from sludge incineration demand a better understanding of the air pollutant generation and control characteristics of these systems. With such knowledge, engineers and owners can design and operate their systems to minimize emissions and substantially mitigate potential health effects.

With this goal in mind, 154 sets of multiple hearth furnace process and emissions data were analyzed (55 sets of uncontrolled emission data, 99 sets of controlled emission data with 45 sets of matched inlet-outlet data for the same unit and sludge). The analysis sought correlations between design and operating configuration and emissions/control efficiency. The results supported the formulation of generation/control algorithms for 17 pollutants (TSP, NO_x, SO_2, SO_3, CO, THC, PCDD, PCDF, As, Be, Cu, Ni, Cd, Pb, Hg, Cr and Zn). These algorithms were incorporated into a proprietary computer model (MHF.EXE) which includes: basic heat and material balances (for furnace, afterburner, scrubber and subcooler), followed by emission and control estimators, a stack dispersion estimator (including both downwash and elevated plume models), and current cancer risk potency slopes and toxicity limits (supporting a simplified but direct health risk output).

MHF.EXE operates such as to allow the user to perform "what-if" evaluations of the net change in health impact of changes in furnace conditions, sludge composition, stack height and velocity, afterburner temperature, etc. From the results, optimal conditions for both permit qualification tests and/or steady state operations can be developed.

The paper presents the emission and control correlations and discusses the modeling results with reference to a specific furnace-emissions situation.

INTRODUCTION

MHF.EXE is founded on a process-based analysis of MHF emission data which produced quantitative relationships between design and operational parameters and emissions. The emission relationships are processed in a subsequent program module to estimate the ground level concentration (GLC) of 17 pollutants as a function of wind speed and atmospheric stability conditions. Building downwash effects are considered in the dispersion analysis. Then, using: (a) the toxicity health risk Reference Dose (RfD) factors for the toxic pollutants arsenic, beryllium, cadmium, chromium, lead, mercury, nickel and polychlorinated dioxins and

furans (PCDD, PCDF); and *(b)* the cancer risk potency factors for the key carcinogenic pollutants (arsenic, nickel, cadmium, chromium, beryllium and PCDD/PCDF), a GLC-weighted net health impact parameter (Figure-of-Merit or FOM) for both toxic and carcinogenic impacts are calculated. Overall, therefore, the model is given the basic sludge, incinerator and meteorological scenario as input and outputs a direct measure of health impact. One can then vary the scenario and follow the changes in the FOM. Such a "what-if?" analysis enables one to rapidly assess the value of operational changes, to visualize the impact of changes in sludge quality through enhanced industrial pretreatment programs, to quantitatively judge the merit of capital improvements, etc.

PROGRAM DESCRIPTION AND DERIVATION

Heat and Material Balance Module

The heat and material balance calculations used in MHF.EXE are straightforward. They draw on input data for sludge chemistry, moisture content and heating value; and target overall MHF excess air and top-hearth temperature. Calculations are made to estimate the temperature and flue gas flow rate at the combustion hearth. The conditions at the combustion hearth are calculated by assuming that at that point in the furnace the sludge has a moisture content of 47% and the full excess air quantity is present. The effective moisture content corresponding to the combustion hearth heat balance was estimated from an analysis by Lewis and Lundberg [27] which is in general agreement with observations of operating furnaces.

The calculations continue with an estimation of the fuel needs to attain the input top hearth temperature. Provisions exist to add an afterburner and/or boiler. Air pollution control options include a wet scrubber or an electrostatic precipitator. Stack gas subcooling and stack gas reheat (with steam, hot air addition or fuel firing) are options. Stack height and building dimensions are also variables.

Emission Correlation Module

The relationships between uncontrolled pollutant emissions and design/operating conditions are complex. The carry-over of particulate, the formation of carbon monoxide and other combustible pollutants, the emission patterns of the key toxic metals and so forth change in a nonlinear manner and in response to different system variables. Therefore, a substantial data base which includes both emission and system variables is needed to characterize system behavior. Also, the data must be both ahead of (the uncontrolled emission rate) and following (the controlled emission rate) the air pollution control device such that insightful system-emission relationships may be developed.

To conduct this analysis, a data base which included 55 sets of uncontrolled emission data and 99 sets of controlled emission data were assembled (Refs. 1–26). The data include 45 inlet/outlet data pairs such that control relationships can be analyzed for the same system, sludge and the same sampling/analysis organization.

As with all "real world" data sets, the data vary in an unknown way with the sophistication of the testing firms and vary in completeness relative to the need for a comprehensive set of design, operating and emissions information. While often frustratingly incomplete or clearly including either inaccuracies or assumptions (rather than hard data), the data base supported what appear to be reasonable and useful correlations.

In general, the analysis was conducted by devising possible process variable-emission relationships and then testing the statistical significance of correlations using the coefficient of determination (COD or r-squared) for the least squares fit of the data for differing functional relationships. The scatter inherent in such a group of data from different testing firms, furnaces etc. regularly led to low COD values (say, 0.3–0.7), so graphical visualization of the degree of fit supplemented the purely mathematical test.

The discussions which follow and, where applicable, the attached graphs show the basic uncontrolled emission correlations for TSP, carbon monoxide, total hydrocarbons (THC), nitrogen oxides, the polychlorinated dioxins and furans and the key metals.

Total Particulate (TSP)

The TSP emissions (percent of ash fed to the furnace which is carried over) showed their strongest correlation to the dry, standard cubic meters per minute of furnace flue gas (DSCM) per pound of ash fed to the furnace". For most plants, 2–3% of the ash fed is carried over although, at high excess/air rates, the emissions can reach 5–6%. The suggested linear functional relationship (19 data points, $r^2 = 0.46$) is:

$$\% \text{ of ash in feed} = -0.2382 + 1.09 \, (DSCM) \text{ emitted}$$

The correlation (Fig. 1) is plausible based on the speculation that the primary mechanism for particulate emission is elutriation of fines in the sludge by the flue gas flow.
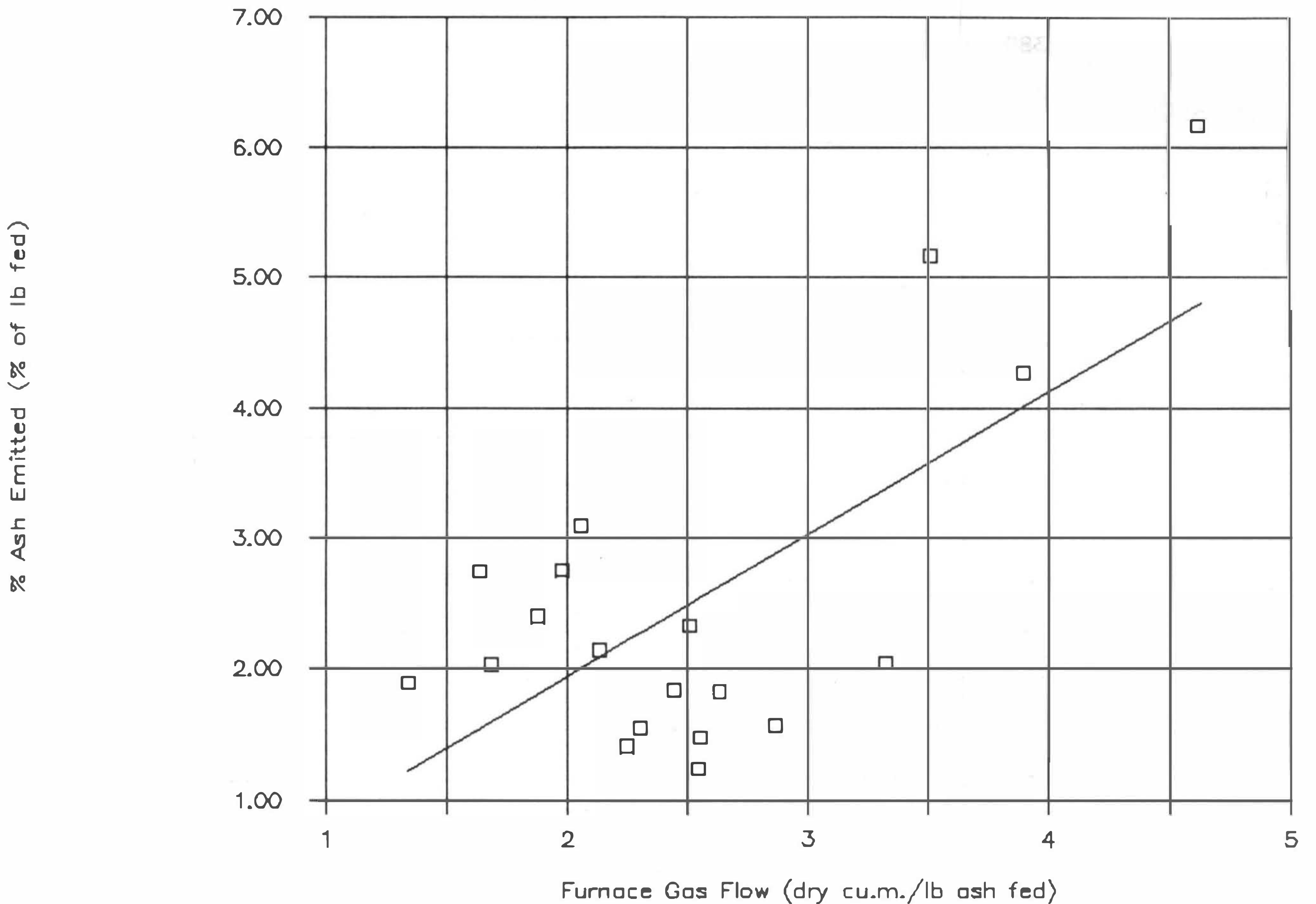
FIG. 1 TSP EMISSION CORRELATION

Nitrogen Oxides (NO$_x$)

Nitrogen oxide emission levels showed a modest correlation with combustion hearth temperature (T_{comb} in °F), but failed to show meaningful relationships with excess air level or other variables which one might expect to drive thermal nitrogen fixation. Unfortunately, the lack of data on sludge nitrogen content made it impossible to explore fuel nitrogen relationships. If one assumes a nominal 3% fuel nitrogen content, no correlations with temperature and oxygen content emerged based on available fuel nitrogen generation algorithms [30].

The best NO$_x$ correlation (shown in Fig. 2) as used in MHF.EXE (38 data points, $r^2 = 0.27$) was:

$$NO_x \text{ ppmdv @ 7\% O}_2 = 2114 - 2.932\, T_{comb} + 0.001096\, T_{comb}{}^2$$

Alternatively, one could use an average NO$_x$ concentration of 283.6 ppmdv (corrected to 7% O$_2$). The standard deviation of these NO$_x$ data is 165.2 ppmdv.

Sulfur Oxides (SO$_2$, SO$_3$)

Since no sludge sulfur content data were available, the SO$_2$ emission factor was set assuming 100% conversion of sludge sulfur content (an input variable to MHF.EXE) to sulfur oxides. The partition between SO$_2$ and SO$_3$ (98.46% SO$_2$), 1.54% SO$_3$ was supported by the data. Of the 35 data points available, the reported uncontrolled SO$_2$ concentration (corrected to 7% O$_2$) ranged from 6.98 ppmdv to 1081.47 ppmdv with an average of 577.6 ppmdv with a standard deviation of 353.4 ppmdv.

Carbon Monoxide

Initial CO emissions data available to the author correlated reasonably well with the temperature on the combustion hearth according to the relationship (15 data points, $r^2 = 0.72$):

$$CO \text{ ppm @ 7\% O}_2 = 23705.11 - 13.7866\, (T_{comb})$$

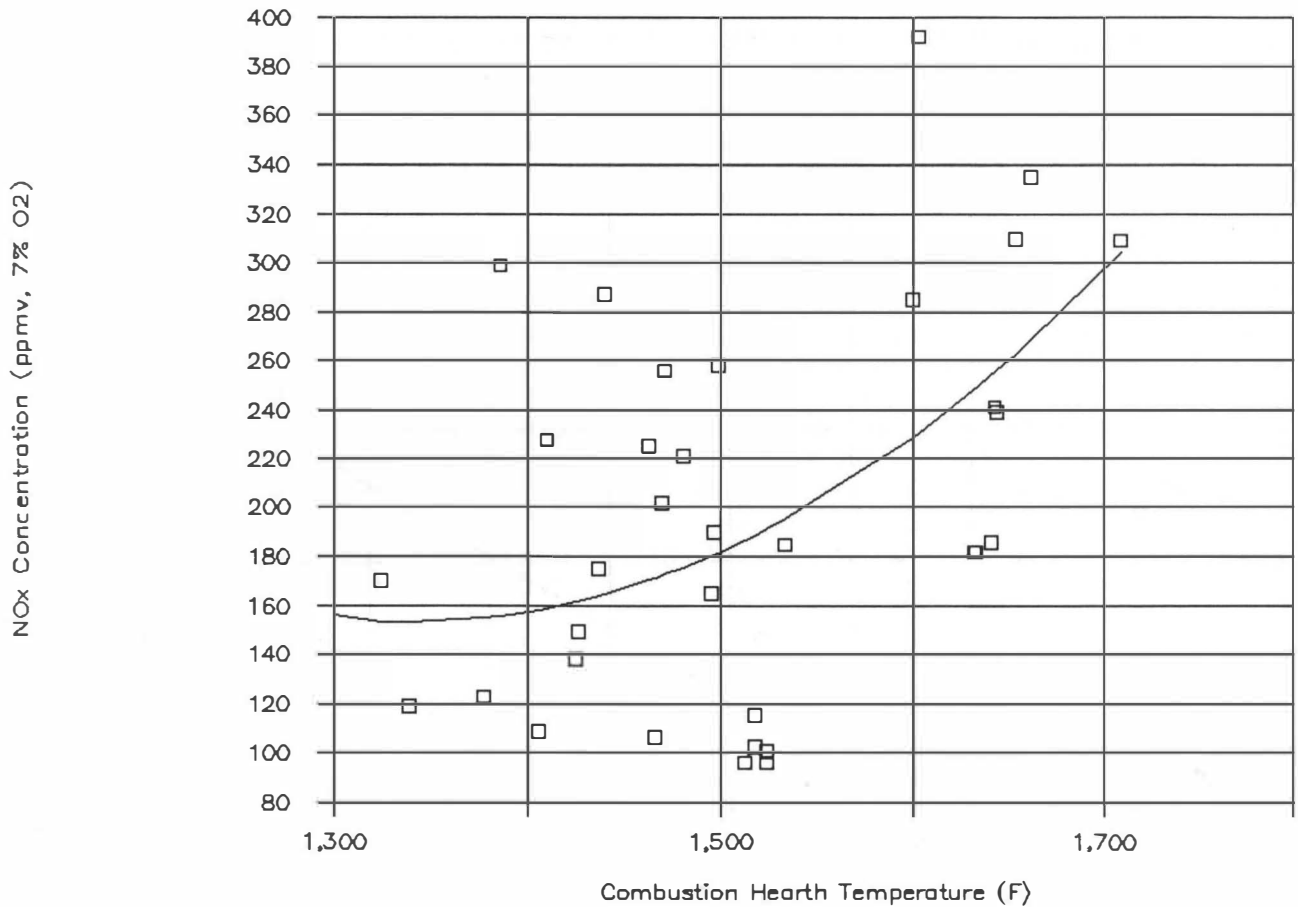Further refinements were attempted to include oxygen concentration but without success. New data [26]

FIG. 2 NO$_x$ VS COMBUSTION HEARTH TEMPERATURE

significantly blurred the correlation (Fig. 3). Exploration of alternate correlations (Fig. 4) indicated a superior correlation between CO and the furnace volumetric flow rate (actual cubic meters/minute) at T_{comb} (32 data points, $r^2 = 0.82$):

$$CO \text{ ppm @ 7\% } O_2 = 1/[0.0001996 + 0.2677E\text{-}6 \text{ (acmm)}]$$

The physical sense of the correlation is uncertain but it is speculated that the relationship reflects turbulence effects and/or, perhaps, the effect of the furnace size. Attempts at correlation with oxygen concentration and top hearth temperature were unfruitful.

Total Hydrocarbons (THC)

THC emission rate correlated well with CO emissions. (14 data points, $r^2 = 0.71$). The data shown in Fig. 5 are correlated by:

$$THC \text{ ppmv @ 7\% } O_2 = 3.14E\text{-}4 \\ (CO \text{ ppmv @ 7\% } O_2)^{1.645}$$

Surprisingly, THC versus temperature correlation was far inferior to that with CO. Correlations with either temperature or oxygen concentration were very poor.

Polychlorinated Dioxins and Furans (PCDD/ PCDF)

Although data are limited and scattered, PCDD and PCDF (independently) showed some limited correlation with combustion hearth temperature. Correlations with CO emission rate were adequate but showed more scatter. The correlations for PCDD and PCDF (10 data points each, $r^2 = 0.22$ and 0.32 respectively) are:

$$PCDD \text{ ug/kg sludge} = 0.3816E3 \exp[-.005778 T_{comb}]$$
$$PCDF \text{ ug/kg sludge} = 0.3142E4 \exp[-.006075 T_{comb}]$$

Metals (Arsenic, Beryllium, Cadmium, Chromium, Copper, Lead, Mercury, Nickel and Zinc)

The metallic emissions showed, in general, a varying sensitivity to the combustion hearth temperature. Es-
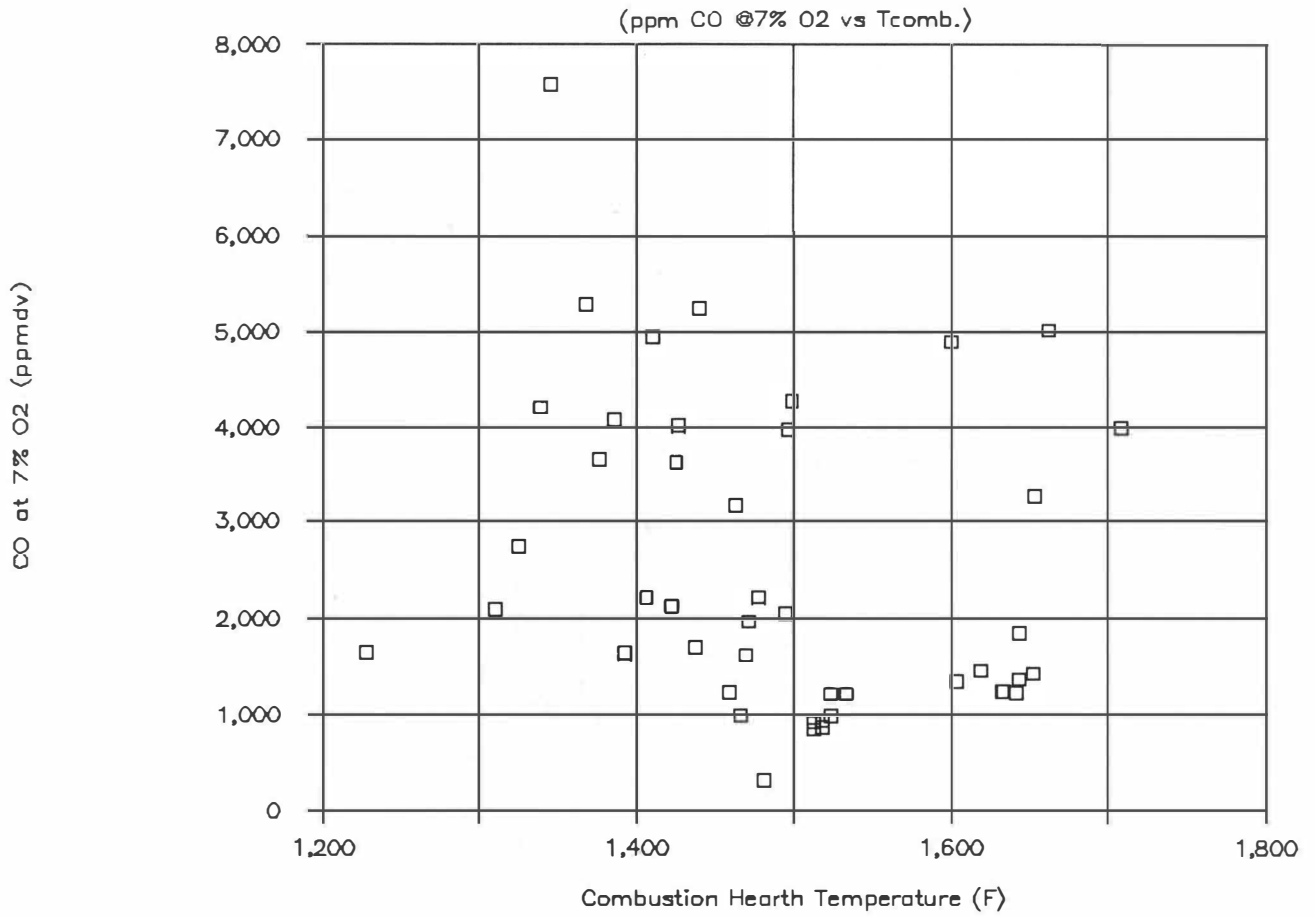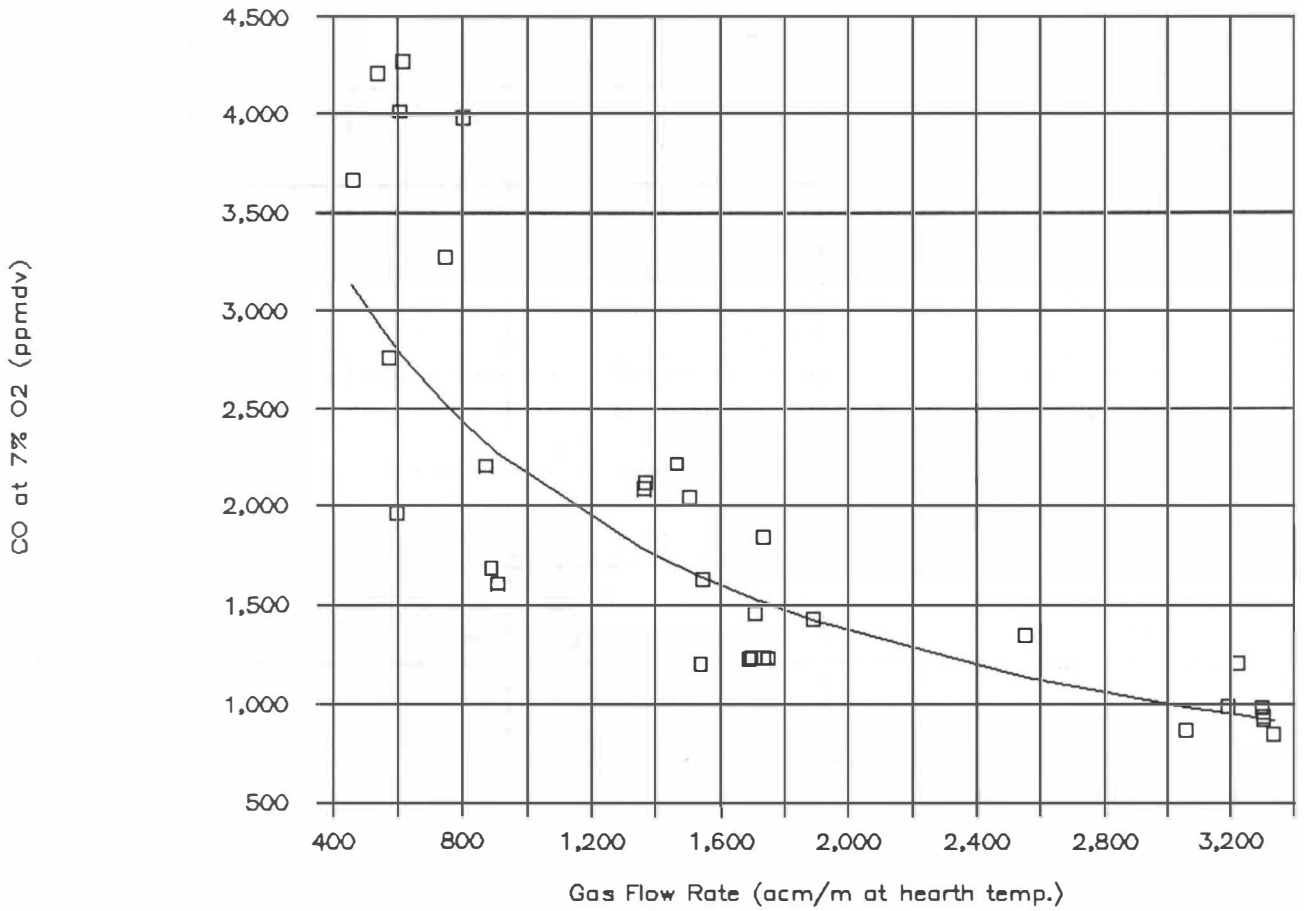
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(ppm CO @7% O2 vs Tcomb.)

FIG. 3   CO BURNOUT CORRELATION

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FIG. 4   CO TURBULENCE CORRELATION
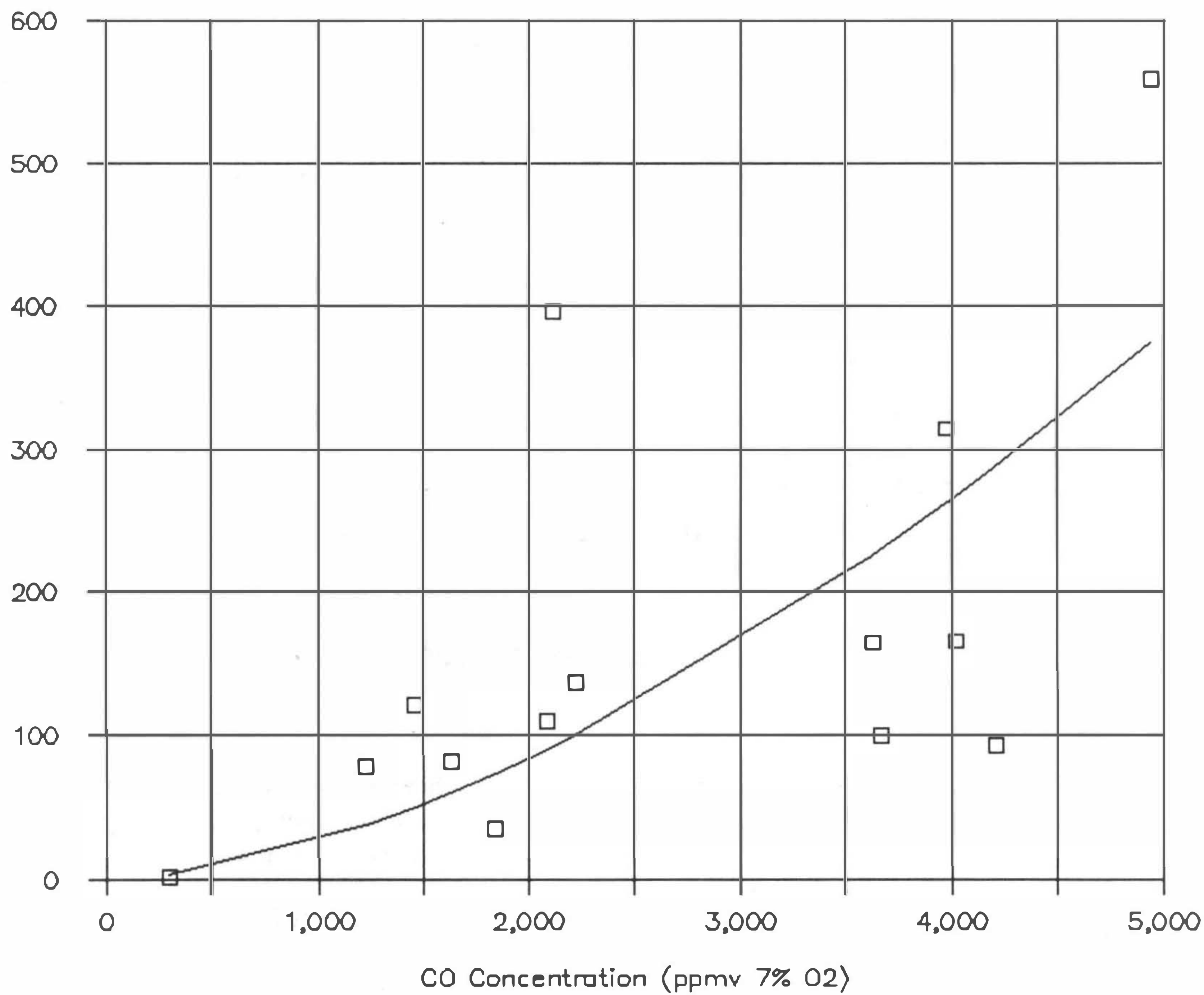
FIG. 5   CORRELATION OF THC WITH CO
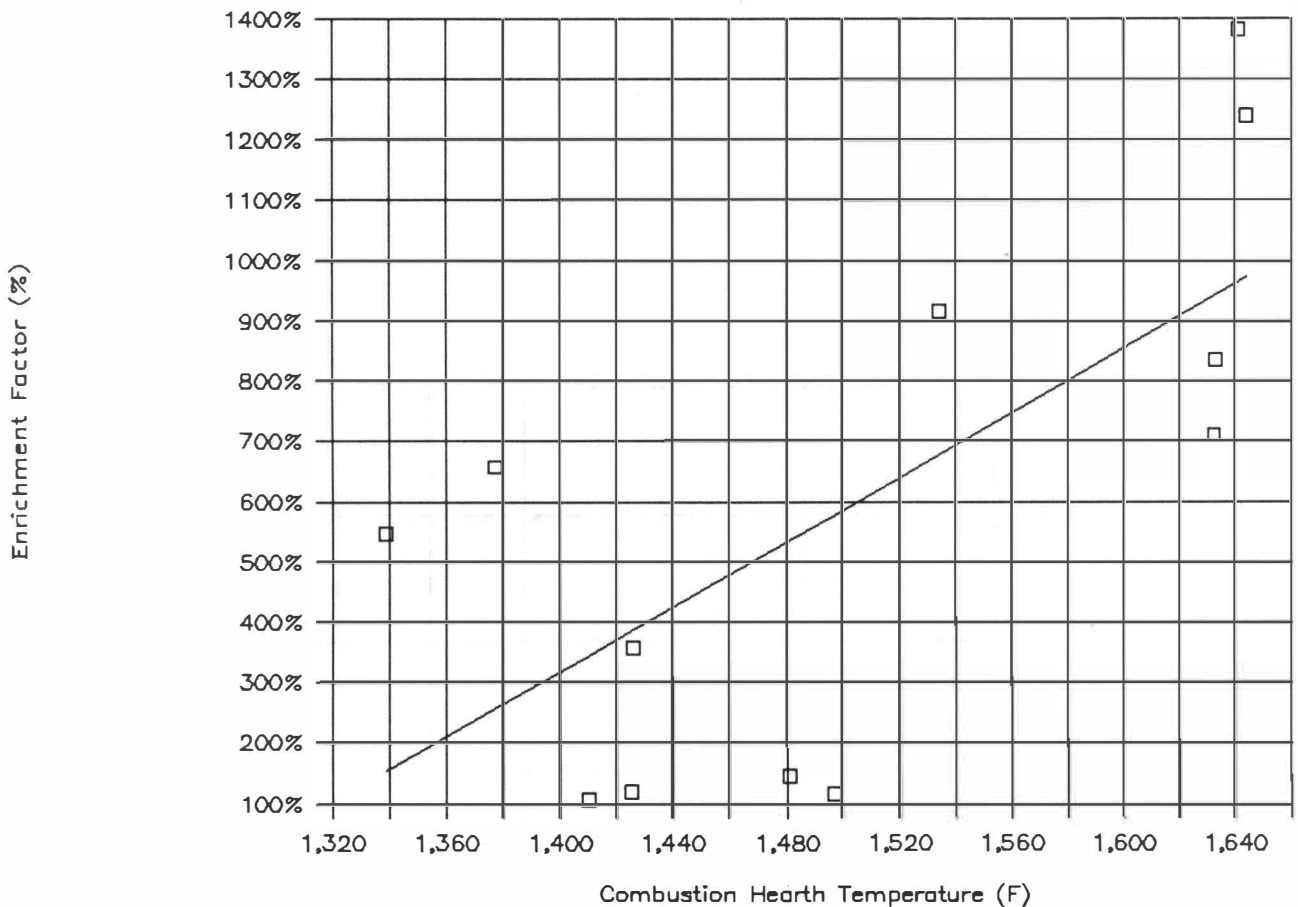
FIG. 6 ARSENIC EMISSION ENRICHMENT

pecially for the elements known to exhibit volatilization (arsenic, cadmium, zinc and lead), uncontrolled emissions calculated as a fraction of the element fed to the incinerator increased as hearth temperature increased. The more refractory compounds of beryllium, copper, chromium and nickel showed lesser sensitivity. The relative temperature sensitivity shown in the data was fully in line with expectations.

The parameter selected for correlation was the "enrichment factor" for the emissions: the multiple of the particular metal emission that is found in the uncontrolled furnace off-gas which one would associate with the TSP emission rate at feed sludge metal concentrations. These factors range from near unity for beryllium, copper etc. to over 10-fold for arsenic and cadmium at elevated temperatures. For the special case of mercury, it was assumed that 100% of the feed metal is emitted.

Arsenic
Above 1400°F, arsenic showed a strong combustion hearth temperature sensitivity (see Fig. 6). The enrichment factor (EF–As) plotted on Fig. 6 for 12 data points ($r^2 = 0.46$) is:

$$EF–As = (T_{comb} - 1281.5)/37.8$$

Cadmium
Above 1400°F, cadmium also showed a strong combustion hearth temperature sensitivity, possibly due to the high vapor pressure of cadmium chloride (Fig. 7). The enrichment factor (EF–Cd) plotted on Fig. 7 for 16 data points ($r^2 = 0.32$) is:

$$EF–Cd = \exp[(T_{comb} - 1273.42)/122.039]$$

Lead
Paralleling experience in municipal solid waste incineration, lead does not show the strong temperature sensitivity seen for arsenic and cadmium. The more modest enrichment factor (EF–Pb) from 17 data points ($r^2 = 0.67$) is:
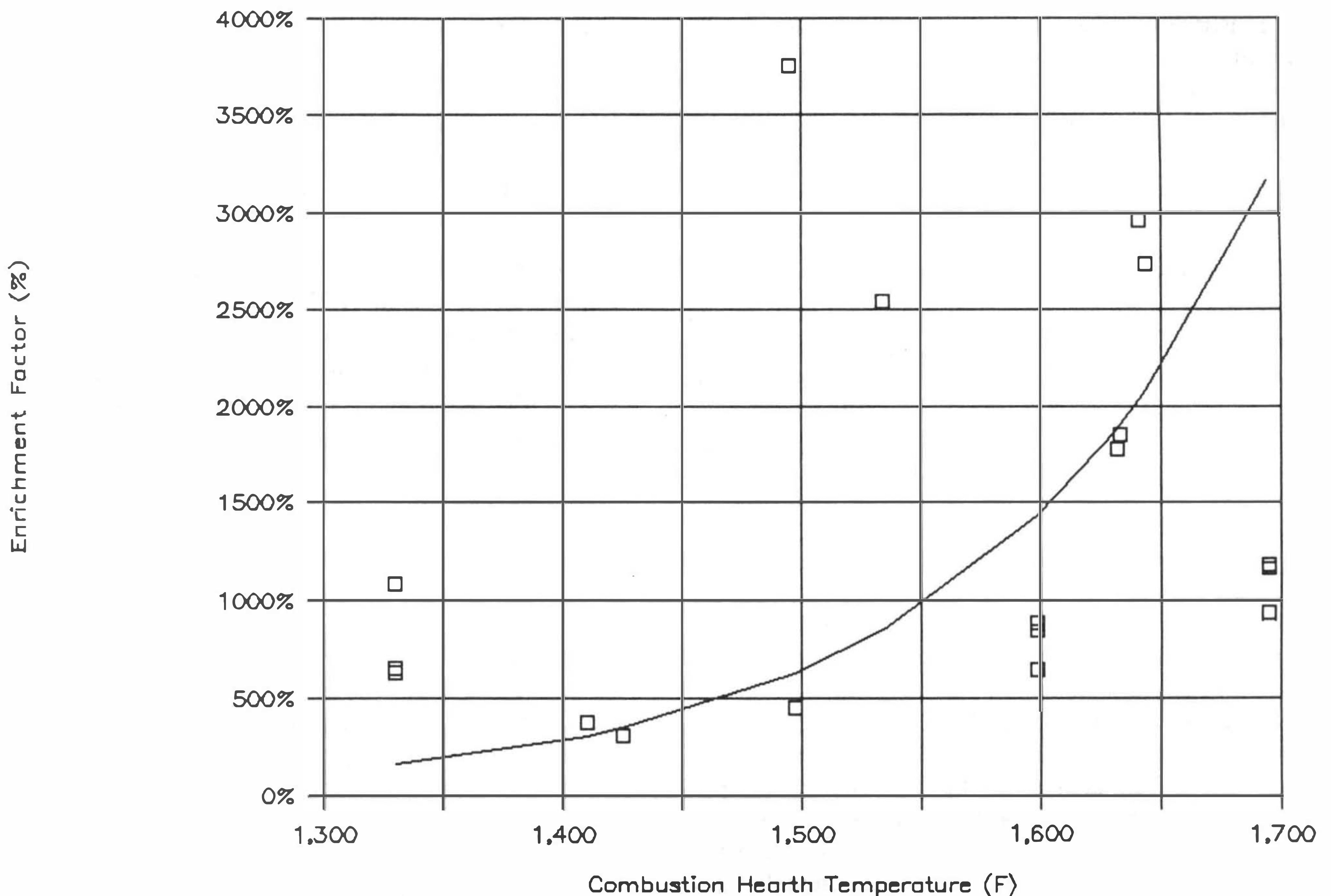
FIG. 7 CADMIUM EMISSION CORRELATION

$$EF\text{-}Pb = \exp[(T_{comb} - 1330.47)/170.918]$$

Zinc

Zinc emission data were irregular in character in attempted correlations with T_{comb}. Little enrichment was observed below 1575°F and a modest enrichment above that. For temperatures above 1575°F, the following relationship roughly parallels the data:

$$EF\text{-}Zn \ (T_{comb} > 1575°F)$$
$$= 1 + 0.016 \ (T_{comb} - 1575)$$

Chromium, Copper, Nickel and Beryllium

Emission data for these metals showed no significant sensitivity to temperature. However, the data show a relatively consistent enrichment/depletion factor compared to the metal content in the original sludge ash. These factors are:

Element	Enrichment Factor	No. Data Points	Std. Dev. (% of Avg.)
Chromium	128.38%	16	34.65%
Copper	94.20%	10	41.65%
Nickel	110.89%	19	59.56%
Beryllium	61.64%	14	74.30%

One might speculate that the lack of a temperature sensitivity for copper and nickel and the fact that the values are close to unity reflects a mix of particle sizes of the compounds of these elements in the ash slightly more finely divided than that of "typical" sludge ash. Conversely, the quite low beryllium factor suggests that the beryllium is in the coarser solids. These generalities are reasonable in that: *(a)* the chromium and copper are probably precipitates or scoured insoluble deposits; and *(b)* the beryllium probably enters the sewage as

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a constituent of beryl or other sand/soil derived beryllium-bearing minerals.

Within MHF.EXE, the emission rates of these elements are calculated using the enrichment ratio multiplied by the natural sludge ash concentration of the respective elements.

Air Pollution Control Correlations

The MHF.EXE model includes correlations of the abatement efficiency of both wet scrubbers and electrostatic precipitators (ESP) relative to the 17 pollutants studied. As for the uncontrolled emissions, analysis of the data indicated variability in collection efficiency for some pollutants with differing operating conditions.

Total Suspended Particulate (TSP)

Collection efficiency for TSP is an input variable for the scrubber. Due to the several process variables known to affect scrubber efficiency (pressure drop and liquid-to-gas ratio, most importantly) and the generally inadequate documentation of the scrubber design/operating parameters, a reliable efficiency predictor did not emerge from analysis of the data. Generalized performance algorithms for both devices are available, but without solid data against which to test them, it was decided not to incorporate them in the model at this time. For the ESP, a general correlation was incorporated assigning an efficiency of 90% per field (99% control for two fields, 99.9% control for three etc.). This ESP generalization was necessary due to the paucity of ESP collection data in sludge incineration applications.

Nitrogen Oxides (NO_x)

Data were lacking to evaluate average collection efficiency for NO_x. Based on the relatively high NO/NO_2 ratio of "NO_x", a maximum of about 5% in scrubbers and no abatement in ESPs is expected. MHF.EXE assumes no NO_x control.

Sulfur Oxides (SO_2, SO_3)

Data indicate an average abatement of 93.43% for SO_2 (24 data points, standard deviation of 11.91% of the mean) and 77.14% for SO_3 (7 data points, standard deviation of 36.18% of the mean) in scrubbers. No abatement is assumed for ESPs.

Carbon Monoxide

Data confirm the lack of abatement in either scrubbers or ESPs for CO.

Total Hydrocarbons (THC)

Data indicate a collection efficiency of 55% for scrubbers and no abatement in ESPs.

Polychlorinated Dioxins and Furans (PCDD/PCDF)

Although one might presume that particulate collection may result in the reduction of PCDD/PCDF, the data were too limited and the environmental importance too great to assume any abatement at this time.

Metals (Arsenic, Beryllium, Cadmium, Chromium, Copper, Lead, Mercury, Nickel and Zinc)

The collection efficiency for some metals differed in comparison to the overall TSP collection efficiency. Inlet-outlet data pairs for TSP and for the individual metals showed trends similar to those for the uncontrolled emission: sensitivity to the combustion hearth temperature for some elements, a lack of strong sensitivity for others.

Consistent with theory, one presumes that volatilization processes lead to enhanced emission rates in the hot zone with subsequent condensation on the smaller, hard-to-collect particles in the cooler regions of the system. Thus, high hearth temperatures not only increase emission but, also, decrease collection efficiency. For mercury, an average collection efficiency of 76% was observed for the scrubbers. No abatement of mercury was assumed for the ESP's.

Arsenic

As for the emission correlation, sensitivity of the scrubber efficiency to T_{comb} was observed. For 20 data points, ($r^2 = 0.39$) the relative efficiency (RE–As) as shown in Fig. 8 is given by:

$$RE–As = 13.91 - 0.004583\,(T_{comb}) - 9139/T_{comb}$$

Cadmium

Cadmium collection efficiency clearly shows degradation reflecting T_{comb} effects (See Fig. 9), but there is more scatter (For 20 data points, $r^2 = 0.22$). The RE–Cd is given by:

$$RE–Cd = 1.839 - 0.0006566\,(T_{comb})$$

Other Metals

Element	Scrubber Collection Factor	No. Data Points	Std. Dev. (% of Avg.)
Chromium	73.31%	9	38.65%
Copper	90.88%	13	26.16%
Nickel	59.50%	12	86.93%
Beryllium	100% (est.)	3	N/A
Zinc	97.70%	13	7.84%
Lead	87.77%	21	16.14%

(Arsenic)
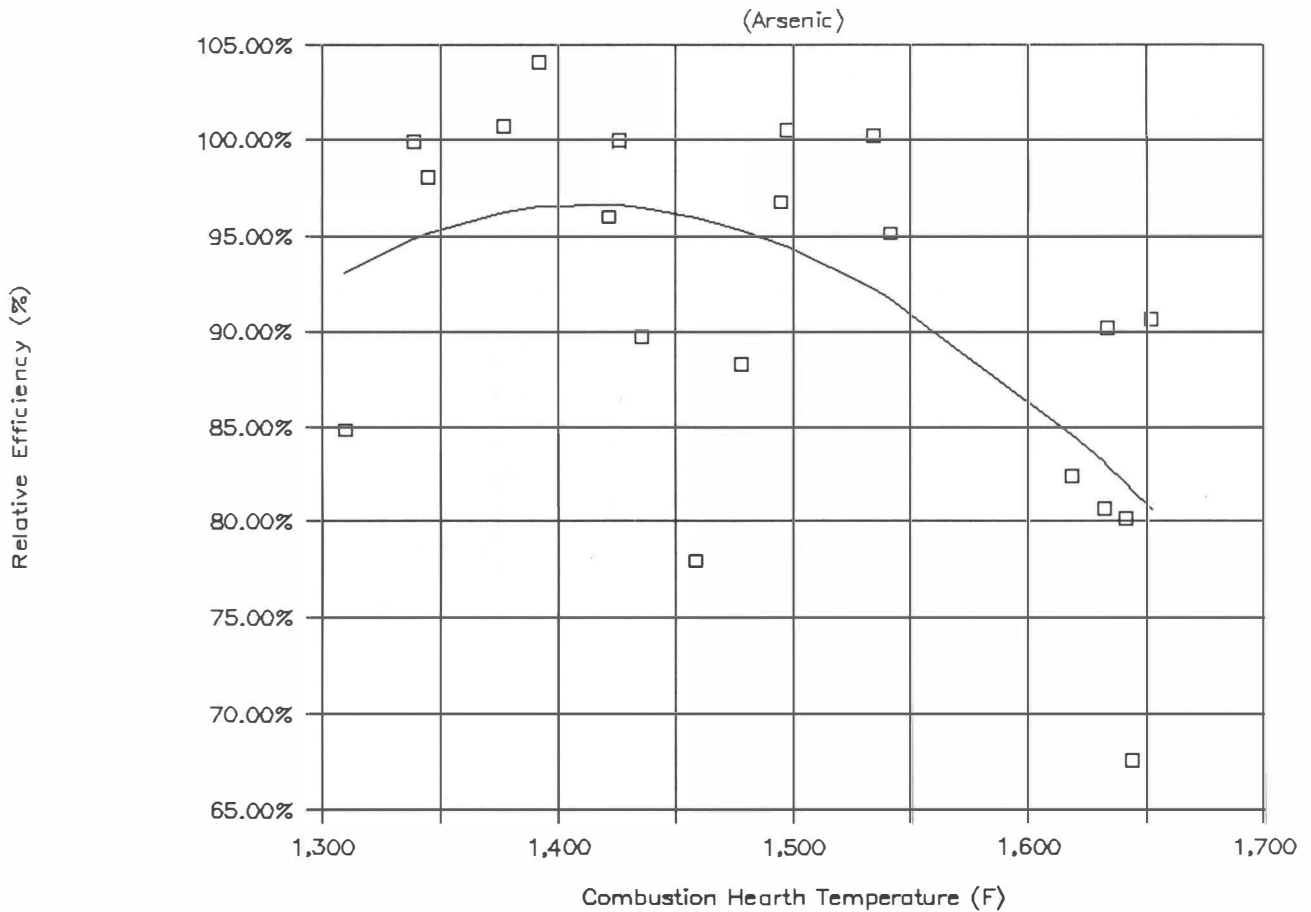
FIG. 8 RELATIVE COLLECTION EFFICIENCY

Afterburner Control of Combustible Pollutants

Although no data were available, estimates were made as to the abatement which could be expected from operation of an afterburner. The abatement of CO, THC, and PCDD/PCDF was assumed as follows:

Afterburner Temperature	Abatement Effect
Below, 1100°F.	None
1100–1300°F.	Linear increase from 0 to 95%
Above 1300°F.	95%

Atmospheric Dispersion Module

Following discharge from the stack, the potential for downwash is tested using the technique developed by Briggs [28]. For short stacks on large buildings, dispersion is hindered at higher wind speeds by capture of the plume in the downwash from the stack and building. This leads to exceedingly high ambient concentrations in and near the down-building eddy which decay slowly with distance. If downwash occurs, the dispersion relationships of Briggs are used.

For tall stacks and small buildings, the plume is "elevated" and disperses in accord with the wind speed and atmospheric stability conditions. The user can select one of the six Pasquill & Gifford stability classes (usually identified "A" through "F" or 1 through 6, respectively, in the model input) which reflect the range from unstable to stable atmospheric conditions. The simplified gaussian Sutton dispersion calculations presented by Turner [29] are used (incorporating the Briggs plume rise algorithm) to calculate the maximum downwind groundlevel concentration (GLC). By use of these correlations, the downwind GLCs of the 17 pollutants can be estimated as a function of wind speed, distance from the source and stability class.

For purposes of health effects analysis, the GLCs of interest are the maximum concentration observed downwind of the facility. To provide this measure of impact, MHF.EXE outputs both the distance from the

(Cadmium)
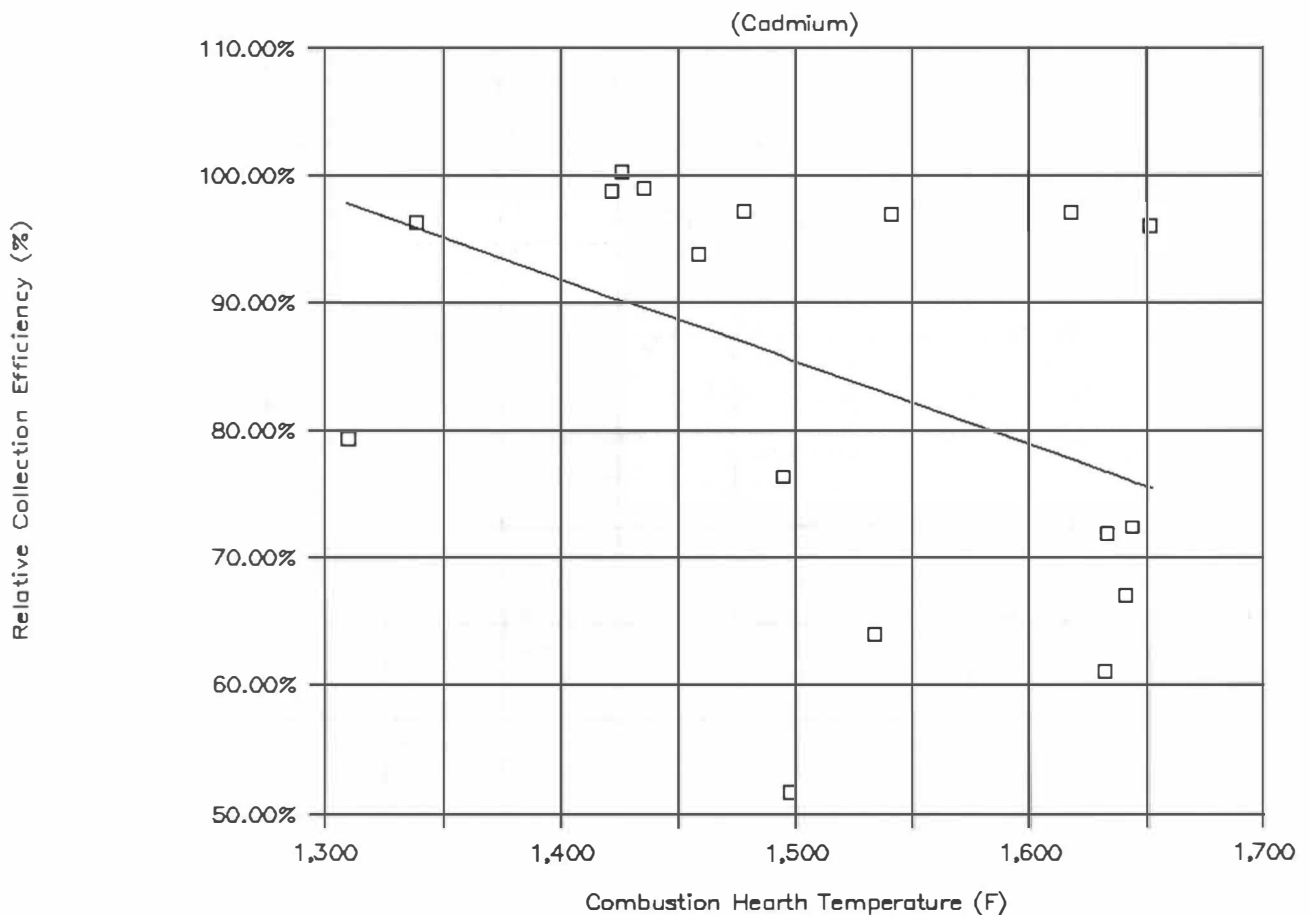
FIG. 9 RELATIVE COLLECTION EFFICIENCY

stack to the point of maximum concentration and the expected maximum GLC. Note, however, that in reality shifts in wind direction and velocity as well as changes in atmospheric stability class throughout the day and the year lead to substantially lower annual average concentration than the MHF.EXE output and consequent health impacts indicate. However, the GLC output of the model may be used as a rough scale of relative annual concentration as a means to judge the benefits of alternate design/operating strategies in health-risk terms.

Health Effects Analysis

Although "pollutant emission" is the physical characteristic of interest in system optimization and analysis, it is human health impact that is the primary issue. MHF.EXE then, takes the observed maximum GLCs and multiplies them by the cancer risk factors for 70 year exposure of a 70 kg person inhaling 20 m^3/day with 100% retention. The resulting indications of the relative cancer risk for each carcinogenic pollutant are then summed into a Figure of Merit (CFOM) reflecting the aggregate cancer health impact. The cancer risk factors used [31] were:

Pollutant	Potency Slope Risk Factor
Arsenic	1.50E + 01
Beryllium	8.40E − 00
Cadmium	4.00E + 01
Chromium (+6)	5.10E + 02
Lead	Noncancerous
Mercury	Noncancerous
Nickel	8.40E − 01
PCDD/PCDF	1.33E + 05
(2, 3, 7, 8 TCDD equivalent)	

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For toxic metals and compounds, MHF.EXE makes use of chronic (long-term) toxicity measures: the Reference Dose (RfD). A RfD for arsenic has not been developed; consequently, the RfD was assumed to be the Threshold Limit Value (TLV) divided by 420, as recommended by the Bay Area Air Quality Management District in San Francisco, CA. In contrast to the carcinogens, the GLC is used to generate the dosage (mg/kg/day for a 70 kg individual inhaling 20 m³ of air per day with 100% retention) and this dosage is compared with the RfD and summed to generate a toxicity figure of merit (TFOM). The TFOM thus indicates the degree of approach to the Reference Dose. The RfD values used are:

Pollutant	Reference Dose (RfD)	Reference
Arsenic	$1.4E - 04$	[32]
Beryllium	$5.0E - 03$	[33]
Cadmium	$2.9E - 04$	[33]
Chromium-+6	$5.0E - 03$	[33]
Lead	$1.4E - 03$	[33]
Mercury	$2.0E - 02$	[33]
Nickel	$2.0E - 02$	[33]
PCDD/PCDF	$1.0E - 09$	[33]

Model Strategy

In operation, MHF.EXE first does a hardware analysis, calculating the flue gas quantities, hearth and off-gas temperatures, fuel usage, etc. in accord with input instructions and input system configuration. As noted below, these input variables can be changed in subsequent runs. Then, based on the emission correlations, the uncontrolled emission rates are calculated for each of the 17 pollutants of interest. Control efficiencies are applied to give the net stack emission rates (grams per second). Dispersion estimates are then generated based on the input building and stack configurations and atmospheric stability class for a range of wind conditions (1–30) meters/s. Finally, cancer and toxicity potency evaluations are made and summed to a net health risk "Figure of Merit" (TFOM and CFOM respectively).

Model Operation

To use the MHF.EXE model, an input file is prepared which inputs 44 system and sludge variables when called from the opening screen instruction. Also, the file name for the output file is requested. For each run execution, MHF.EXE writes a comprehensive output file (recapitulation of the scenario for the run, emission and operating data and the GLOs and the CFOM and TFOM for the elevated plume case and, if pertinent, the downwash case. A summary of the results is written to the screen. The user can request that the summary table output to the monitor be either the downwash or forced to the elevated plume results (and can toggle between them if desired) and can have the GLC and FOM output reported either as absolute numerical values (micrograms per cubic meter, cancer incidence frequency and toxic dose approach to the RfD) or as relative values normalized to the base case results (the initializing conditions read from the input file).

After the base case has run, the operator can change one or more variables (examining the effect of higher stacks, different excess air levels etc.). The program re-executes and displays the new results. This progression can continue as long is desired. When the analysis is complete, the output file is closed and is subject to subsequent detailed review and analysis from a hard-copy printout or display on the monitor.

A sample run is appended showing as the base case an existing system configuration in California (Fig. 10). Downwash effects are seen to seriously impact on the calculated GLC's and FOM values. A second run with the "Relative Mode" option (Fig. 11) shows the effects of an elevated stack, an afterburner and higher excess air (lower combustion hearth temperature). It can be seen that the FOMC and FOMT have been reduced to 3.5% and 9.1% of their base case values, respectively, through these changes.

SUMMARY

Given the present state of knowledge and the process complexity, it is almost impossible to use intuition to judge the consequences of system changes on the health impacts of MHF operation. Is increasing excess air helpful or hurtful? Will an incremental improvement in pretreatment have significant consequences? These are just a few of the questions now being asked. MHF.EXE offers a tool to quantify the results of various assumptions as an aid to policy formulation, system set-up, testing and operating modes and the like. With MHF.EXE engineers can now analyze many hardware and operational options at minimum cost to find the solutions to these questions.

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RUN    1       RUN CONDITIONS

VARIABLE      VALUE              DEFINITION

    6         1.0000   SLUDGE TYPE: 1=RAW, 2=DIG, 3=ZIMPRO
    7          .2500   PERCENT SOLIDS
    8          .0200   PERCENT NITROGEN
    9         1.0000   EXCESS AIR
   10        84.0000   STACK HEIGHT (Ft)
   11         3.4100   STACK DIAM. (Ft)
   12          .4700   % SOLIDS FOR COMBUSTION
   13       850.0000   TOP HEARTH TEMP (F)
   14          .0000   PRIMARY AFTERBURNER TEMP (F)
   15          .0000   SECONDARY A/B TEMP (F)
   16         1.0000   APC TYPE: 1=SCRUBBER, 2=ESP
   17       450.0000   BOILER EXIT TEMP (F)
   18          .0000   REHEAT AIR TEMP (F)
   19          .0000   REHEAT AIR QUANTITY (acfm)
   20        60.0000   AMBIENT TEMP (F)
   21       350.0000   ASH DISCHARGE TEMP (F)
   22         1.0000   FUEL TYPE: 1=GAS, 2=#2 OIL
   23          .7000   PERCENT VOLATILE
   24     10000.0000   BTU PER LB. VOLATILE
   25     16000.0000   WET Lb/Hr SLUDGE FEED RATE
   26         4.0000   ATMOSPHERIC STABILITY CLASS
   27          .0050   PERCENT SULFUR
   28         1.8400   mg/kg CADMIUM IN DRY SLUDGE
   29         8.0000   mg/kg NICKEL IN DRY SLUDGE
   30          .2000   mg/kg CHROMIUM IN DRY SLUDGE
   31         1.2400   mg/kg ARSENIC IN DRY SLUDGE
   32        15.2000   mg/kg LEAD IN DRY SLUDGE
   33         5.0000   mg/kg ZINC IN DRY SLUDGE
   34          .4400   mg/kg MERCURY IN DRY SLUDGE
   35          .4000   mg/kg BERYLLIUM IN DRY SLUDGE
   36         1.0000   mg/kg COPPER IN DRY SLUDGE
   37         2.0000   No. ESP FIELDS
   38       110.0000   SUBCOOLER EXIT TEMP. (F)
   39        70.0000   BUILDING HEIGHT (Feet)
   40       215.0000   BUILDING LENGTH (Feet)
   41       150.0000   BUILDING WIDTH (Feet)
   42          .9570   SCRUBBER EFFICIENCY (Dec %)
   43          .0100   % Cr as Cr+6
   44          .0150   2,3,7,8-PCDD as %(PCDD+0.1xPCDF)

          SYSTEM VARIABLES
COMB. HEARTH TEMP.       1498.3  DEG. F
TOP TEMP. c/o FUEL/H2O    818.4  DEG. F
BURNER FUEL                 .5   MMBtu/Dry Ton
AFTERBURNER FUEL            .0   MMBtu/Dry Ton
REHEATER FUEL               .0   MMBtu/Dry Ton
WATER                       .0   Gallons/Dry Ton
STACK VELOCITY             9.4   Feet/Second
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FIGURE 10

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RUN   1        EMISSION RATES (g/sec)
   UNCONTROLLED                 CONTROLLED
POLLUTANT    RATE        POLLUTANT    RATE
   TSP      .2188E+04       TSP      .9407E+02
   NOx      .1539E+01       NOx      .1539E+01
   SO2      .4967E+01       SO2      .3263E+00
   SO3      .1942E+00       SO3      .5685E-01
   CO       .1536E+02       CO       .1536E+02
   THC      .6408E+00       THC      .2884E+00
   Be       .1798E-02       Be       .7731E-04
   Cd       .8469E-01       Cd       .1537E-01
   Ni       .6463E-01       Ni       .2783E-01
   Cr       .1872E-02       Cr       .5588E-03
   As       .5113E-01       As       .4952E-02
   Pb       .2958E+00       Pb       .4735E-01
   Zn       .3646E-01       Zn       .1568E-02
   Hg       .2220E-03       Hg       .5327E-04
   CDD      .3353E-07       CDD      .3353E-07
   CDF      .1767E-06       CDF      .1767E-06
   Cu       .6869E-02       Cu       .2954E-03
```

ADDITIONAL EMISSION VALUES

POLLUTANT	UNITS	UNCONTROLLED	CONTROLLED
TSP	lb/dry ton	8673.6750	372.9679
TSP	gr/dscf @ 7% O2	361.5364	15.5461
NOx	ppmdv @ 7% O2	181.3860	132.4118
NOx	ppmv	74.9754	54.7320
SO2	ppmdv @ 7% O2	657.9036	164.7391
SO2	ppmv	271.9425	68.0944
SO3	ppmdv @ 7% O2	25.7255	6.4417
SO3	ppmv	10.6335	2.6626
CO	ppmdv @ 7% O2	4650.7380	4650.7380
CO	ppmv	1922.3690	1922.3690
THC	ppmdv @ 7% O2	338.8466	152.4810
THC	ppmv	140.0612	63.0276
Hg	grams/day	19.1770	4.6025

DISTANCE TO MAXIMUM IMPACT

WINDSPEED (m/sec)	DOWNWASH?	EFF. STACK HEIGHT (Feet)	DISTANCE (Feet)
1.	YES	7.	140.
2.	YES	7.	140.
4.	YES	7.	140.
6.	YES	7.	140.
8.	YES	7.	140.
10.	YES	7.	140.
15.	YES	7.	140.
20.	YES	7.	140.
25.	YES	7.	140.
30.	YES	7.	140.

FIGURE 10   (Cont'd)

```
RUN    1        MAXIMUM GROUND LEVEL CONCENTRATIONS - (MICROGRAMS PER M3)
WIND (m/s)/DOWNWASH?  1./YES        2./YES        4./YES        6./YES        8./YES
       TSP      .196E+06      .979E+05      .489E+05      .326E+05      .245E+05
       NOx      .320E+04      .160E+04      .801E+03      .534E+03      .400E+03
       SO2      .679E+03      .340E+03      .170E+03      .113E+03      .849E+02
       SO3      .118E+03      .591E+02      .296E+02      .197E+02      .148E+02
       CO       .320E+05      .160E+05      .799E+04      .533E+04      .400E+04
       THC      .600E+03      .300E+03      .150E+03      .100E+03      .750E+02
       Be       .161E+00      .804E-01      .402E-01      .268E-01      .201E-01
       Cd       .320E+02      .160E+02      .800E+01      .533E+01      .400E+01
       Ni       .579E+02      .290E+02      .145E+02      .965E+01      .724E+01
       Cr       .116E+01      .581E+00      .291E+00      .194E+00      .145E+00
       As       .103E+02      .515E+01      .258E+01      .172E+01      .129E+01
       Pb       .985E+02      .493E+02      .246E+02      .164E+02      .123E+02
       Zn       .326E+01      .163E+01      .816E+00      .544E+00      .408E+00
       Hg       .111E+00      .554E-01      .277E-01      .185E-01      .139E-01
       CDD      .698E-04      .349E-04      .174E-04      .116E-04      .872E-05
       CDF      .368E-03      .184E-03      .920E-04      .613E-04      .460E-04
       Cu       .615E+00      .307E+00      .154E+00      .102E+00      .768E-01
      FOMC      .426E+00      .213E+00      .106E+00      .710E-01      .532E-01
      FOMT      .113E+02      .567E+01      .284E+01      .189E+01      .142E+01


RUN    1        MAXIMUM GROUND LEVEL CONCENTRATIONS - (MICROGRAMS PER M3)
WIND (m/s)/DOWNWASH? 10./YES       15./YES       20./YES       25./YES       30./YES
       TSP      .196E+05      .131E+05      .979E+04      .783E+04      .653E+04
       NOx      .320E+03      .214E+03      .160E+03      .128E+03      .107E+03
       SO2      .679E+02      .453E+02      .340E+02      .272E+02      .226E+02
       SO3      .118E+02      .789E+01      .591E+01      .473E+01      .394E+01
       CO       .320E+04      .213E+04      .160E+04      .128E+04      .107E+04
       THC      .600E+02      .400E+02      .300E+02      .240E+02      .200E+02
       Be       .161E-01      .107E-01      .804E-02      .644E-02      .536E-02
       Cd       .320E+01      .213E+01      .160E+01      .128E+01      .107E+01
       Ni       .579E+01      .386E+01      .290E+01      .232E+01      .193E+01
       Cr       .116E+00      .775E-01      .581E-01      .465E-01      .388E-01
       As       .103E+01      .687E+00      .515E+00      .412E+00      .344E+00
       Pb       .985E+01      .657E+01      .493E+01      .394E+01      .328E+01
       Zn       .326E+00      .218E+00      .163E+00      .131E+00      .109E+00
       Hg       .111E-01      .739E-02      .554E-02      .443E-02      .370E-02
       CDD      .698E-05      .465E-05      .349E-05      .279E-05      .233E-05
       CDF      .368E-04      .245E-04      .184E-04      .147E-04      .123E-04
       Cu       .615E-01      .410E-01      .307E-01      .246E-01      .205E-01
      FOMC      .426E-01      .284E-01      .213E-01      .170E-01      .142E-01
      FOMT      .113E+01      .757E+00      .567E+00      .454E+00      .378E+00
```

FIGURE 10   (Cont'd)

```
RUN    2         RUN CONDITIONS

VARIABLE       VALUE                DEFINITION

   6            1.0000   SLUDGE TYPE: 1=RAW, 2=DIG, 3=ZIMPRO
   7             .2500   PERCENT SOLIDS
   8             .0200   PERCENT NITROGEN
   9            1.2500   EXCESS AIR
  10          160.0000   STACK HEIGHT (Ft)
  11            3.4100   STACK DIAM. (Ft)
  12             .4700   % SOLIDS FOR COMBUSTION
  13          850.0000   TOP HEARTH TEMP (F)
  14         1450.0000   PRIMARY AFTERBURNER TEMP (F)
  15             .0000   SECONDARY A/B TEMP (F)
  16            1.0000   APC TYPE: 1=SCRUBBER, 2=ESP
  17          450.0000   BOILER EXIT TEMP (F)
  18             .0000   REHEAT AIR TEMP (F)
  19             .0000   REHEAT AIR QUANTITY (acfm)
  20           60.0000   AMBIENT TEMP (F)
  21          350.0000   ASH DISCHARGE TEMP (F)
  22            1.0000   FUEL TYPE: 1=GAS, 2=#2 OIL
  23             .7000   PERCENT VOLATILE
  24        10000.0000   BTU PER LB. VOLATILE
  25        16000.0000   WET Lb/Hr SLUDGE FEED RATE
  26            4.0000   ATMOSPHERIC STABILITY CLASS
  27             .0050   PERCENT SULFUR
  28            1.8400   mg/kg CADMIUM IN DRY SLUDGE
  29            8.0000   mg/kg NICKEL IN DRY SLUDGE
  30             .2000   mg/kg CHROMIUM IN DRY SLUDGE
  31            1.2400   mg/kg ARSENIC IN DRY SLUDGE
  32           15.2000   mg/kg LEAD IN DRY SLUDGE
  33            5.0000   mg/kg ZINC IN DRY SLUDGE
  34             .4400   mg/kg MERCURY IN DRY SLUDGE
  35             .4000   mg/kg BERYLLIUM IN DRY SLUDGE
  36            1.0000   mg/kg COPPER IN DRY SLUDGE
  37            2.0000   No. ESP FIELDS
  38          110.0000   SUBCOOLER EXIT TEMP. (F)
  39           70.0000   BUILDING HEIGHT (Feet)
  40          215.0000   BUILDING LENGTH (Feet)
  41          150.0000   BUILDING WIDTH (Feet)
  42             .9570   SCRUBBER EFFICIENCY (Dec %)
  43             .0100   % Cr as Cr+6
  44             .0150   2,3,7,8-PCDD as %(PCDD+0.1xPCDF)

            SYSTEM VARIABLES
COMB. HEARTH TEMP.        1381.8  DEG. F
TOP TEMP. c/o FUEL/H2O     767.0  DEG. F
BURNER FUEL                  1.4  MMBtu/Dry Ton
AFTERBURNER FUEL            14.2  MMBtu/Dry Ton
REHEATER FUEL                .0  MMBtu/Dry Ton
WATER                        .0  Gallons/Dry Ton
STACK VELOCITY              18.6  Feet/Second
```

FIGURE 11

```
RUN    2        EMISSION RATES (g/sec)
  UNCONTROLLED                 CONTROLLED
POLLUTANT    RATE         POLLUTANT    RATE
   TSP      .2520E+04        TSP      .1084E+03
   NOx      .3088E+01        NOx      .3088E+01
   SO2      .4967E+01        SO2      .3263E+00
   SO3      .1942E+00        SO3      .5685E-01
   CO       .1541E+01        CO       .1541E+01
   THC      .6427E-01        THC      .2892E-01
   Be       .2071E-02        Be       .8906E-04
   Cd       .3756E-01        Cd       .1615E-02
   Ni       .7445E-01        Ni       .3206E-01
   Cr       .2157E-02        Cr       .6436E-03
   As       .1042E-01        As       .4479E-03
   Pb       .1724E+00        Pb       .2759E-01
   Zn       .4200E-01        Zn       .1806E-02
   Hg       .2220E-03        Hg       .5327E-04
   CDD      .9860E-08        CDD      .9860E-08
   CDF      .5380E-07        CDF      .5380E-07
   Cu       .7913E-02        Cu       .3402E-03
```

```
            ADDITIONAL EMISSION VALUES
POLLUTANT    UNITS            UNCONTROLLED        CONTROLLED

   TSP    lb/dry ton           9990.9520          429.6108
   TSP    gr/dscf @ 7% O2       207.5845            8.9261
   NOx    ppmdv @ 7% O2         155.2317          113.3191
   NOx    ppmv                  112.2702           81.9572
   SO2    ppmdv @ 7% O2         327.9454           82.1175
   SO2    ppmv                  237.1841           59.3909
   SO3    ppmdv @ 7% O2          12.8234            3.2110
   SO3    ppmv                    9.2744            2.3223
   CO     ppmdv @ 7% O2        4650.2450          232.5123
   CO     ppmv                  168.1628          168.1628
   THC    ppmdv @ 7% O2         338.7875          152.4544
   THC    ppmv                  245.0256          110.2615
   Hg     grams/day              19.1770            4.6025
```

```
                DISTANCE TO MAXIMUM IMPACT
WINDSPEED (m/sec) DOWNWASH? EFF. STACK HEIGHT (Feet)   DISTANCE (Feet)
      1.            NO            194.                    4934.
      2.            NO            177.                    4378.
      4.            NO            168.                    4107.
      6.            NO            166.                    4017.
      8.            NO            164.                    3972.
     10.            NO            163.                    3945.
     15.            NO            162.                    3910.
     20.            NO            162.                    3892.
     25.            NO            161.                    3881.
     30.            NO            161.                    3874.
```

FIGURE 11 (Cont'd)

WIND (m/s)/DOWNWASH?	1./NO	2./NO	4./NO	6./NO	8./NO
TSP	.283E+00	.284E+00	.285E+00	.286E+00	.286E+00
NOx	.492E+00	.495E+00	.497E+00	.498E+00	.498E+00
SO2	.245E+00	.247E+00	.248E+00	.248E+00	.248E+00
SO3	.245E+00	.247E+00	.248E+00	.248E+00	.248E+00
CO	.246E-01	.248E-01	.249E-01	.249E-01	.249E-01
THC	.246E-01	.248E-01	.249E-01	.249E-01	.249E-01
Be	.283E+00	.284E+00	.285E+00	.286E+00	.286E+00
Cd	.258E-01	.259E-01	.260E-01	.261E-01	.261E-01
Ni	.283E+00	.284E+00	.285E+00	.286E+00	.286E+00
Cr	.283E+00	.284E+00	.285E+00	.286E+00	.286E+00
As	.222E-01	.223E-01	.224E-01	.224E-01	.225E-01
Pb	.143E+00	.144E+00	.144E+00	.145E+00	.145E+00
Zn	.283E+00	.284E+00	.285E+00	.286E+00	.286E+00
Hg	.245E+00	.247E+00	.248E+00	.248E+00	.248E+00
CDD	.721E-01	.726E-01	.729E-01	.730E-01	.730E-01
CDF	.747E-01	.752E-01	.754E-01	.755E-01	.756E-01
Cu	.283E+00	.284E+00	.285E+00	.286E+00	.286E+00
FOMC	.350E-01	.353E-01	.354E-01	.354E-01	.355E-01
FOMT	.912E-01	.918E-01	.921E-01	.922E-01	.923E-01

RUN 2   MAXIMUM GROUND LEVEL CONCENTRATIONS - (RELATIVE TO RUN 1)

WIND (m/s)/DOWNWASH?	10./NO	15./NO	20./NO	25./NO	30./NO
TSP	.286E+00	.286E+00	.286E+00	.286E+00	.286E+00
NOx	.498E+00	.499E+00	.499E+00	.499E+00	.499E+00
SO2	.248E+00	.249E+00	.249E+00	.249E+00	.249E+00
SO3	.248E+00	.249E+00	.249E+00	.249E+00	.249E+00
CO	.249E-01	.249E-01	.249E-01	.249E-01	.249E-01
THC	.249E-01	.249E-01	.249E-01	.249E-01	.249E-01
Be	.286E+00	.286E+00	.286E+00	.286E+00	.286E+00
Cd	.261E-01	.261E-01	.261E-01	.261E-01	.261E-01
Ni	.286E+00	.286E+00	.286E+00	.286E+00	.286E+00
Cr	.286E+00	.286E+00	.286E+00	.286E+00	.286E+00
As	.225E-01	.225E-01	.225E-01	.225E-01	.225E-01
Pb	.145E+00	.145E+00	.145E+00	.145E+00	.145E+00
Zn	.286E+00	.286E+00	.286E+00	.286E+00	.286E+00
Hg	.248E+00	.249E+00	.249E+00	.249E+00	.249E+00
CDD	.730E-01	.731E-01	.731E-01	.731E-01	.731E-01
CDF	.756E-01	.757E-01	.757E-01	.757E-01	.757E-01
Cu	.286E+00	.286E+00	.286E+00	.286E+00	.286E+00
FOMC	.355E-01	.355E-01	.355E-01	.355E-01	.355E-01
FOMT	.923E-01	.924E-01	.924E-01	.924E-01	.924E-01

FIGURE 11 (Cont'd)

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