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FINAL REPORT

on

INSEA USER'S MANUAL ENVIRONMENTAL PERFORMANCE MODEL OF INCINERATION AT SEA OPERATIONS

by

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ABSTRACT

INSEA (INcineration at SEA) is a screening tool to estimate the maximum allowable concentration of wastes that can be incinerated at sea without exceeding standards for marine aquatic life. The relationship between the water quality standards and the maximum allowable concentrations in the incinerator feed are defined by the processes considered by the model. A consistent bias toward conservatism in the model is required to compensate for the present inability to reliably predict many of the processes that may occur in the atmosphere and ocean, or to measure the parameters that could be used to define these processes. The model considers the primary atmospheric and oceanic processes that are responsible for dispersing the incinerator emissions into the environment. These processes are dispersion and transport of the contaminant plume in the atmosphere and dispersion and advection of the contaminant in the ocean.

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1.0 MODEL OVERVIEW

1.1 BACKGROUND

The U.S. Environmental Protection Agency (EPA) is proposing a regulation that will govern the incineration of hazardous wastes at sea. The regulation, which is being proposed under the authority of the Marine Protection, Research, and Sanctuaries Act of 1972, will provide specific criteria for the Agency to use in reviewing and evaluating ocean incineration permit applications, and in designating and managing ocean incineration sites.

The proposed regulation requires that incineration permit applicants demonstrate that certain environmental performance standards will be met. Two environmental performance standards are described in Section 234.48 (new Section 234.49) of the proposed regulation. The first standard limits total acid-forming emissions such that after initial mixing, the change in the average total alkalinity in the release zone is no more than 10%, based on stoichiometric calculations. The second standard limits incinerator emissions so that after initial mixing, the ambient marine concentrations of chemical constituents of the emissions in marine waters do not exceed applicable water quality criteria or, where there are no applicable water quality criteria, a marine aquatic life no-effect level, or a toxicity threshold defined as 0.01 of an ambient marine water concentration shown to be acutely toxic to appropriate sensitive marine organisms in a bioassay carried out in accordance with EPA-approved procedures.

The first environmental performance standard can be evaluated using a simple dilution equation to estimate the quantity of acid-forming emissions that can be burned per hour without changing the alkalinity of the water in the release zone by more than 10%. The second environmental performance standard, however, is more complex. EPA is requiring the use of a mathematical model of atmospheric dispersion and ocean mixing to evaluate whether incinerator vessels will meet this second environmental performance standard (i.e., that the emissions do not exceed the marine water quality criteria/no-effect levels). EPA's policy on water quality standards recognizes a mixing zone as a limited area where chronic criteria can be exceeded during incineration operations as long as acutely toxic conditions do not occur and safe chronic levels are met at the boundaries of the zone. The chronic criteria, however, cannot be exceeded anywhere four hours after incineration operations have ceased. The mathematical model must have a sufficient level of sophistication to show whether the incinerator emissions, after an allowance for initial mixing, will meet acute criteria within the mixing zone and chronic criteria at the boundaries of the mixing zone.

This report describes a screening model of atmospheric dispersion and ocean mixing that can be used to evaluate both environmental performance standards in the proposed ocean incineration regulation. The model can be used for estimating the maximum waste concentration of each waste constituent that can be fed into the incinerator without exceeding the marine water quality criteria/no-effect levels. The estimated maximum waste concentrations are based on the acute water quality criteria within the initial mixing zone, which by definition extends 100 m on either side of the incineration vessel, and the chronic criteria at the boundaries of the mixing zone.

1.2 SUMMARY OF INSEA MODEL

The model, INSEA (INcineration at SEA), considers the transport and dispersion of the incinerator plume in the atmosphere, the deposition of the contaminants onto the ocean surface, and the longitudinal advection and vertical dispersion of the contaminants in the ocean. The model assumes a single constant wind and current direction (steady state). The model can be used to simulate an incineration operation over a time period of days to weeks, and up to a distance of 50 km from the source.

INSEA was developed as a screening tool to be used by reviewers of incineration permits to evaluate potential worst case effects of the incineration operations. The model is intended for use at the reviewer's desk where a large number of interactive runs can be made at very little cost. The steady state nature of the model and some limiting assumptions in the model do not allow it to be used onboard ship during monitoring activities to evaluate the real time position of the atmospheric or ocean plumes. INSEA is designed to be run on an IBM-PC or any DOS 2.1 (or later) compatible computer with a minimum of 384K of memory. Graphical routines for displaying concentation versus depth at selected points assume the availability of a plotter using Hewlett-Packard Graphics Language. Graphics output is optional and use of INSEA does not require a plotter. Using a computational grid of 14 layers and 70 columns, a ten-day simulation on an IBM-AT with a math coprocessor requires four minutes to execute.

The operation of the INSEA model is shown in Figure 1.1. The INSEA model consists of three submodels: an atmospheric transport and dispersion submodel, an ocean mixing submodel, and a criteria evaluation submodel. The atmospheric submodel computes the rise and dispersion of the plume using a three-dimensional Gaussian air plume model that is based on a model originally developed by EPA (Petersen et al. 1984). With the Gaussian plume model, atmospheric dispersion of constituents from a point or line source is simulated using the assumption that the distribution of plume constituents across the plume (transverse) is bell-shaped or normal. The model assumes the stringent situation in which there are no lateral winds during the entire burn and the wind always blows the emissions directly behind the incineration vessel. The model uses over-water Pasquill stability class equivalents to estimate the dispersion of the atmospheric plume. Rates of dispersion for each stability class are provided as a function of the distance the plume travels. The stability classes represent fast (unstable) to slow (stable) dispersion rates.

Maximum deposition of the plume's constituents occurs under the centerline of the plume because of the assumed normal distribution of constituents across the plume. The model determines the total deposition rates, attributable to dry and wet depositional processes, along the plume centerline and along a parallel line that is offset from the centerline. Normally, the offset distance in the INSEA model is set at 100 m to correspond to the width of the mixing zone (i.e., 100 m to each side of the incineration vessel). The effects of atmospheric chemistry on the removal efficiency are not considered in the model. The deposition rates under the plume centerline or the offset line are then input to a two-dimensional (longitudinal and vertical) oceanic transport and dispersion model.

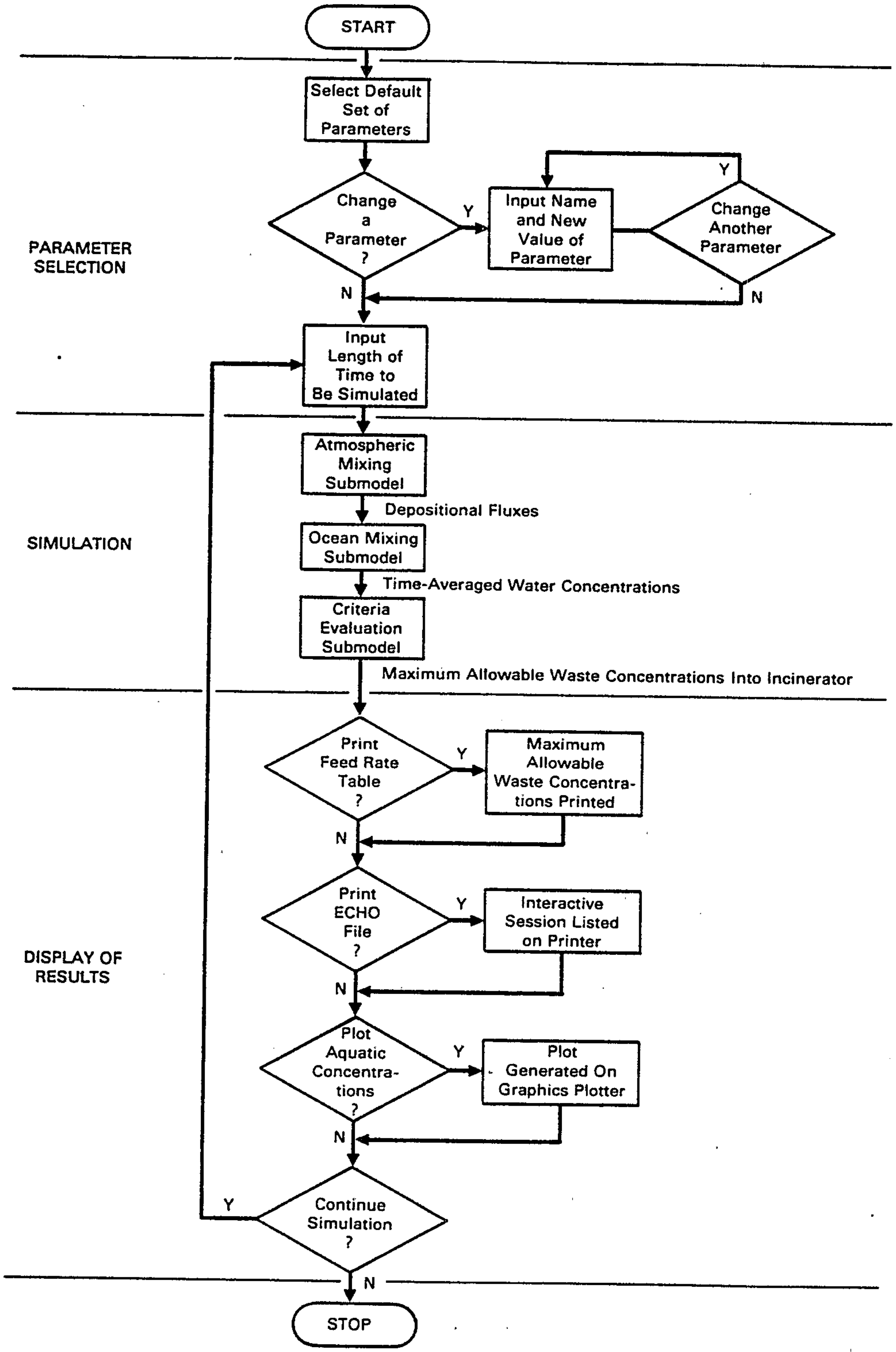


FIGURE 1.1. Operation of INSEA Model

Exchange of plume constituents from the atmosphere to the ocean is simulated in the model by the use of an initial surface mixing layer, the depth of which must be specified by the user. Constituents are assumed to instantaneously mix into this initial surface mixing layer as they are deposited on the sea surface. Decay, transformation, and accumulation of stack constituents at the sea surface are not considered in the present version of the INSEA model. After deposition in the initial surface mixing layer, plume constituents are distributed longitudinally by advective transport and mixed vertically in the ocean by dispersion. Large-scale or regional currents are used in the model for longitudinal advective transport. Superimposed on the regional current are locally wind-generated currents for additional advective transport. The regional and wind-generated currents are assumed to be in the same direction. It is assumed in the model that the vertical dispersion coefficient is related to turbulence generated by wind-generated currents. Because wind-generated currents decrease exponentially with depth in the water column, the vertical dispersion coefficient decreases as the depth increases. The ocean currents are assumed to be in the same direction as the wind and along the path of the incineration vessel in the model, so that longitudinal advection occurs along a line parallel to the path of the incineration vessel. Although the wind and current direction seldom coincide during an incineration operation, the highest constituent concentrations in the ocean will occur when the wind and current are in the same or opposite direction. The use of the assumption that the wind and current are in the same direction will make it difficult to verify the model's predicted transport and fate of stack constituents in the field, except empirically or statistically as worst case predictions.

The total area of the ocean in which stack constituents are deposited is not directly calculated by the INSEA model, but can be estimated by analyzing the concentrations of constituents along the centerline of the plume and along lines at various offset distances from the centerline. The distribution of stack constituents reaching the ocean surface depends on whether the incineration ship is stationary or moving, the ambient meteorological conditions (e.g., the magnitude of the wind, atmospheric stability and precipitation), and the movement of the ocean surface waters.

The criteria evaluation submodel computes the maximum allowable concentrations for various constituents in the waste. A linear relationship is assumed between the stack emission rate and the concentrations calculated in the ocean mixing model through the use of a unit emission rate from the stack. The unit emission rate assumption will hold true as long as inter-particle and chemical reactions do not occur in the atmosphere. The water concentrations resulting from a unit emission rate are combined with the incinerator's operating parameters (destruction efficiency and volumetric feed rate) to compute the maximum concentrations of each constituent in the final blended waste. At the end of the simulation, the model displays the maximum allowable concentrations of each constituent that may be in the waste mixture without exceeding the water quality criteria/no-effect level. The chronic and acute criteria for the waste constituents currently used in the model are shown in Table 1.1. The model can also be used to graphically display the resulting concentration in the water column at any specified location along the centerline or offset distance of the plume.

TABLE 1.1. Aquatic Life Criteria

Waste Constituent	Chronic Criteria μg/L	Acute Criteria μg/L
Aluminum	200	1,500
Arsenic	36	69
Cadmium	9.3	43
Chlorine	16,300	16,300
Chromium III	10,300	10,300
Chromium VI	50	1,100
Copper	2.9	2.9
Lead	5.6	140
Mercury	0.025	2.1
Nickel	7.1	140
Selenium	54	410
Silver	0.023	2.3
Thallium	0.02	2.13
Tin	0.7	0.7
Zinc	58	170
Cyanide	0.01	1.0
Dioxin	0.00001	0.01
DDT	0.001	0.13
PCB	0.03	10
Dichloroethane	1,130	113,000
Trichloroethane	312	31,200
Tetrachloroethane	90	9,020
Hexachloroethane	9.4	940
Chlorobenzenes	130	160
Halomethanes	6,400	12,000
Carbon Tetrachloride	500	50,000
Hexachlorobutadiene	0.32	32
Phenol	58	5,800

2.0 TECHNICAL BACKGROUND

The incineration of industrial wastes at sea and the subsequent behavior of incinerated wastes when in the atmosphere, deposited on the sea surface, and in the ocean, can be viewed as a sequence of processes taking place in adjoining compartments. In order, these compartments are the incinerator ship, the atmosphere, and the ocean. The processes that occur in each of the compartments are outlined below.

2.1 TRANSPORT AND DISPERSION PROCESSES

2.1.1 Incinerator Operations

During an incinerator operation, the ship must operate at a sufficient speed to ensure that the relative air movement past the stacks keeps the atmospheric plume away from the ship and its personnel. Past European incineration operations have been conducted with the ship at a fixed location when the ambient winds were sufficient to blow the plume away from the ship. At lower wind speeds, the ship moves to ensure the effective separation of the plume and ship.

The incinerator ship burns the waste in a high-temperature burner. The combustion products, which are released to the atmosphere, include gases and particulate matter that contain organics and trace metals. The physical characteristics of these releases depend on the chemical and physical characteristics of the industrial wastes and the availability of oxygen during combustion (Chan and Mishima 1983). Assuming that the incineration conditions maximize the burn efficiency, the particles should generally be small, with a mass median diameter (MMD) of about 1 μm (Chan and Mishima 1983). Particles of this size are small enough to be passively transported and diffused in the atmosphere. In addition, the particles should have limited tendencies to agglomerate.

Incinerator emissions can be controlled by regulating the contaminant concentrations in the waste and the feed rate to the incinerators. The emissions are also related to the destruction efficiency of the incinerator. The incinerators are required to have specific destruction efficiencies for various organic materials. Trace metals are not destroyed by incineration and have a zero destruction efficiency. For the purpose of this study, the waste concentrations and waste feed rates are assumed to be regulated in such a way that the specified destruction efficiencies are maintained during the incineration operation. The emission characteristics of the incinerator will vary with the incinerator design and particulate and/or gaseous emission controls.

2.1.2 Atmospheric Transport and Dispersion

After the plume leaves the incinerator ship's stack, it will rise as a result of buoyancy and vertical momentum. The initial dispersion is a function of the interaction between stack release characteristics and ambient atmospheric conditions. As the plume constituents are diluted by mixing with ambient air, passive atmospheric turbulence becomes the dominant dispersion process.

The vertical plume rise and dispersion can be limited by atmospheric inversion layers. The height to the first inversion layer is often referred to as the atmospheric mixing depth. Depending on the inversion strength and the plume rise energy, the plume can rise through these inversion layers. The assumption that the plume rise is limited by the atmospheric mixing depth will lead to a conservative estimate of the deposition of plume constituents on the sea surface because the plume will remain within the lowest atmospheric layer.

Previous observations of the atmospheric plumes generated from incinerator ships provide information on plume behavior under different ambient conditions. Wastler et al. (1975) noted that during low wind speeds and unstable atmospheric conditions, the plume looped and fanned out in an apparently random manner. During low wind speed conditions when the incinerator ship was operating under power (assumedly to meet a 3-knot minimum relative wind speed past the stacks), the plume, when visible, trailed the ship at an angle of about 20° from the horizontal and usually reached a maximum altitude of no more than 850 m (JRB 1983).

Weitkamp et al. (1984) used a vertically scanning deuterium fluoride LIDAR in the North Sea to locate and quantify the hydrogen chloride plume from an incinerator ship. The plume was observed to rise between 300 to

600 m under different atmospheric conditions. Vigorous downward mixing of the plume to the ocean surface was noted at times during daylight hours within a few kilometers of the ship and a less vigorous mixing with an elevated plume rise between 400 and 800 m was noted at night up to a distance of 10 km from the ship.

The rate of atmospheric dispersion varies greatly depending on the atmospheric turbulence. Factors contributing to turbulence include the local water surface roughness, boundary layer energy budget, and wind speed. The degree of turbulence is usually characterized in terms of atmospheric stability. Stability has been defined by Hasse and Weber (1985) as a function of the air/sea temperature difference. This expedient practice does not account for other possible sources of atmospheric mixing, such as cooling at the top of the boundary layer that may occur when a stratus cloud layer is present (Chaughey 1982). Irwin et al. (1985) recommend procedures to directly measure stability. When possible, the operational procedures described by Irwin et al. should be used to characterize the state of the atmospheric boundary layer.

Roll (1965) provides an overview of the processes of dispersion in the marine boundary layer. A recent report by Joffre (1985) provides a detailed review of the structure of the marine atmospheric boundary layer from the point of view of modeling transport, dispersion, and deposition processes. Many other studies of the air/sea boundary layer have been performed. Although these studies are important for understanding the boundary layer, their usefulness for assessing the impacts of at-sea incineration of hazardous wastes is limited because of the site and seasonal specificity of the information reported in these references.

Incinerator plume constituents may be deposited on the sea surface through either dry or wet deposition processes. When incinerator plume constituents reach the sea surface through dispersion or impaction, the process by which the material is deposited is referred to as dry deposition. Dry deposition rates are characterized by a 'deposition velocity' that is the ratio of the deposition flux to the air concentration. The dry deposition of particulate material is largely a function of the particle sizes. Assuming that the particulate material composing the incinerator plume is in a size class in which gravitational settling is negligible, then the air/sea interface processes, such as surface impaction and droplet collection, become important. The dry deposition of gaseous material will be a function of the chemical properties of the material. Relationships for estimating gaseous removal rates generally use Henry's law constants and solubility. The roughness state of the air/sea interface is also critical in determining the rate of gaseous deposition. For example the rate of deposition of gaseous contaminants have been shown to be orders of magnitude larger on a rough sea than on a calm sea (Merlivat 1980).

Broecker and Peng (1984) point out that no broadly accepted theory currently exists to reliably predict the rate of transfer of gas across an air/sea interface from basic information such as the wind velocity and turbulence in the water. Valuable information that could be used for assessing transfer rates of contaminants across the air/sea interface can be found in three recent proceedings. These proceedings include "Gas Transfer at Water Surfaces" (Brutsaert and Jirka 1984), "Air-Sea Exchange of Gases and Particles" (Liss and Slinn 1983), and the "Symposium on Capillary Waves and Gas Exchange" (University of Hamburg 1980).

When the plume constituents reach the sea surface as a result of precipitation, the process is referred to as wet deposition. Wet deposition is frequently characterized by washout coefficients that are directly related to the precipitation rates. The amount of material deposited per unit sea surface area is related to the total mass of material in the air column extending through the plume, rather than to the air conditions near the air/sea interface. Precipitation falling through any portion of the atmospheric plume incorporates contaminants into and carries them downward in the water droplets. The rate of capture of gaseous contaminants, will depend largely on the properties of the contaminant, such as solubility. In the case of virga (precipitation that evaporates before falling to the earth), contaminants can be reintroduced into the atmosphere at a lower height. If droplets fall through a 'cleaner' air layer under an elevated plume, desorption of gaseous contaminants into the 'cleaner' air layer is also possible. Otherwise, the contaminants in the water droplets will be carried to the ocean surface.

Wet deposition of particulate contaminants depends on the size distribution of the liquid water droplets. In overland studies, the droplet size distribution shows a wide variation, depending on the type of storm. Marine storms are expected to have different droplet size distributions, reflecting the differences in energy and aerosol inputs. Particulate washout will also depend on the particle size distribution. Slinn (1977) discusses the magnitude of these effects.

When the buoyancy of the plume is sufficient for the plume to reach the lift condensation level, a visible plume (cloud) can form. Cloud droplets can form on the more hygroscopic particles in the plume. The droplets can then collect other plume constituents in a manner similar to precipitation scavenging. The result will be an aqueous phase for the plume constituents in the atmosphere, which can be important in terms of chemical reaction rates for the formation of different materials. The formation of a visible cloud can also increase the plume rise through the release of latent heat. If the resultant cloud develops sufficiently to produce precipitation, contaminants may be carried directly to the water surface.

2.1.3 Ocean Mixing

Because plume constituent concentrations are low when deposited on the sea surface and the constituents are normally deposited far enough away from the incineration vessel where the vessel's wake will not have an effect on dispersion, mixing of incineration constituents in the ocean after deposition results mainly from the presence of natural turbulence in the near-surface ocean waters. After passing across the air/sea interface, incinerator plume constituents are transported horizontally through the process of advection and mixed horizontally and vertically through the process of dispersion. Plume constituent concentrations can also be affected by chemical and biological processes, such as degradation, decay and bio-accumulation. Horizontal dispersion of the plume constituents in the water column is by far greater than vertical dispersion. However, in terms of incineration operations where atmospheric deposition is occurring over a large area for an extended period of time, vertical dispersion becomes very important because the horizontal concentration gradients are small compared to the vertical gradients.

Few field investigations of vertical mixing in the ocean have been performed, probably because the engineering importance of vertical dispersion is generally small when compared to horizontal dispersion in terms of the magnitude of the mixing process. Csanady (1973) does report on the results of horizontal and vertical dispersion studies in the Great Lakes during light winds, using dye injected into the near-surface water. These studies indicated that the vertical spread of the dye cloud was initially similar to the horizontal spread, but the rate of vertical growth of the dye cloud was significantly less and more complicated. The rate of growth of the vertical dye cloud was more complicated due to the change of current speed, direction, and turbulence level with increasing depth. The rate of growth of the vertical dye cloud was relatively rapid to a depth of 1 to 2 m within a short distance of the dye source, but was much slower below 2 m. The dye cloud continued to spread vertically at a much slower rate until reaching a diffusion floor. The diffusion floor discussed by Csanady (1973) is analogous to the thermocline found in the north Atlantic at a depth of about 20 m during the summer months. Mixing across the thermocline probably is not completely absent, but is probably much subdued. Csanady reports values of the vertical dispersion typically ranging from a value of 30 cm^2/s within the first 0.5 m of the water surface to 5 cm^2/s at a depth of several meters.

At wind speeds higher than about 5 m/s, vertical mixing becomes quite complex because of the presence of surface waves and the possible formation of Langmuir circulation cells. At these higher wind speeds, vertical dispersion in the near-surface water is greatly enhanced, and plume constituents will be quickly mixed vertically to the depth of the thermocline.

The large-scale movement of material in the water column results from advective transport by currents. The material will be transported along with the currents at some rate proportional to the velocity and in the direction of water movement. Changes in the magnitude and/or direction of the current with depth (current shear) will result in the nonuniform advective transport of material as it is mixed downward by dispersion. Large-scale or regional circulation dominates the advective transport in the upper ocean. Superimposed on the regional circulation are the locally generated currents. Locally generated currents are dominated by the wind-induced currents where the wind shear stress exerted at the water surface drags the water along. These wind-induced currents decay exponentially with depth in the water column, setting up an internal current shear in the vertical dimension, which enhances the vertical mixing in the near-surface water.

2.2 MODEL FORMULATION

The INSEA model estimates the maximum allowable waste concentration that can be fed to the incinerator during an at-sea incineration operation without exceeding the marine aquatic life standards. The model considers the mixing of the incinerator plume in the atmosphere, the deposition of the contaminants onto the ocean surface, and the longitudinal advection and vertical dispersion of the contaminant in the ocean. INSEA is composed of three submodels: atmospheric, ocean mixing, and criteria evaluation submodels.

2.2.1 Atmospheric Submodel

The INSEA model considers the localized maximum inputs that occur directly from atmospheric plumes. The atmospheric submodel accounts for the major factors controlling the atmospheric pathway of incinerator plume constituents to the ocean. These controlling processes include plume rise, transport, dilution, and deposition processes. The atmospheric submodel is based on the following limiting assumptions during the incineration operation.

- The ship is either stationary or moving along a straight line.
- Wind direction is constant.
- Wind and ship speeds are constant when moving along the line.

The incineration operation may occur while the ship is stationary or moving along a line. When moving, the initial movement of the ship is assumed to be in the direction opposite the wind direction. Once the ship has traveled the length of the specified path, the ship is assumed to travel back along the same line. When the ship is moving with the wind, the ship speed is increased, if necessary, to achieve the minimum relative air speed flowing past the ship stacks.

Constant wind speed, wind direction, and atmospheric conditions will provide an upper limit of possible deposition of plume constituents on the sea surface. Variable wind speeds and wind directions would result in greater dispersion and lower deposition rates over a larger area. The assumption of no lateral winds (i.e., lateral to the direction of the ship movement) represents a limiting case for the maximum deposition to the ocean. In actual incineration operations, some lateral movement may occur because the ship operator probably will attempt to avoid entering and following the incinerator plume. The model, however, considers the limiting case of overlapping plumes along a single line.

Plume meander, which can contribute to effective plume dispersion, is not taken into account in the INSEA model. Calm atmospheric conditions are modeled with INSEA by assuming a 0.5 m/s drift of the plume along the model computation line. The use of a minimum drift value is based on observations that the atmosphere has some movement even under calm conditions (Hanna, Briggs and Hosker 1982). Although observations have indicated that the actual drift under calm conditions shifts direction randomly, the INSEA model assumes that the drift occurs along a straight line.

The INSEA atmospheric submodel is based on standard routines for estimating plume impacts. The dispersion and plume rise routines are taken directly from EPA's INPUFF model (Petersen et al. 1984). The reader is referred to this document for additional information on subroutines PGSZG and PLMRS. Gaussian dispersion is assumed using Pasquill dispersion categories; standard Pasquill categories are used in the INSEA model with the exception of daytime/nighttime "D" classes, following Pasquill's original recommendations.

2.2.1.1 Gaussian Plume Concentration

The basis of the atmospheric submodel of the INSEA model is the Gaussian plume equation. Routines are included in the model that use this Gaussian plume relationship to account for plume rise and deposition of plume material that is transported and diffused.

Two Gaussian plume relationships are used in the INSEA model. The first considers a continuous point source release (point source) and the second considers a series of point releases along a line (line source). The

Gaussian diffusion equation for the concentrations of a contaminant in a plume downwind of a continuous point source release is given by Slade (1968) as

$$C = \frac{Q}{2\pi \sigma_y \sigma_z \bar{u}} \exp[-y^2/(2 \sigma_y^2)]$$

$$[\exp [- (z-H)^2/(2 \sigma_z^2)] + \exp [- (z+H)^2/(2 \sigma_z^2)]] \quad (1)$$

where C = time-averaged value of concentration for a contaminant (g/cm^3)

Q = amount of material released from a point source of a con taminant (g/s)

x,y,z = positions in a Cartesian coordinate system that are oriented such that the x-axis is in the direction of the mean horizontal wind vector, the y-axis is crosswind, and the z-axis is vertical height above local ground or sea level (m)

σ_y = standard deviation of the distribution of material in the y-direction (m)

σ_z = standard deviation of the distribution of material in the z-direction (m)

$\bar{u}$ = average wind speed in the x- (along-wind) direction (m/s)

H = effective height of release over local ground or sea level (m).

The near-surface atmospheric concentrations are computed with Equation (1) using z equal to 0. The operation of the incinerator ship at a stationary position is modeled using Equation (1) with a coordinate system centered at the stationary position of the ship. For acute exposures, the value of y is 0 (along the plume centerline); for chronic exposures y is assigned a value of 100 m, corresponding to one-half the proposed mixing zone width.

The operation of the incinerator ship along a line is modeled as a series of point releases based on Equation (1). The downwind concentrations from the moving ship are computed as the sum of inputs from a series of points equally spaced along the path of the moving ship,

$$C_{line} = \frac{1}{T} \sum_{n=1}^{m} t \left(\frac{Q_{line}}{2\pi\, \sigma_y \sigma_z \bar{u}} \exp[-y^2/(2\, \sigma_y^2)]\right.$$

$$\left.[\exp[-(z-h)^2/(2\, \sigma_z^2)] + \exp[-(z+h)^2/(2\, \sigma_z^2)]\right) \qquad (2)$$

where C_{line} = time-averaged value of concentration for a contaminant along a line (g/cm^3)

Q_{line} = Amount of material released from a moving source of a contaminant over the time increment, t (g/s)

t = time increment for ship to traverse each distance increment(s),

T = total time for travel (s)

n = index of number of distance increments to be summed

m = number of distance increments used to approximate the line source by a series of point releases

Since the atmospheric inputs to the water occur at 1-h intervals in the INSEA model, the distance increments are computed with the following relationship

$$t = d / u_z$$

where t = the time for a plume at height, z, to travel the distance increment (3600 s)

d = the distance increment (m)

u_z = the wind speed at height, z, above the sea (m/s)

Equation (2) is applied in the same fashion as Equation (1) for computing air concentrations. As with the point source computation, the acute exposures are computed with y equal to 0 m, and the chronic exposures are computed with y equal to 100 m.

2.2.1.2 Pasquill Stability Classes Over Water Surfaces

The INSEA model uses Pasquill stability classes to estimate the dispersion rates of the atmospheric plume. The Pasquill stability classes provide a method of defining atmospheric dispersion rates. Curves for each of the stability classes provide values of the dispersion parameters as a function of travel distance of the plume. The six stability classes are normally expressed by the letters A to F, progressively representing fast (unstable) to slow (stable) dispersion rates. The original stability classes (Pasquill 1961, 1962) were strictly defined in terms of parameters applicable to dispersion over land surfaces. Applying these land surface classes to over-water surfaces requires careful translation.

The stability classes used in the INSEA model are the over-water equivalents of the original classes (Hasse and Weber 1985). Although stability in the original Pasquill method is defined in terms of the daytime insolation and nighttime cloud cover, Hasse and Weber define stability in terms of the local radiation budget and wind speed.

Hasse and Weber (1985) compute sensible heat flux from radiation budget estimates. They use a Bowen ratio (equal to sensible heat flux divided by latent heat flux) of 0.4 for unstable and neutral conditions, and assume negligible evaporation under stable conditions. For application over water, the sensible heat fluxes are converted to air/sea temperature gradients.

The wind speed difference between land and water surfaces is accounted for by converting the stability classes to a friction velocity. The friction velocity conversion is based on the assumption of a roughness length equal to 3 cm for the original Pasquill stability classes.

Figure 2.1 presents the Hasse and Weber diagram for the Pasquill stability classes converted for use over water surfaces. They assume that the drag coefficient for momentum, C_D, and heat, C_H, are both equal to 1.3×10^{-3}. The over-water wind speed, u, and potential temperature gradient, $\Delta\theta$, are defined by

$$u = u_*(C_D)^{-1/2}$$

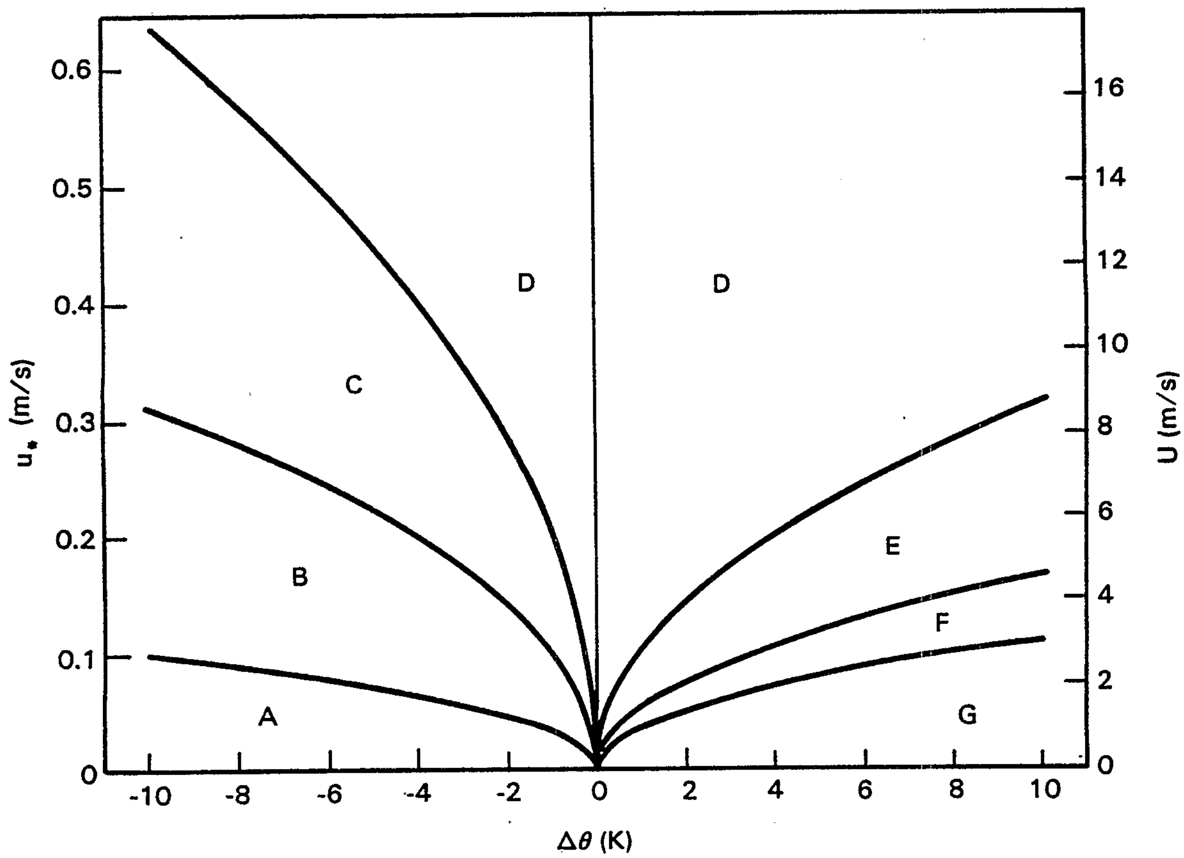


FIGURE 2.1. Hasse and Weber Diagram for Stability Class

and

$$\Delta\theta = - H/(C_H c_p \rho \; u)$$

where H = sensible heat flux

c_p = specific heat at constant pressure

ρ = density of air

u_* = friction velocity.

A seventh dispersion class, G, with very restrictive dispersion has been suggested. This class was not included in the INSEA model because the class was not necessary or appropriate for defining the limiting cases of the maximum air/sea deposition rates. The greatest dry deposition rates from an elevated plume occur under unstable conditions. Although the use of class G would increase the computed wet deposition rates, such extremely limiting conditions are not expected to occur during precipitation conditions.

2.2.1.3 Wind Speed Variation With Height

The variation of wind speed with height is used in the INSEA model to extrapolate the speed at the stack release height and the height of plume rise from the 10 m wind speed. These wind speeds are used in the model to approximate the plume movement with the Gaussian plume Equations (1) and (2).

The general formulation of wind variation with height, derived from a combination of observations and micrometeorological similarity theory, is used in the INSEA model. This approach is used instead of the power-law formulations used in other EPA models (Irwin et al. 1985) because the power-law formulations were derived for winds over land surfaces.

For unstable atmospheric conditions, the following expression is used in the INSEA model to calculate the wind variation with height (Paulson 1970):

$$\bar{u} = \frac{u_*}{4} \ln \frac{z}{z_o} - 2 \ln \left[\frac{1}{2} \left(1 + \frac{1}{\phi_m} \right) \right]$$

$$- \ln \left[\frac{1}{2} \left(1 + \frac{1}{\phi_m^2} \right) \right] + 2 \tan \frac{1}{\phi_m} - \frac{\pi}{2} \qquad (3)$$

where $\bar{u}$ = average wind speed (m/s)
u_* = friction velocity (m/s)
z = height over land/water surface (m)
z_o = roughness length of surface (m)
ϕ_m = dimensionless wind gradient parameter

For stable conditions the following expression is used in the INSEA model to calculate the wind variation with height (Hanna, Briggs and Hosker 1982):

$$\bar{u} = \frac{u_*}{0.4} \left(\ln \frac{z}{z_0} + 5 \frac{z}{L} \right) \qquad (4)$$

where L is the Monin-Obukhov length (m), a scaling length of atmospheric turbulence. Equations (3) and (4) are integrated forms of relationships derived from field studies by Businger et al. (1971).

To use Equations (3) and (4) for determining the wind variation with height over the ocean, the roughness length, friction velocity, and Monin-Obukhov length must be calculated. The following paragraphs describe how these parameters are calculated in the INSEA model.

Charnock's relationship for the roughness length (z_0) as described by Joffre (1985), is used by the INSEA model.

$$z_o = m\, u_*^2/g \qquad (5)$$

where g = acceleration of gravity (m/s^2)
m = coefficient [= 0.0144 recommended by Garratt (1977)]

Equation (6) is used in the INSEA model to estimate the friction velocity (u_*). These friction velocity relationships were taken from drag coefficient relationships reported in Large and Pond (1981) by substituting for the friction velocity using $C_D = u_*^2/u_s$.

$$u_* = u_s\,(1.2 \times 10^{-3})^{1/2} \qquad \text{for } 4 \leq u_s < 11 \text{ m/s}$$

$$u_* = u_s[(0.49 + 0.065\, u_s) \times 10^{-3}]^{1/2} \qquad \text{for } 11 \leq u_s \leq 25 \text{ m/s} \qquad (6)$$

where u_s = wind speed at the 10 m height.

For wind speeds less than 11 m/s, the friction velocity relationships are nearly identical to those used by Hässe and Weber (1985) in their transposing of Pasquill categories to use over water surfaces.

The Monin-Obukhov length is a function of atmospheric stability and is related to the Pasquill stability classes in the INSEA model using Table 2.1. Table 2.1 provides approximate 1/L values for each of the stability classes.

TABLE 2.1. Summary of Approximate Central 1/L Values for Each of the Pasquill Stability Categories (derived from Hasse and Weber 1985)

Pasquill Stability Classes	Central 1/L Magnitude	Dimensionless Height Z/L
A	-0.60	-6.0
B	-0.28	-2.8
C	-0.03	-0.3
D	0.00	0.0
E	0.12	1.2
F	0.30	3.0
G	0.50	5.0

2.2.1.4 Plume Rise

Plume rise formulations given by Briggs (1969, 1971, 1973 and 1975) and reported in Petersen et al. (1984), are used in the INSEA model. The plume rise equations are based on the assumption that plume rise depends on the inverse of the mean wind speed and is directly proportional to the two-thirds power of the downwind distance from the source. Different equations are used for different atmospheric stabilities.

Application of the plume rise equations for a moving ship is complicated because the relative wind speed past the stack will be higher or lower, depending on whether the ship is moving into or with the prevailing wind. As an approximation, the reference frame in the INSEA model is shifted to allow use of the Briggs plume rise relationship. The relative ship-air speed past the stack is used in the plume rise equations in place of the ambient wind speed.

The plume rise equations used in the INSEA model for unstable and stable atmospheric conditions are summarized below. For additional details of the plume rise formulation, the reader is referred to a detailed description of the plume rise formulations by Petersen et al. (1984).

Unstable and Neutral Atmospheric Conditions

The plume rise relationships are as follows:

$$x_f = 3.5\ x^*$$

where x_f = downwind distance of final plume rise (m)

x^* = distance at which atmospheric turbulence begins to dominate entrainment.

The value of x^* is computed from

$$x^* = 14\ F^{5/8} \qquad \text{for } F < 55\ m^4/s^3$$

or

$$x^* = 34\ F^{2/5} \qquad \text{for } F \geq 55 m^4/s^3$$

where F is the buoyancy flux parameter (m^4/s^3). The final plume rise is given by

$$H = h' + [1.6\ F^{1/3}\ (3.5\ x^*)^{2/3}/u_h]$$

where H = Effective height of plume (m)

h' = Stack height above sea level adjusted for stack downwash (m)

u_h = Wind speed at top of stack (m/s)

Stable Atmospheric Conditions

The relationships for distance expressed as a function of stability parameter is

$$x_f = 0.0020715\ u_h\ s^{-1/2}$$

where s = stability parameter (1/s)

The plume rise height for windy conditions is given by

$$H = h' + 2.6\ (F/[u_z s])^{1/3}$$

or for near-calm conditions

$$H = h' + 4\ F^{1/4} s^{-3/8}$$

The lower value of H computed from these two equations is used as the final plume rise in the INSEA model.

2.2.1.5 Air-to-Sea Deposition

The wet deposition along the centerline of the plume, W, for rain falling completely through a Gaussian plume from a point source (Equations (1) and (2)) is shown by Hanna, Briggs and Hosker (1982) to be

$$W = \frac{\Lambda Q'}{(2\pi)^{1/2}\ \sigma_y \bar{u}} \tag{7}$$

where Λ is the scavenging coefficient (1/s) and Q' is the air concentration over the water surface allowing for depletion by wet deposition.

The dry deposition, D, is represented by

$$D = V_t\ Q' \tag{8}$$

where V_t is the dry transfer velocity with units of length per time.

The total deposition, T, is the sum of the wet and dry deposition rates:

$$T = W + D \tag{9}$$

These total deposition fluxes are input to the upper layer of the ocean at hourly intervals.

2.2.2 Ocean Mixing Submodel

The ocean submodel is a two-dimensional contaminant transport model of vertically stratified longitudinal advection and vertical dispersion. The ocean submodel estimates the longitudinal and vertical distributions of contaminants in the water column from the contaminant flux to the water surface defined by the atmospheric submodel.

Exchange of contaminants from the atmosphere to the water is simulated in the ocean mixing submodel by the use of a surface mixing layer. This mixing layer is the depth that the atmospheric deposition is instantaneously mixed to convert the contaminant flux to a concentration. The surface mixing layer thickness can be specified by the user. The sensitivity of selection of the depth of the surface mixing layer is discussed in Section 6.1.4. A value of 1.0 m or less for the surface mixing layer is recommended for use in the INSEA model.

Longitudinal advection of the water column is simulated in the ocean mixing submodel by use of a steady-state water velocity profile resulting from regional and wind-induced currents. The regional and wind-induced currents are additive in the model to arrive at a current profile. The regional current is specified by the user and is uniform with depth. The wind-induced current profile is calculated internally in the model using the specified wind speed. The assumption of the steady-state current profile is consistent with the steady-state wind in the atmospheric submodel. The contribution to the velocity profile by the wind is based on an exponential profile developed by Ekman (1905), where the surface water velocity is calculated from the surface wind shear. The velocity profile is used to determine an average longitudinal velocity for each layer defined in the ocean submodel.

Vertical dispersion is calculated in the ocean submodel with the use of a dispersion coefficient. The dispersion coefficient is calculated internally in the model from a user specified diffusion coefficient and dispersivity. The vertical dispersion coefficient varies with depth because the dispersivity term of the dispersion equation is also a function of velocity, which varies with depth. Horizontal dispersion is not included in the ocean submodel because under steady-state conditions the atmospheric deposition of plume constituents is constant during the incineration operation. Horizontal dispersion would be important only at the fringes of the plume during incineration under steady-state conditions, where continuous atmospheric deposition does not occur. Since the INSEA model is primarily concerned with the concentrations at the plume centerline and at small offset distances from the centerline horizontal dispersion has not been included in the model.

2.2.2.1 Estimating Current Magnitude

The current magnitude in each horizontal layer of the ocean submodel is the sum of the user specified regional current and the wind-induced current. The regional current is uniform with depth, whereas the wind-induced current profile is calculated internally in the model from the wind shear at the sea surface, which results in the variation of the current with depth.

The wind-induced current profile used in the ocean submodel is derived from Ekman (1905). Only the magnitude of the wind-induced current is used in the model. Ekman showed theoretically that wind-induced currents will be deflected to the right in the northern hemisphere and the current magnitude will decrease exponentially with depth (Ekman spiral). At some depth, referred to as the depth of frictional resistance, the current is opposed to the surface current, and is only one-twenty-third of the magnitude of the surface current. The rapid decay of the current magnitude with depth has been observed, and in some areas, water masses have been observed to be deflected at some angle to the wind. However, the occurrence of the Ekman spiral has not been demonstrated in the wind-influenced layer of the ocean (von Arx 1962). Although other researchers such as Rossby and Montgomery (1935), Lamb (1932) and Mellor and Durbin (1975) also have developed methods for estimating wind-induced currents, Ekman's formulation is used in the ocean submodel because of the ease in solving the equation.

The wind-induced current velocity at any depth is obtained from the exponential velocity profile equation developed by Ekman (1905). This equation is

$$V = V_o \, e^{-\frac{\pi}{D} Z} + V_g \qquad (10)$$

τ_a

where $V_o = \overline{\sqrt{\rho A 2\omega \sin \phi}}$

z = depth (m)

D = depth of frictional resistance (m)

a = the shear stress at the water surface (g/ms^2)

ρ = the water density (g/m^3)

A = the eddy viscosity (g/m-s)

ω = the rotational velocity of the earth (m/s)

ϕ = the latitude of the site

V_g = regional current velocity (m/s).

Eddy viscosity is calculated using either of two empirical relationships, depending on wind speed (Sverdrup, Johnson and Fleming 1942). For wind speeds below 6 m/s, it is calculated as

$$A = 1.02\ W^3 \tag{11}$$

where A has the units of g/cm-s and W is the wind speed in m/s. For wind speeds greater than 6 m/s, eddy viscosity is calculated as

$$A = 4.3\ W^2 \tag{12}$$

where the units are the same as the first expression.

The shear stress at the water surface is also calculated using either of two relationships, depending on wind speed. For wind speeds below 6 m/s, the surface shear is estimated using the following expression developed by von Karman (Sverdrup, Johnson and Fleming 1942):

$$\frac{W}{\sqrt{\tau/\rho}} = 5.5 + 5.75 \log (z\rho/\mu \bullet \sqrt{\tau/\rho}) \tag{13}$$

where W = the wind speed (m/s)

τ = the shear stress (m/ms^2)

z = the elevation at which the wind speed is measured (m)

ρ = the density of air (g/m^3)

μ = the viscosity of air (g/m-s)

For wind speeds greater than 6 m/s, the shear stress is obtained using an empirical expression developed by Ekman (1905)

$$\tau = 2.4 \times 10^{-3} \rho W^2 \tag{14}$$

where τ = the shear stress (g/ms^2)

p = the density of air (g/m^3)

W = the wind speed (m/s).

2.2.2.2 Estimating Vertical Dispersion

Dispersion in the ocean is the result of both molecular diffusion and turbulent dispersion. Generally, the effect of dispersion will far exceed the molecular diffusion. In INSEA, the apparent dispersion coefficient, D, is expressed as

$$D = D^* + dv \tag{15}$$

where D = dispersion coefficient (m^2/s)

D^* = diffusion coefficient (m^2/s)

d = dispersivity (m)

v = wind-generated current of layer (m/s)

The dispersion coefficient in the ocean submodel takes into consideration both molecular diffusion and turbulent dispersion. The diffusion term (D^*) is specified by the user and is uniform over the entire water depth. The turbulent dispersion term (dv) varies with depth because of the velocity term, v. The turbulent dispersion term was incorporated into the model because the observed dispersion rates tend to increase with increasing velocity. Additional field studies are needed to develop a better understanding of oceanic dispersion processes.

The one-dimensional Fickian diffusion equation can be expressed as

$$\frac{\partial C}{\partial t} = D(z) \frac{\partial^2 C}{\partial z^2} \tag{16}$$

where C = concentration (g/m^3)
t = time (s)
z = vertical direction (m)
D = diffusion coefficient (m^2/s)

Analytic solutions of the diffusion equation are not available when D is an arbitrary function of z. Dispersion is estimated in the ocean submodel using the fully-implicit finite-difference scheme, described in Equation 15. Using this scheme to approximate dispersion for each layer of the system results in a tridiagonal matrix which is easily solved with Thomas's algorithm.

To verify the solution procedure, the results of the finite-difference scheme have been compared against an analytic solution of the diffusion equation. Carslaw and Jaeger (1959) published an analytic solution of a one-dimension Fickian diffusion equation where D is a constant. A comparison of the numerical solution and the analytic solution is shown in Figure 2.2. The comparison shows good agreement.

2.2.2.3 Estimating Longitudinal Advection

INSEA represents the ocean as a series of vertically stratified layers. Each layer moves at discrete time intervals, defined by the estimated water velocity at mid-depth of the layer. The distance each layer moves is the same, but the time between moves for each layer will be different, unless the vertical current velocity profile is uniform.

The method used for estimating longitudinal advection is similar to the method-of-characteristics, except the time step is constant and the distances vary. By employing this method, the problem of numerical dispersion, which is often present when classical methods such as finite differences are applied to advection-dominated advection/dispersion problems, is avoided. Numerical dispersion results in an overestimation of dispersion, which in turn results in an underestimation of constituent concentrations in the water column.

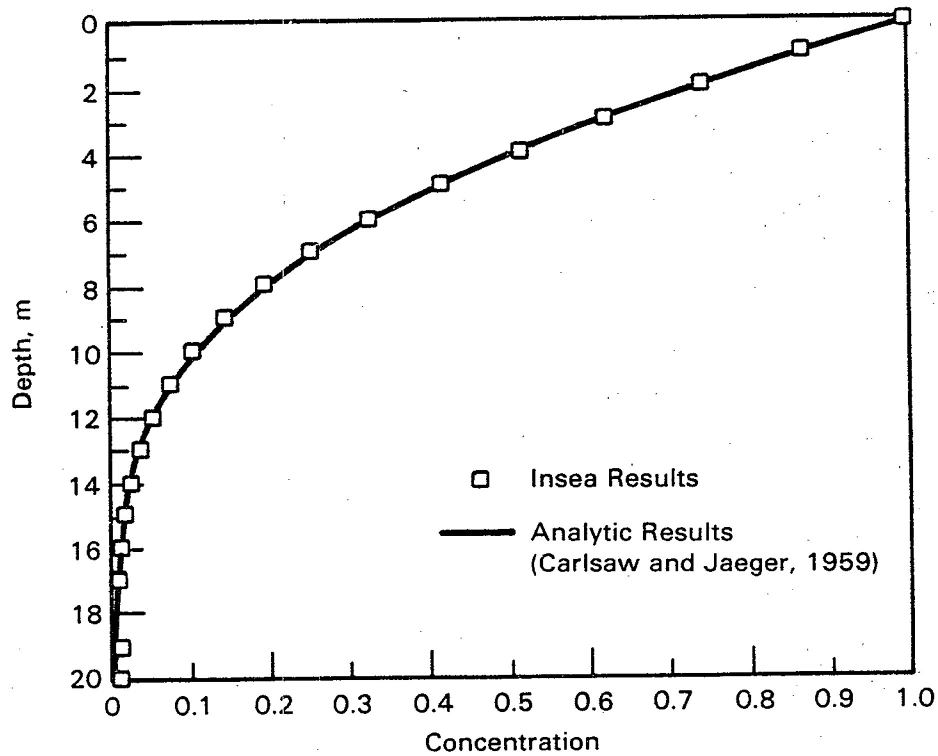


FIGURE 2.2. Comparison of INSEA Dispersion Estimation Procedure with Analytic Solution

2.2.3 Criteria Evaluation Submodel

The purpose of the criteria evaluation submodel is to derive maximum allowable concentrations in the final blended waste for each constituent based on the time-averaged concentrations predicted with the ocean submodel and the aquatic criteria provided by the INSEA database. Since the concentrations predicted by the ocean submodel are based on a unit emission (1 g/s), the maximum allowable concentration (MAC) can be expressed as

$$MAC = \frac{S}{C\ (1 - DE)} \tag{17}$$

where S = maximum concentration allowed by aquatic criteria
C = predicted concentration based on unit emission
DE = destruction efficiency of incinerator for the particular constituent.

This equation implies the destruction efficiency is a constant. The use of this destruction efficiency method is consistent with the regulation proposed by EPA that requires specific destruction efficiencies for certain contaminants.

2.2.4 Computation Scheme

The atmospheric submodel uses the ship, incinerator, and atmospheric properties to estimate the distribution of a unit flux of incinerator effluent on the ocean surface. The atmospheric submodel assumes the incinerator effluent behaves as a Gaussian plume. The removal of contaminants from the atmosphere to the ocean is defined by a deposition velocity and scavenging coefficient. Fluxes from the atmosphere to the ocean are provided along a line parallel with the direction of the wind behind the incinerator ship.

The ocean mixing submodel estimates the aquatic concentrations that would result from the unit flux of incinerator emissions. To compute the aquatic concentrations, the mixing fluxes of emissions provided by the atmospheric submodel are mixed downward by dispersion and advected longitudinally by the ocean current. Atmospheric fluxes of emissions are deposited onto the ocean surface each hour. The mass resulting from one hour of deposition is instantaneously mixed into the surface mixing layer of each column of the grid. The mass entering the surface layer of each column is different, because the columns are at different distances downwind of the incineration vessel. The depth of the surface layer, if too large, can have an effect on subsequent mixing of stack constituents and resulting aquatic concentrations. It is recommended that the surface layer depth be set at 1.0 m or less by the user.

Once the mass is mixed into the surface layer, it is allowed to mix downward according to Equation 15. The dispersion time step is one hour. Next, longitudinal advection is allowed to occur for those layers assigned to move within the next hour. As long as the time period between advection events is less than the deposition and dispersion time step of one hour, decoupling the dispersion and advection computations in the INSEA model presents no serious problems with numerical dispersion. The model warns the user if the time step conditions are violated. The user can correct the time step violation by using fewer and larger cells with longer time steps between the advective computations. After the advective computations have been made, the model repeats the deposition of atmospheric fluxes and performs the vertical dispersion/computations.

The aquatic concentrations provided by the ocean mixing submodel are used by the criteria evaluation submodel to estimate the maximum allowable concentration in the waste for each of the substances listed in Table 1.1. The allowable concentrations for each substance are displayed by the model and the user may have the model graphically display the relative concentrations in the ocean.

3.0 MODEL INPUT PARAMETERS

The selection of input parameters required to run the INSEA model has been streamlined so the user can either use preset default values or select independent input values. The input parameters in the model are categorized into ship parameters, incinerator parameters, atmospheric parameters, and oceanic parameters. Table 3.1 is a listing of the INSEA input parameters, along with the default values, reasonable ranges that can be used and references from which additional information can be obtained. The selection of input parameters is discussed in more detail in this section.

3.1 DEFAULT CASES

INSEA uses eight default cases representing a range of conditions that is likely to occur during an incineration operation. It is unlikely, however, that the input parameters in the default cases will exactly match the conditions the user would like to simulate. All the default cases are set to neutral atmospheric stability (class D) with 1.5 m/s wind speed. The user should select the default case that most closely represents the conditions to be simulated, then change the input parameters for that default case to represent the actual ship operation, atmospheric and oceanic conditions to be simulated. Table 3.2 summarizes the eight default cases. Table 3.3 summarizes the values for the input parameters for each of the eight default cases.

If stationary or near-stationary operation is expected, then default cases 1 to 4 apply. If the ship is expected to be under way, then cases 5 to 8 provide computations based on a line source. Cases 1, 2, 5, and 6 are based on the acute water quality criteria along the plume centerline. Cases 3, 4, 7, and 8 are based on the chronic water quality criteria at an offset distance of 100 m from the plume centerline. All cases consider dry deposition. Cases 1, 3, 5 and 7 also consider wet deposition. All default cases consider neutral atmospheric conditions (stability class D).

TABLE 3.1. INSEA Model Input Parameters, Default Values and Ranges

CATAGORY/INPUT PARAMETER	UNITS	DEFAULT VALUE	RANGE	REMARKS
SHIP PARAMETERS				
POINT SOURCE/LINE SOURCE	N/A	Point/Line	Point/Line	Will Depend on Incineration Plan and Meteorological Conditions
SHIP SPEED	Knots	3.0	1.5 - 10.0	Will Depend on Incineration Plan, Ship Characteristics and Meteorological Conditions
PATH LENGTH OF LINE SOURCE	Kilometers	5.0	5 - 50	Will Depend on Incineration Plan and Size of the Incineration Site
INCINERATOR PARAMETERS				
NUMBER OF INCINERATORS	N/A	3	1-3	Will Depend on Incinerator Ship Characteristics
HEIGHT OF STACK	Meters	12	10-20	Will Depend on Incinerator Ship Characteristics
VELOCITY OF STACK EMISSIONS	Meters/Sec	15	10-20	Will Depend on Incinerator Characteristics
TEMPERATURE OF STACK EMISSIONS	Degrees C	1429	1200-1500	Will Depend on Incinerator Characteristics
DIAMETER OF STACK	Meters	3.2	3-4	Will Depend on Incinerator Characteristics
MINIMUM AIR SPEED PAST STACK	Meters/Sec	1.5	1.5	Minimum Air Speed Past Stack is Set by Regulation to 1.5 m/s
ATMOSPHERIC PARAMETERS				
STABILITY CLASS	N/A	D	A - F	A to F Represents Very Unstable to Stable Conditions (See Section 3.3.1 and Hasse and Weber 1985)
WIND SPEED	Meters/Sec	1.5	1.5 - 15	Will Depend on Incineration Site Characteristics
AIR TEMPERATURE	Degrees C	10	5-25	Will Depend on Incineration Site Characteristics
MIXING HEIGHT	Meters	500	200-800	Will Depend on Meteorological Conditions (See Section 3.3.4 and Joffre 1985)
WET SCAVENGING COEFFICIENT	1/Sec	0.00015	0.00004-0.003	Will Depend on Meteorological Conditions (See Section 3.3.5 and McMahon and Denison 1979)
DRY DEPOSITION VELOCITY	Meters/Sec	0.03	0.003-0.3	Will Depend on Meteorological Conditions (See Section 3.3.6)
OFFSET FROM CENTERLINE	Meters	0 or 100	Any Value	Although Default Values are Set Up For Chronic and Acute Criteria, Any Offset Distance Can be Used

TABLE 3.1. INSEA Model Input Parameters, Default Values and Ranges (continued)

CATAGORY/INPUT PARAMETER	UNITS	DEFAULT VALUE	RANGE	REMARKS
OCEAN PARAMETERS				
REGIONAL CURRENT	Meters/Sec	0	0 - 0.25	Will Depend on Incineration Site Characteristics
DIFFUSION COEFFICIENT	Sq.Meters/Sec	0.0005	0.0003-0.003	Will Depend on Incineration Site Characteristics (See Csanady 1973)
DISPERSIVITY	Meters	0	0 - 0.10	Will Depend on Incineration Site Characteristics (See Csanady 1973)
LATITUDE	Degrees	26	N/A	Will Depend on which Incineration Site is to be Used (Default Value is for Gulf of Mexico Site)
LENGTH OF OCEAN SIMULATED	Kilometers	10	10 - 50	Will Depend on Size of Incineration Site
GRID SPACING (HORIZONTAL LAYERS)	N/A	14	1 - 20	Layer Depth Must Also be Specified. Surface Layer Should be 1 m or Less
GRID SPACING (VERTICAL COLUMNS)	N/A	70	1 - 100	Spacing Between Columns is Calculated Internally in INSEA (Spacing = Length of Ocean Simulated Divided by Number of Vertical Columns)

TABLE 3.2. INSEA Default Cases

1	Point Source, Centerline Values, Precipitation Conditions
2	Point Source, Centerline Values, Non-precipitation Conditions
3	Point Source, Offset Values, Precipitation Conditions
4	Point Source, Offset Values, Non-precipitation Conditions
5	Line Source, Centerline Values, Precipitation Conditions
6	Line Source, Centerline Values, Non-precipitation Conditions
7	Line Source, Offset Values, Precipitation Conditions
8	Line Source, Offset Values, Non-precipitation Conditions

3.2 SHIP PARAMETERS

3.2.1 Point Source/Line Source

The point source mode refers to stationary operation of the incineration ship, and the line source refers to operation of the ship back and forth along a line. The choice of operating in the stationary mode or line mode affects the definition of other input parameters. Selecting the stationary mode of operation automatically sets the ship speed at 0 and makes the input value for the path length unnecessary. When running the model in the line mode, the ship speed and path length also must be defined. The requirement for a minimum air speed past the stack relates to the minimum required wind speed for a point source and the minimum ship speed required for a line source.

3.2.2 Ship Speed

For a line source, the speed of the ship must be specified. The default value in the line source cases is set at 3 knots. The model uses the ship speed as a minimum value. The ship speed will be increased automatically in the model, if necessary, to ensure that sufficient air moves past the incinerator stack. The ship speed used in each computation is included in the model output.

TABLE 3.3. Input Parameter Values for Eight Default Cases

INPUT PARAMETERS	DEFAULT CASES (SEE TABLE 3.2) CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
SHIP PARAMETERS								
POINT SOURCE/LINE SOURCE	Point	Point	Point	Point	Path	Path	Path	Path
SHIP SPEED	0	0	0	0	3	3	3	3
PATH LENGTH OF LINE SOURCE	0	0	0	0	5	5	5	5
INCINERATOR PARAMETERS								
NUMBER OF INCINERATORS	3	3	3	3	3	3	3	3
HEIGHT OF STACK	12	12	12	12	12	12	12	12
VELOCITY OF STACK EMISSIONS	15	15	15	15	15	15	15	15
TEMPERATURE OF STACK EMISSIONS	1429	1429	1429	1429	1429	1429	1429	1429
DIAMETER OF STACK	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
MINIMUM AIR SPEED PAST STACK	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
ATMOSPHERIC PARAMETERS								
STABILITY CLASS	D	D	D	D	D	D	D	D
WIND SPEED	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
AIR TEMPERATURE	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
MIXING HEIGHT	500	500	500	500	500	500	500	500
WET SCAVENGING COEFFICIENT	0.00015	0.0	0.00015	0.0	0.00015	0.00015	0.00015	0.0
DRY DEPOSITION VELOCITY	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
OFFSET FROM PLUME CENTERLINE	0	0	100	100	0	0	100	100
OCEAN PARAMETERS								
REGIONAL CURRENT VELOCITY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DIFFUSION COEFFICIENT	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
DISPERSIVITY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LATITUDE	26	26	26	26	26	26	26	26
LENGTH OF OCEAN SIMULATED	10	10	10	10	20	20	20	20
GRID SPACING	Default	Default	Default	Default	Default	Default	Default	Default

3.2.3 Path Length of the Line Source

For a line source, the length of the ship path must be specified. Normally, the path length will be the distance the ship traverses in the incineration operation area before it reverses its course. For the default cases with a line source, the path length is initially set at 5.0 km. The path length of the line source is limited by the requirement to stay within the specified burn area. To allow for computations of downwind water concentrations, the model assumes that the incineration operation occurs on the upwind end of the specified burn area. The INSEA model also limits the length of the ship path to one-half of the width of the burn area. Because the model allows the ship to move back and forth along the line, the ship speed and duration of the incineration operation do not affect the selection of path length.

3.3 INCINERATOR PARAMETERS

3.3.1 Number of Incinerator Units

The number of incinerators will determine the total emission rate. Normally, one to three incinerators are on the ship. The default value is three incinerators.

3.3.2 Height of Stack

The height of the incinerator stack is used to determine the initial height of the plume in the atmosphere. The stack height is defined as the height of the top of stack over the water surface. The default value for the stack height is 12 m.

3.3.3 Velocity of Stack Emissions

The velocity of the emissions exiting the stack contributes to the plume rise. The default value for the stack exit velocity is 15 m/s.

3.3.4 Temperature of Stack Emissions

The temperature of the stack emissions contributes to the buoyancy of the contaminant plume. The default value for the stack exit temperature is 1429°K.

3.3.5 Diameter of Stack

The diameter of the incinerator stack along with the velocity of the emissions exiting the stack define the total volume flowing out of the stack. The total volume will affect the plume rise. The default value for the stack diameter is 3.2 m.

3.3.6 Minimum Air Speed Past Stack

The minimum operational air speed past the incinerator stack refers to the horizontal speed of the air past the stack resulting from the combination of ship movement and wind speed. This speed is required for both the line source and point source modes of operation. The default value for the minimum air speed past the stack is 1.5 m/s.

3.4 ATMOSPHERIC PARAMETERS

3.4.1 Stability Class

Six stability classes are designated by the letters A, B, C, D, E, and F. Class A represents very unstable conditions and class F represents very stable conditions. Although the selection of the stability class for INSEA is normally dictated by the stability that most restricts the computed waste concentrations in the waste, the user may wish to compare the most limiting atmospheric case with expected stability conditions for the time and location of a proposed burn. The atmospheric stability class can be selected based on air/sea surface temperature differences. Hasse and Weber (1985) give a method for estimating stability classes over water surfaces. Figure 2.1 is reproduced from their paper. To use this figure, one uses the air/sea surface temperature difference and friction velocity (computed using Equation (6)) to define a stability class. Stability class D is used as the default value, which represent neutral atmospheric stability conditions.

3.4.2 Wind Speed

The surface wind speed at 10 m above the sea surface is used in both the atmospheric and ocean submodels. In the ocean submodel, the surface wind speed is used to compute the vertical current velocity profile. The default value is 1.5 m/s. The default value corresponds to the minimum relative wind speed past the incinerator ship stack, as proposed by the EPA regulations.

3.4.3 Air Temperature

The ambient air temperature is used along with the stack exit temperature for computing plume buoyancy. The default value for the air temperature is 10°C. If available, the expected average ambient temperature during a planned incineration operation should be used.

3.4.4 Mixing Height

The mixing height (height of the atmospheric boundary layer) is the height above the sea surface at which vertical atmospheric transport can occur. The default value for the height of the atmospheric boundary layer is 500 m.

Information on average mixing heights over oceans is limited by the lack of routine observations in most regions. The processes maintaining the marine boundary layer are different than the processes operating over land. Data from coastal stations are of questionable value for defining offshore boundary layer heights. Also, techniques for estimating mixing heights over land surfaces cannot be directly applied to the marine boundary layer. In situations for which information on mixing height is not available, Joffre (1985) provides a general method of estimating mixing heights.

3.4.5 Wet Scavenging Coefficient

The scavenging coefficient is used to calculate the wet deposition rate of the airborne contaminants onto the sea surface. The scavenging coefficient is theoretically a function of the droplet size distribution, physical and chemical characteristics of the contaminant, and precipitation rate. Values of 0.00015 s^{-1}, 0.00004 s^{-1}, and 0.003 s^{-1} represent mid, low, and high values, respectively, based on particulate scavenging coefficients measured in 20 field experiments (McMahon and Denison 1979). The mid-range value of scavenging coefficients is an upper range for gaseous contaminant deposition. The default value for the scavenging coefficient is 0.00015 s^{-1}.

The use of a scavenging coefficient to estimate wet deposition is at best an order-of-magnitude approximation and may be inappropriate for gases that are not highly reactive or for those that are soluble in water. The user has the option of using a scavenging coefficient of zero to specify non-precipitation conditions during the incineration operation. When the scavenging coefficient is set at zero, the dry deposition determines the deposition pattern.

3.4.6 Deposition Velocity (Dry Deposition)

The deposition velocity is the ratio of the dry deposition flux onto the sea surface to the contaminant concentrations over the sea surface. The model uses the deposition velocity to calculate the dry deposition rate of the airborne contaminants onto the sea surface. The default value for the deposition velocity is 0.03 m/s.

INSEA allows input of two types of deposition velocities; air-sea deposition velocities and gravitational settling velocities. The air-sea deposition velocities are entered as positive numbers and gravitational settling velocities are entered as negative numbers. The change in sign indicates only the type of deposition velocity and not the direction of the flux.

The gravitational settling option can be used for the special case for which a significant number of larger particles are released. The upper limit to settling velocities should be 20 to 30 cm/s. The INSEA formulation is inappropriate for settling velocities greater than 30 cm/s.

Most at-sea incinerators are expected to emit either gaseous or particulate releases that are small enough to not have a significant gravitational settling velocity. As a guide, particulate mid, low, and high values of deposition velocities are 0.03 m/s, 0.003 m/s, or 0.30 m/s, respectively. The deposition velocities for gaseous materials depend on the molecular weight and air-sea surface concentration difference.

The high range value for deposition velocities applies mainly to reactive or quite soluble gases, and is based on studies of dry deposition of gases such as O_2 and SO_2. The mid-range value refers mainly to gas mass transfer equivalent to evaporation. The mid range also represents the greatest deposition velocities that can be expected by nonhygroscopic aerosols. The low range value represents predicted velocities for aerosols on the order of 0.3 μm diameter. If predicted maximum dry deposition rates for a particular contaminant are unreasonably high, a more realistic removal rate may be estimated for a particular gaseous or particulate material based on the actual chemical and physical properties of the material.

3.4.7 Offset Distance From Plume Centerline for Computation

The offset distance allows the computations to be performed at some distance away from and parallel to the plume centerline. This option was incorporated into the model to assess the proposed chronic criterion based on the use of a mixing zone. The default value for the offset distance is zero for computations along the plume centerline and 100 m for computations at the edge of the mixing zone. Figure 3.1 illustrates the offset from the plume centerline.

3.5 OCEANIC PARAMETERS

3.5.1 Regional Current Velocity

Large-scale circulation is an important process for the advective transport in the upper layers of the ocean. INSEA incorporates a user-specified regional current along with a calculated wind-generated current to compute the longitudinal advection in the model. The default value used for the regional current velocity is 0. This default value is used because it will result in the most conservative concentrations of constituents in the waste.

3.5.2 Diffusion Coefficient and Dispersivity

The dispersion coefficient relates the concentration gradient to the flux rate. INSEA defines the dispersion coefficient as

$$D = D^* + dv$$

where D = dispersion coefficient (m^2/s)
D^* = diffusion coefficient (m^2/s)
d = diffusivity (m)
v = wind generated current (m/s)

This expression allows D to vary as a function of depth. Csanady (1973) reports values for the dispersion coefficient of 30 cm^2/s near the surface, reducing to 5 cm^2/s at a depth of several meters.

Except during rapid surface cooling resulting in strong vertical buoyancy-driven flows, a stable water layer (thermocline) generally occurs at less than 30 m. Transport through this thermocline is generally limited to molecular diffusion.

Moderate winds (5 m/s) can result in dramatic changes in the apparent dispersion coefficients because of the presence of Langmuir circulations. Although the exact physical mechanism of Langmuir circulations is not fully understood, the circulations cause significant vertical velocities that will rapidly disperse any contaminant entering the ocean.

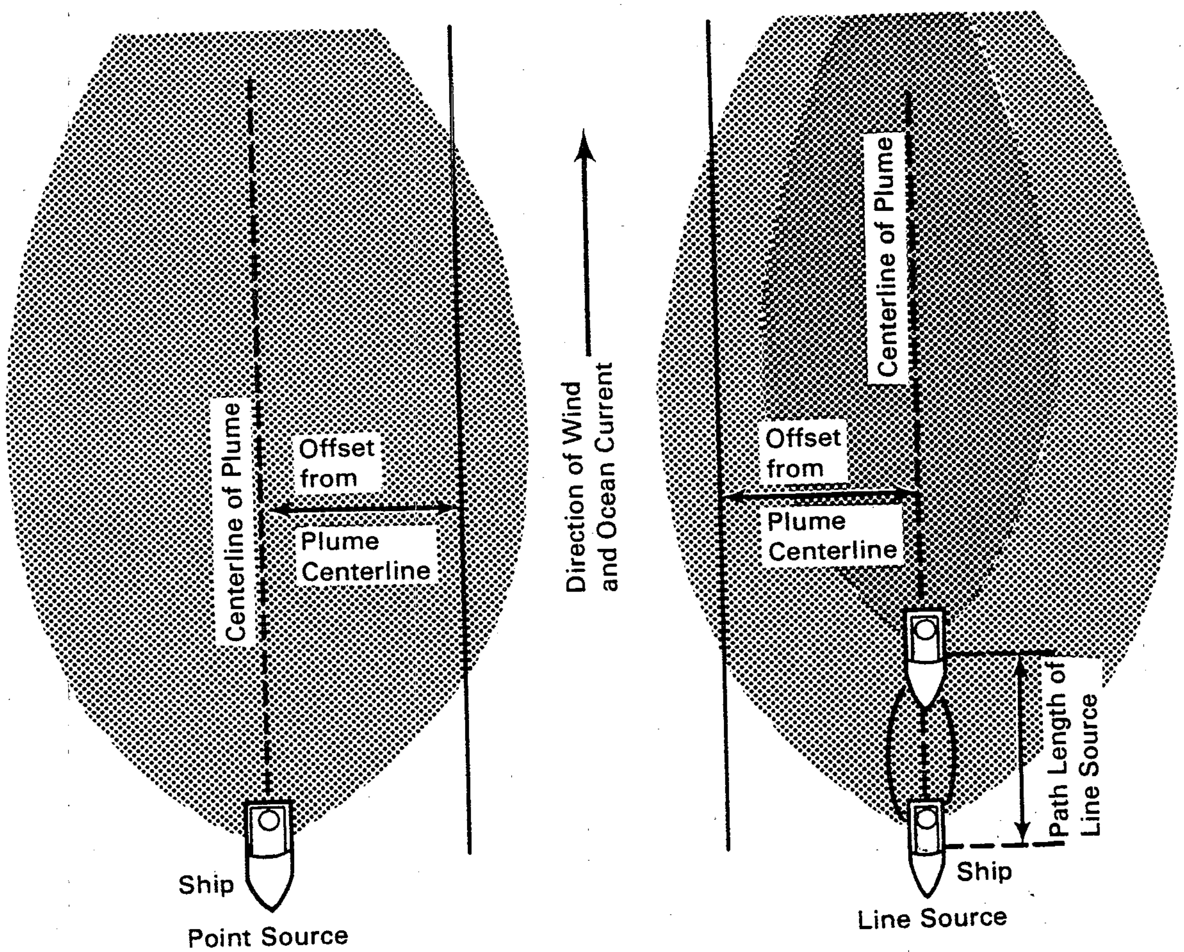


FIGURE 3.1. Plan View of INSEA Domain

A default value of 5 cm^2/s is assumed for the diffusion coefficient. A default value of 0 is assumed for the dispersivity.

3.5.3 Latitude of Operation

The latitude of the burn site is used in the ocean submodel for computing the current velocity. The Gulf of Mexico incineration site is located at the latitude of 26 degrees, and this value is used as the default value.

3.5.4 Length of Ocean Simulated

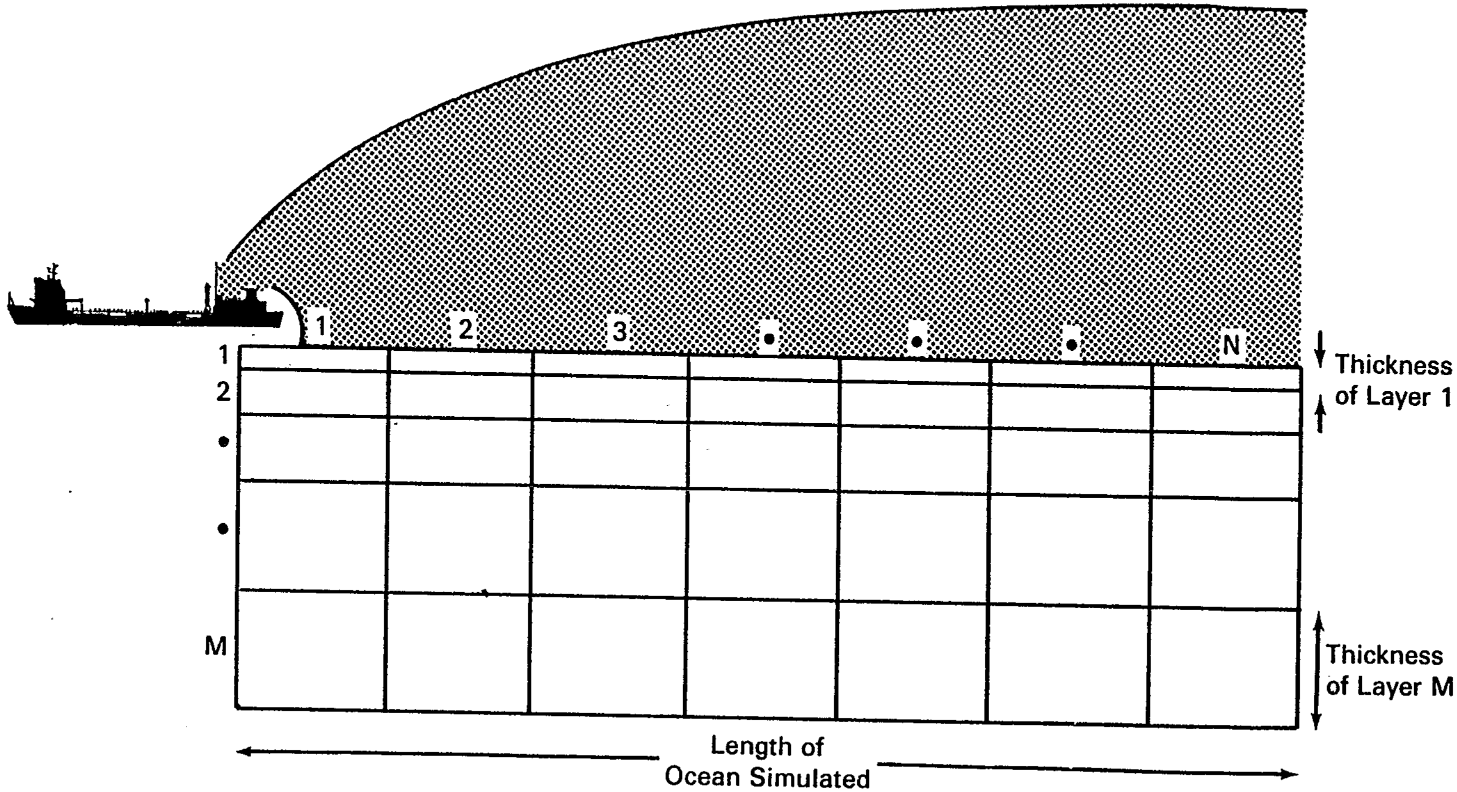
The length of ocean simulated is the distance over which the user wishes the atmospheric and ocean computations to occur. The length of reach specified by the user must be greater than the path length of the line source. The maximum computation reach recommended is about 50 km. The default value for the computation reach is 20 km.

3.5.5 Grid Spacing

Figure 3.2 shows an example grid for INSEA. Defining the appropriate spacings is critical to using INSEA.

INSEA does not allow contaminant flux through the bottom of the deepest layer. Therefore, the total vertical depth should be great enough that the diffusion process is not seriously affected by the lower boundary. Because the thermocline often occurs at a depth less than 30 m, 20 m to 30 m is considered adequate for the total depth.

Up to 20 horizontal layers and 100 vertical columns can be used in the INSEA model. The default values are 14 horizontal layers and 70 vertical columns. The number of horizontal layers and vertical columns are changed with the GRId parameter on the parameter list in the model. The number of horizontal layers and the thickness of each layer must then be specified by the user. The thickness of the surface layer can be critical in the computations of the aquatic concentrations. If the surface layer thickness is too large, the resulting concentrations will be underestimated because the depositional flux from the atmosphere is instantaneously mixed into the surface layer. A thickness of 0.5 m to 1.0 m is recommended for the surface layer. The default thickness of the surface layer, as well as the other horizontal layers, is 1 meter. The spacing between vertical columns depends on the length of ocean simulated and the number of vertical columns, both of which can be specified by the user. The spacing between vertical columns is computed internally in the INSEA model and is equal to the length of ocean simulated, divided by the number of columns.



Vertical Cross-Section of Grid with N Columns and M Layers

FIGURE 3.2. Vertical Cross-Section of INSEA Domain

4.0 MODEL OUTPUT

Three principal outputs are provided by the INSEA model:

- table of maximum allowable concentrations in the waste
- plot of vertical concentration profiles
- echo listing of interactive session.

Each of these outputs is discussed in the following sections.

4.1 TABLE OF MAXIMUM ALLOWABLE FEED RATES

On request, INSEA prints the maximum allowable concentration of each constituent considered in the final blended waste. Waste concentrations are estimated based on both acute and chronic water quality criteria and where acute or chronic do not exist. The user can select only one table (either chronic or acute) at a time. The user should run the model twice, once each for the chronic and acute values. The final allowable waste concentrations should be based on the limiting concentrations in the two tables. The concentrations in the waste are estimated using an incinerator feed rate specified by the user (i.e., l/min).

Table 4.1 is an example of the Waste Concentration Table printed by the INSEA model. In this example, the chronic criteria were used with an incinerator feed rate of 175 l/min. The table provides the waste constituent (contaminant name), the chronic water quality criterion (or acute criterion), the maximum allowable concentration of each constituent in the waste (maximum feed concentration), and the destruction efficiency. Destruction efficiency is defined as the following:

$$DE = \frac{(Win - Wout)*100}{W_{out}}$$

where W_{in} = mass feed rate into the incinerator
W_{out} = mass flow rate out of the incinerator.

TABLE 4.1. Waste Concentration Table

TITLE: example

CONTAMINANT NAME	CHRONIC STANDARD (ug/l)	MAXIMUM FEED CONC (mg/l)	DESTRUCTION EFFICIENCY
Aluminum	200.	.131E+05	.0000
Arsenic	36.0	.235E+04	.0000
Cadmium	9.30	607.	.0000
Chlorine	.163E+05	.106E+07	.0000
Chromium III	.103E+05	.672E+06	.0000
Chromium VI	50.0	.326E+04	.0000
Copper	2.90	189.	.0000
Lead	5.60	365.	.0000
Mercury	.250E-01	1.63	.0000
Nickel	7.10	463.	.0000
Selenium	54.0	.352E+04	.0000
Silver	.230E-01	1.50	.0000
Thallium	.200E-01	1.31	.0000
Tin	.700	45.7	.0000
Zinc	58.0	.379E+04	.0000
Cyanide	.100E-01	.653	.0000
Dioxin	.100E-04	658.	99.9999
DDT	.100E-02	653.	99.9900
PCBs	.300E-01	.197E+07	99.9999
Dichloroethane	.113E+04	.737E+09	99.9900
Trichloroethane	312.	.204E+09	99.9900
Tetrachloroethane	90.0	.587E+08	99.9900
Hexachloroethane	9.40	.613E+07	99.9900
Chlorobenzenes	130.	.848E+08	99.9900
Halomethanes	.640E+04	.418E+10	99.9900
Carbon Tetrachloride	500.	.326E+09	99.9900
Hexachlorobutadiene	.320	.209E+06	99.9900
Phenol	58.0	.378E+08	99.9900

Average over entire domain
Computed using chronic criterion and feed rate of 175.0 l/min
CRITERIA PROVIDED BY EPA
Based on deposition computed at an offset distance of 100.0 m

Before printing the feed rate table, INSEA prints the present input parameter values. This printout provides a traceable link between the model input and output.

The file that contains the marine aquatic criteria standards data, STANDARD.DAT, is discussed in Appendix C.

4.2 PLOT OF VERTICAL CONCENTRATION PROFILES

INSEA has the ability to plot vertical concentration profiles on a graphics plotter. Figure 4.1 is an example of a plot generated with INSEA.

The plot shows concentration as a function of depth. The depth axis is expressed as the percent of the total depth being simulated (DMAX). The concentration is expressed as the percent of the maximum surface concentration at the time considered.

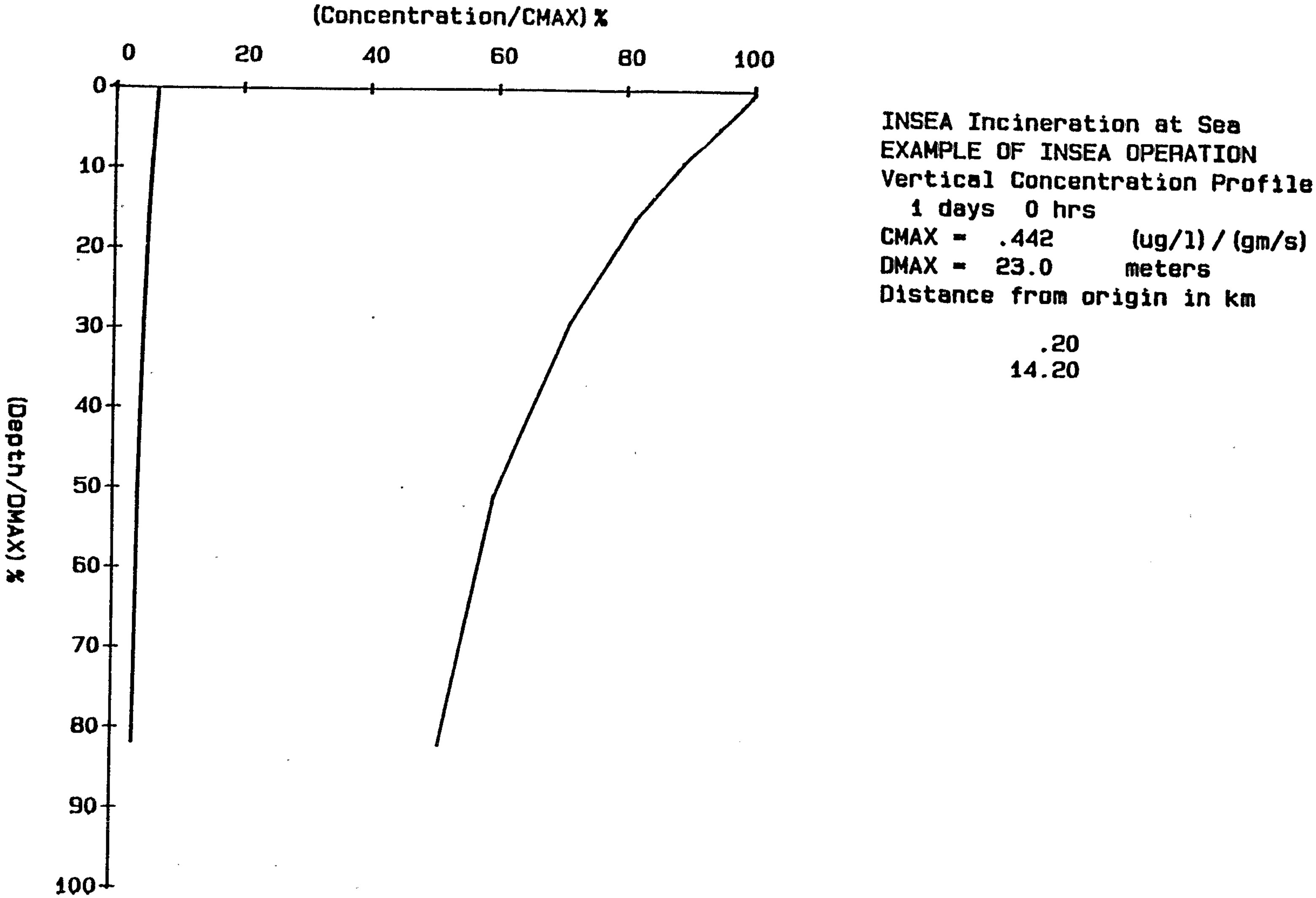
The concentration profile can be plotted for any column (column 1 is immediately downwind of the ship, Column 2 is immediately downwind of Column 1, etc.). The distance from the origin to the column chosen is written on the plot.

4.3 ECHO LISTING OF INTERACTIVE SESSION

If the user requests, INSEA will print a complete listing of the current interactive session. This printout is a useful feature because it provides a record of the interactive session. In addition to the interactive output, certain values not displayed during the interactive session are printed:

- horizontal velocities for each layer
- diffusion coefficient for each layer
- depositional fluxes from the atmospheric submodel
- concentrations of the surface layer nodes
- other data useful in debugging and verification.

The echo listing for the interactive session discussed in the following section is provided in Appendix B.



<u>FIGURE 4.1</u>. Plot Generated by INSEA

5.0 PROCEDURES FOR RUNNING INSEA MODEL

5.1 MODEL OPERATION

The INSEA model is a user-friendly, interactive model that allows the user to specify a number of parameters before running the program. This section describes the operation of the model.

INSEA prompts the user with simple questions for responses of Yes, No, an integer value (e.g., **240**), a real value (e.g., **1.5** or **-1.5e-3**), or a title (e.g., **Gulf of Mexico Burn Site Simulation**). If the user provides an illegal response to any of INSEA's prompts, INSEA will reprompt the user. To stop INSEA at any point, the user can type **QUIT**, **STOP**, or **EXIT** in response to any prompt by INSEA.

Once the program has been activated, the user is prompted for a title. After a list of default cases has been displayed, the user is requested to specify which default case will provide the initial values for the user-specified parameters. The default cases are defined in the DEFAULT.DAT file (see Appendix D). Once the user has chosen an appropriate starting set of parameters, INSEA lists the parameters and allows the user to change any of the values. After the user has settled on a set of parameters, INSEA prompts for the number of hours to be simulated. While the simulation proceeds for the specified period, INSEA continuously writes out the current simulation time so the user can estimate how much longer the simulation will take. When the simulation is complete, several types of output are available.

At the user's request, a table of the maximum allowable concentrations that will not violate the respective aquatic criteria is printed for each of the constituents provided in the STANDARD.DAT (see Appendix C) file.

A plot of the aquatic concentration as a function of depth for various points on the grid can be generated if the user is connected to a graphics plotter that is compatible with the Hewlett-Packard Graphics Language. The plotted concentrations are based on a unit (1 gm/s) emission from the incinerator.

A complete listing of the interactive session along with some debug information can be printed if the user requests. This option allows the users to completely document the simulation.

5.2 EXAMPLE SIMULATION

The following text provides an example of an INSEA simulation. The user responses are shown in bold type.

```
                    INSEA - INCINERATION AT SEA MODEL
TITLE OF RUN                                      >example
                 DEFAULT CASE MENU
===============================================

CASE  1  Point Source, Centerline Values, Precipitation Conditions
CASE  2  Point Source, Centerline Values, Non-precipitation Conditions
CASE  3  Point Source, Offset From Centerline Values, Precipitation Condit
CASE  4  Point Source, Offset From Centerline Values, Non-precipitation Co
CASE  5  Line Source, Centerline, Precipitation Conditions
CASE  6  Line Source, Centerline, Non-precipitation Conditions
CASE  7  Line Source, Offset From Centerline Values, Precipitation Conditi
CASE  8  Line Source, Offset From Centerline Values, Non-precipitation Con

SELECT CASE NUMBER                                >3


                     PARAMETER LIST
          TITLE: example
******************* SHIP PARAMETERS ********************
POInt source
**************** INCINERATOR PARAMETERS ****************
NUMber of incinerators              3
HEIght of stack                    12.0       METERS
VELocity of stack emission           15.      METERS/SEC
TEMperature of stack emissions     1429.      DEGREES C
DIAmeter of stack                   3.2       METERS
MINimum air speed past stack   1.5            METERS/SEC
***************** ATMOSPHERIC PARAMETERS ***************
STAbility class                    D
WINd speed                           1.5      METERS/SEC
AIR temperature                     10.       DEGREES C
MIXing height                      500.       METERS
WET scavenging coefficient         .15E-03    1/SEC
DRY deposition velocity            .30E-01    METERS/SEC
OFFset from plume centerline       100.       METERS
```

```
******************** OCEAN PARAMETERS *******************
REGional current velocity        .00        METERS/SEC
DIFfusion coefficient            .50E-03    SQ. METERS/SEC
DISpersivity                     .00        METERS
LATitude                         26.        DEGREES
LENgth of ocean simulated        10.        KILOMETERS
GRId spacing                     DEFAULT
CHANGE PARAMETERS                      (Y/N)>y
Enter Parameter Keyword (or HELP)           >wind
WIND SPEED IN METERS/SEC                    >2.0
CHANGE ANOTHER PARAMETER               (Y/N)>n


                  PARAMETER LIST
        TITLE: example
******************** SHIP PARAMETERS ********************
POInt source
**************** INCINERATOR PARAMETERS *****************
NUMber of incinerators              3
HEIght of stack                    12.0      METERS
VELocity of stack emission            15.    METERS/SEC
TEMperature of stack emissions    1429.      DEGREES C
DIAmeter of stack                   3.2      METERS
MINimum air speed past stack   1.5           METERS/SEC
***************** ATMOSPHERIC PARAMETERS ****************
STAbility class                   D
WINd speed                          2.0      METERS/SEC
AIR temperature                     10.      DEGREES C
MIXing height                      500.      METERS
WET scavenging coefficient        .15E-03    1/SEC
DRY deposition velocity           .30E-01    METERS/SEC
OFFset from plume centerline      100.       METERS
******************** OCEAN PARAMETERS *******************
REGional current velocity         .00        METERS/SEC
DIFfusion coefficient             .50E-03    SQ. METERS/SEC
DISpersivity                      .00        METERS
LATitude                          26.        DEGREES
LENgth of ocean simulated         10.        KILOMETERS
GRId spacing                      DEFAULT
NUMBER OF COLUMNS IN OCEAN GRID = 70
NUMBER OF LAYERS IN OCEAN GRID    = 14
LAYER  1 THICKNESS OF LAYER  1.00 METERS
LAYER  2 THICKNESS OF LAYER  1.00 METERS
LAYER  3 THICKNESS OF LAYER  1.00 METERS
LAYER  4 THICKNESS OF LAYER  1.00 METERS
LAYER  5 THICKNESS OF LAYER  1.00 METERS
LAYER  6 THICKNESS OF LAYER  1.00 METERS
LAYER  7 THICKNESS OF LAYER  1.00 METERS
LAYER  8 THICKNESS OF LAYER  1.00 METERS
LAYER  9 THICKNESS OF LAYER  1.00 METERS
LAYER 10 THICKNESS OF LAYER  1.00 METERS
```

```
LAYER 11 THICKNESS OF LAYER  1.00 METERS
LAYER 12 THICKNESS OF LAYER  1.00 METERS
LAYER 13 THICKNESS OF LAYER  1.00 METERS
LAYER 14 THICKNESS OF LAYER  1.00 METERS
NUMBER OF HOURS TO BE SIMULATED              >240
Combined air/sea deposition velocity =   .142E-02 m/s
for friction velocity, U* =   .546E-01 m/s
and roughness length, zo  =   .439E-05m.
START SIMULATION::
**********************************************************************
PRINT FEED RATE TABLE                        (Y/N)>y
Enter Incinerator Feed Rate (l/min)            >175
Specify Water Concentration as:
  1  Average of Entire Domain
  2  Maximum Surface
  3  Average Surface
  4  User Specified
Enter Selection                                >1
CRITERIA TO BE USED
  1  ACUTE
  2  CHRONIC
SELECTION                                      >2
ANOTHER TABLE                                (Y/N)>n
PRINT ECHO FILE                              (Y/N)>n
PLOT AQUATIC CONCENTRATION DATA              (Y/N)>n
CONTINUE SIMULATION                          (Y/N)>n
```

6.0 NOTES ON SOME INSEA TESTS

6.1 INSEA SENSITIVITY TESTS

A number of sensitivity tests on the INSEA model were performed to evaluate the effects of incineration vessel movement, wind speed, atmospheric stability and initial mixing depth on the allowable constituent concentrations in the final blended waste. Sensitivity tests were performed for three basic sets of conditions corresponding to the best, intermediate, and worst case conditions for at-sea incineration. Copper is used as the indicator constituent in the test cases because it will normally be the limiting constituent in the final blended waste. These case conditions are summarized below:

- Best Case Conditions--10-day burn with ship moving along a 50-km path with a 70-km impact area and 10 days of dry deposition.
- Worst Case Conditions--10-day burn with ship stationary with a 70-km impact area and 10 days of wet deposition.
- Intermediate Case Conditions--2-day burn with ship moving along a 20-km path with a 70-km impact area and 2 days of wet deposition.

6.1.1 Demonstration of Vessel Movement Effects

During an incineration operation, the vessel must operate at a sufficient speed to ensure that the relative air movement past the stacks keeps the atmospheric plume away from the vessel and its personnel. When the ambient winds are sufficient to blow the plume away from the vessel, European incineration operations are generally conducted with the vessel stationary at a fixed location. In Europe, the vessel moves only at a rate to ensure the effective separation of the plume and vessel. INSEA uses two modeling alternatives regarding vessel operations to calculate the permissible concentrations of the waste's constituents. These two alternatives are a stationary incineration vessel and the vessel moving along a single line while the wastes are being incinerated. The moving vessel approach assumes the vessel moves back and forth along a straight line within the site. The length of the vessel's path and the impact area can be specified in the model.

Table 6.1 shows the effect of vessel's pathlength on the allowable waste concentration of copper in the incinerator. For all the cases shown in Table 6.1, the highest allowable copper concentration in the final blended waste occurs for a ship moving along a 50-km path. For the best and intermediate case conditions, the lowest allowable copper concentrations in the final blended waste occur for the incineration ship moving along a 20-km path, instead of for a stationary ship as would be expected. Logic indicates that the most stringent limits on concentration of constituents in the final blended waste will occur when the incineration vessel is in the stationary mode of operation. However, under certain meteorological conditions, as shown in Table 6.1, there exists a minimum ship path length below which the allowable constituent concentrations in the final blended waste will be higher for a stationary ship. The minimum ship path length phenomenon is due to the decrease in plume rise (plume down-wash) resulting from the movement of the incineration ship. The effect of the plume down-wash on allowable constituent concentrations in the final blended waste is nullified at some critical ship path length at which the decreased dispersion due to plume down-wash is offset by an increase in area over which the stack emissions are being dispersed due to longer path lengths.

6.1.2 Wind Speed and Atmospheric Stability

The rate of atmospheric dispersion and the height of plume rise vary depending on atmospheric turbulence, which in turn depends on wind speed. The degree of turbulence is characterized in terms of atmospheric stability. In addition to wind speed, the INSEA model uses over-water equivalents of the Pasquill stability classes to estimate the dispersion rates of the atmospheric plume. The six stability classes are expressed by the letters A to F, progressively representing fast (unstable) to slow (stable) dispersion rates.

Tables 6.2 through 6.4 illustrate how the allowable concentration of cooper in the final blended waste varies with different wind speeds and stability classes for the best, worst, and intermediate case conditions. All the allowable copper concentrations in these tables are for the acute criterion and for a total waste feed rate of 175 l/min. For the best case

TABLE 6.1. Changes in the Allowable Copper Concentrations Depending on the Vessel's Movement

Vessel Movement	Initial Mixing Layer Depth (m)	Allowable Copper Conc. (mg/l)* Best**	Worst**	Inter-mediate**
Stationary with 70-km Impact	20.0	166,000	151	2,010
	0.5	102,000	115	1,140
20-km Path with 70-km Impact	20.0	105,000	169	1,890
	0.5	63,000	125	1,070
50-km Path with 70-km Impact	20.0	183,000	222	2,090
	0.5	101,000	152	1,140

* Allowable copper concentrations in the final blended waste are based on the acute criterion and a total waste feed rate of 175 l/min.

** Best Case Conditions are based on a 10-day burn with 10 days of dry deposition, wind speed of 1.5 m/s and stability class F.

Worst Case Conditions are based on a 10-day burn with 10 days of wet deposition, wind speed of 1.5 m/s and stability class D.

Intermediate Case Conditions are based on a 2-day burn with 2 days of wet deposition, wind speed of 6 m/s and stability class D.

conditions shown in Table 6.2, the allowable copper concentrations in the final blended waste increase with decreasing atmospheric stability (going from class A to class F), and decrease with increasing wind speed. The lowest allowable copper feed concentration in the waste for the best case conditions occurs at an atmospheric stability class D and a wind speed of 8 m/s. The highest allowable copper concentration in the waste for the best case conditions occurs at an atmospheric stability class F and a wind speed of 1.5 m/s.

Allowable copper concentrations in the final blended waste under the worst case conditions are shown in Table 6.3. The difference between the worst and best case conditions is that for the best case conditions it is assumed that no precipitation occurs during the 10-day burn, while with the best case conditions it is assumed that precipitation occurs for the entire

TABLE 6.2. Effects of Wind Speed and Stability Class on Allowable Copper Concentrations in the Waste Under Best Case Conditions*

Initial Mixing Layer Depth (m)	Wind Speed (m/s)	Allowable Copper Concentration** (mg/l) For Each Stability Class					
		A	B	C	D	E	F
20.0	1.5	10,600	14,100	15,600	42,100	48,700	183,000
0.5	1.5	6,820	8,910	9,590	23,000	28,400	101,000
20.0	2.0	9,140					143,000
0.5	2.0	5,850					79,500
20.0	2.5	8,120					115,000
0.5	2.5	5,200					64,400
20.0	3.0	7,510					92,300
0.5	3.0	4,820					52,300
20.0	3.5		7,450	7,390	8,780	26,600	
0.5	3.5		4,780	4,690	5,260	15,900	
20.0	6.0		7,560		4,450	22,300	
0.5	6.0		5,010		2,880	13,900	
20.0	8.0		7,930	5,240	3,300	19,500	
0.5	8.0		5,280	3,520	2,190	12,300	
20.0	15.0			5,100			
0.5	15.0			3,500			

* Best case conditions assume a 10-day burn with 10 days of dry deposition and the ship moving along a 50-km path with a 70-km impact area

** The allowable copper concentration in the final blended waste is based on the acute criterion and a total waste feed rate of 175 l/min

TABLE 6.3. Effects of Wind Speed and Stability Class on Allowable Copper Concentrations in the Waste Under Worst Case Conditions*

Initial Mixing Layer Depth (m)	Wind Speed (m/s)	Allowable Copper Concentration** (mg/l) For Each Stability Class					
		A	B	C	D	E	F
20.0	1.5	479	347	229	151	446	391
0.5	1.5	365	264	175	115	336	293
20.0	2.0	624					491
0.5	2.0	474					368
20.0	2.5	739					581
0.5	2.5	560					435
20.0	3.0	851					674
0.5	3.0	643					504
20.0	3.5		715	488	334	864	
0.5	3.5		540	369	253	645	
20.0	6.0		1,280		643	864	
0.5	6.0		980		492	645	
20.0	8.0		1,610	1,130	801	2,150	
0.5	8.0		1,230	869	612	1,630	
20.0	15.0			1,720			
0.5	15.0			1,330			

* Worst case conditions assume a 10-day burn with 10 days of wet deposition and the ship is stationary with a 70-km impact area

** The allowable copper concentration in the final blended waste is based on the acute criteria and a total waste feed rate of 175 l/min

10-day burn. For the worst case conditions the allowable copper concentrations in the waste initially decrease with decreasing atmospheric stability (between classes A and D), increase for atmospheric stability class E, then decrease again for atmospheric stability class F. Allowable copper concentrations in the waste increase with increasing wind speed for all the atmospheric stability classes. The lowest allowable copper concentration in the waste for the worst case conditions occurs at an atmospheric stability class D and a wind speed of 1.5 m/s. The highest allowable copper concentration in the waste occurs at an atmospheric class E and a wind speed of 8 m/s.

For the intermediate case conditions shown in Table 6.4, the allowable copper concentrations in the waste initially decrease with decreasing atmospheric stability (between classes A and D), increase for class E, then decrease again for class F. The allowable copper concentrations in the waste increase with increasing wind speed for all the atmospheric stability classes. The lowest allowable copper concentration in the waste for the intermediate case conditions occurs at an atmospheric stability class D and a wind speed of 1.5 m/s. The highest allowable copper concentration in the waste occurs at an atmospheric class E and a wind speed of 8 m/s.

6.1.3 Allowable Contaminant Concentrations in the Final Blended Waste for Best, Worst, and Intermediate Case Conditions Based on Acute and Chronic Water Quality Criteria

EPA's policy on water quality standards recognizes a mixing zone as a limited area in which the chronic criterion can be exceeded as long as acutely toxic conditions do not occur and chronic levels are not exceeded at the boundaries of the zone. The INSEA model was developed to provide the allowable contaminant concentrations in the final blended waste corresponding to the acute criterion along the centerline of the incineration ship's path and to the chronic criterion along an line offset 100 m from the centerline. Tables 6.5 through 6.7 summarize the allowable contaminant concentrations for the best, worst, and intermediate case conditions based on the acute and chronic water quality criteria. The best case conditions are based on a ship moving along a 50-km path with a 70-km impact area, 10 days of dry deposition, stability class F, and wind speed of 1.5 m/s. The worst case conditions are based on a stationary ship with a 70-km impact area, 10 days of wet deposition, stability class D, and wind speed of 1.5 m/s. The intermediate case conditions are based on ship moving along a 20-km path with a 70-km impact area, 2 days of wet deposition, stability class D and wind speed of 6 m/s. The reported allowable contaminant concentrations in the final blended waste are based on three incinerators with feed rates of 175 l/min per incinerator. The 20 m values for allowable contaminant

TABLE 6.4. Effects of Wind Speed and Stability Class on Allowable Copper Concentrations in the Waste Under Intermediate Case Conditions*

Initial Mixing Layer Depth (m)	Wind Speed (m/s)	Allowable Copper Concentration** (mg/l) For Each Stability Class					
		A	B	C	D	E	F
20.0	1.5	2,240	1,630	10,080	717	1,840	1,600
0.5	1.5	1,050	763	506	336	855	744
20.0	2.0	2,940					2,140
0.5	2.0	1,370					990
20.0	2.5	3,440					2,550
0.5	2.5	1,610					1,190
20.0	3.0	3,900					2,950
0.5	3.0	1,840					1,380
20.0	3.5		3,320	2,210	1,510	3,780	
0.5	3.5		1,520	1,040	712	1,770	
20.0	6.0		4,110		1,890	5,160	
0.5	6.0		2,320		1,070	2,880	
20.0	8.0		4,720	3,110	2,010	5,990	
0.5	8.0		2,780	1,840	1,190	3,500	
20.0	15.0			3,550			
0.5	15.0			2,360			

* Intermediate case conditions assume a 2-day burn with 2 days of wet deposition and the ship moving along a 20-km path with a 70-km impact area

** The allowable copper concentration in the final blended waste is based on the acute criteria and a total waste feed rate of 175 l/min

concentrations in the waste correspond to the average over the first 20 m of the water column and the 0.5 m values correspond to the average over the first 0.5 m of the water column.

TABLE 6.5. Allowable Concentrations of Contaminants for Best Case Conditions Based on Acute and Chronic Water Quality Criteria

CONTAMINANT	ACUTE CRITERIA ug/l	ALLOWABLE CONTAMINANT CONCENTRATIONS IN WASTE: ACUTE CONCENTRATIONS 20m mg/l	ACUTE CONCENTRATIONS .5m mg/l	CHRONIC CRITERIA ug/l	CHRONIC CONCENTRATIONS 20m mg/l	CHRONIC CONCENTRATIONS .5m mg/l
Aluminum	1.500E+03	9.460E+07	5.230E+07	2.000E+02	1.300E+07	7.160E+06
Arsenic	6.900E+01	4.350E+06	2.400E+06	3.600E+01	2.340E+06	1.290E+06
Cadmium	4.300E+01	2.710E+06	1.500E+06	9.300E+00	6.040E+05	3.330E+05
Chlorine	1.630E+04	1.030E+09	5.680E+08	1.630E+04	1.060E+09	5.830E+08
Chromium III	1.030E+04	6.500E+08	3.590E+08	1.030E+04	6.690E+08	3.690E+08
Chromium VI	1.100E+03	6.940E+07	3.830E+07	5.000E+01	3.250E+06	1.790E+06
Copper	2.900E+00	1.830E+05	1.010E+05	2.900E+00	1.880E+05	1.040E+05
Lead	1.400E+02	8.830E+06	4.880E+06	5.600E+00	3.640E+05	2.000E+05
Mercury	2.100E+00	1.320E+05	7.320E+04	2.500E-02	1.620E+03	8.940E+02
Nickel	1.400E+02	8.830E+06	4.880E+06	7.100E+00	4.610E+05	2.540E+05
Selenium	4.100E+02	2.590E+07	1.430E+07	5.400E+01	3.510E+06	1.930E+06
Silver	2.300E+00	1.450E+05	8.020E+04	2.300E-02	1.490E+03	8.230E+02
Thallium	2.130E+00	1.340E+05	7.420E+04	2.000E-02	1.300E+03	7.160E+02
Tin	7.000E-01	4.410E+04	2.440E+04	7.000E-01	4.550E+04	2.500E+04
Zinc	1.700E+02	1.070E+07	5.920E+06	5.800E+01	3.770E+06	2.080E+06
Cyanide	1.000E+00	6.310E+04	3.480E+04	1.000E-02	6.490E+02	3.580E+02
Dioxin	1.000E-02	6.360E+08	3.510E+08	1.000E-05	6.550E+05	3.610E+05
DDT	1.300E-01	8.200E+07	4.530E+07	1.000E-03	6.490E+05	3.580E+05
PCBs	1.000E+01	6.360E+11	3.510E+11	3.000E-02	1.960E+09	1.080E+09
Dichlorethane	1.130E+05	7.130E+13	3.940E+13	1.130E+03	7.340E+11	4.040E+11
Trichloroethane	3.120E+04	1.970E+13	1.090E+13	3.120E+02	2.030E+11	1.120E+11
Tetrachoroethane	9.020E+03	5.690E+12	3.140E+12	9.000E+01	5.840E+10	3.220E+10
Hexachloroethane	9.400E+02	5.930E+11	3.280E+11	9.400E+00	6.100E+09	3.360E+09
Chlorobenzenes	1.600E+02	1.010E+11	5.570E+10	1.300E+02	8.440E+10	4.650E+10
Halomethanes	1.200E+04	7.570E+12	4.180E+12	6.400E+03	4.160E+12	2.290E+12
Carbon Tetrachloride	5.000E+04	3.150E+13	1.740E+13	5.000E+02	3.250E+11	1.790E+11
Hexachorobutadiene	3.200E+01	2.020E+10	1.110E+10	3.200E-01	2.080E+08	1.140E+08
Phenol	5.800E+03	3.660E+12	2.020E+12	5.800E+01	3.770E+10	2.070E+10

Best Case: Ship Moving Along a 50km Path With a 70km Impact Area, 10 Days of Dry Deposition, Stability Class F and Wind Speed of 1.5m/s

Acute Criteria Are Based on Deposition Rates at Plume Centerline

Chronic Criteria Are Based on Deposition Rates at an Offset Distance of 100m from the Plume Centerline

Maximum Feed Concentrations Are Based on 3 Incinerators With Feed Rates of 175 l/m Per Incinerator

20m Values for Maximum Feed Concentrations Correspond to Average Over the First 20m of the Water Column

0.5m Values for Maximum Feed Concentrations Correspond to Average Over the First 0.5m of the Water Column

TABLE 6.6. Allowable Concentrations of Contaminants for Worst Case Conditions Based on Acute and Chronic Water Quality Criteria

CONTAMINANT	ACUTE CRITERIA ug/l	ACUTE CONCENTRATIONS 20m mg/l	ACUTE CONCENTRATIONS .5m mg/l	CHRONIC CRITERIA ug/l	CHRONIC CONCENTRATIONS 20m mg/l	CHRONIC CONCENTRATIONS .5m mg/l
		ALLOWABLE CONTAMINANT CONCENTRATIONS IN WASTE				
Aluminum	1.500E+03	7.820E+04	5.960E+04	2.000E+02	3.680E+04	2.770E+04
Arsenic	6.900E+01	3.600E+03	2.740E+03	3.600E+01	6.620E+03	4.990E+03
Cadmium	4.300E+01	2.240E+03	1.710E+03	9.300E+00	1.710E+03	1.290E+03
Chlorine	1.630E+04	8.500E+05	6.480E+05	1.630E+04	3.000E+06	2.260E+06
Chromium III	1.030E+04	5.370E+05	4.100E+05	1.030E+04	1.890E+06	1.430E+06
Chromium VI	1.100E+03	5.730E+04	4.370E+04	5.000E+01	9.200E+03	6.930E+03
Copper	2.900E+00	1.510E+02	1.150E+02	2.900E+00	5.330E+02	4.020E+02
Lead	1.400E+02	7.300E+03	5.570E+03	5.600E+00	1.030E+03	7.760E+02
Mercury	2.100E+00	1.090E+02	8.350E+01	2.500E-02	4.600E+00	3.460E+00
Nickel	1.400E+02	7.300E+03	5.570E+03	7.100E+00	1.310E+03	9.830E+02
Selenium	4.100E+02	2.140E+04	1.630E+04	5.400E+01	9.930E+03	7.480E+03
Silver	2.300E+00	1.200E+02	9.140E+01	2.300E-02	4.230E+00	3.190E+00
Thallium	2.130E+00	1.110E+02	8.470E+01	2.000E-02	3.680E+00	2.770E+00
Tin	7.000E-01	3.650E+01	2.780E+01	7.000E-01	1.290E+02	9.700E+01
Zinc	1.700E+02	8.860E+03	6.760E+03	5.800E+01	1.070E+04	8.030E+03
Cyanide	1.000E+00	5.210E+01	3.980E+01	1.000E-02	1.840E+00	1.390E+00
Dioxin	1.000E-02	5.250E+05	4.010E+05	1.000E-05	1.850E+03	1.400E+03
DDT	1.300E-01	6.770E+04	5.170E+04	1.000E-03	1.840E+03	1.380E+03
PCBs	1.000E+01	5.250E+08	4.010E+08	3.000E-02	5.560E+06	4.190E+06
Dichlorethane	1.130E+05	5.890E+10	4.490E+10	1.130E+03	2.080E+09	1.560E+09
Trichloroethane	3.120E+04	1.630E+10	1.240E+10	3.120E+02	5.740E+08	4.320E+08
Tetrachoroethane	9.020E+03	4.700E+09	3.590E+09	9.000E+01	1.660E+08	1.250E+08
Hexachloroethane	9.400E+02	4.900E+08	3.740E+08	9.400E+00	1.730E+07	1.300E+07
Chlorobenzenes	1.600E+02	8.340E+07	6.360E+07	1.300E+02	2.390E+08	1.800E+08
Halomethanes	1.200E+04	6.250E+09	4.770E+09	6.400E+03	1.180E+10	8.860E+09
Carbon Tetrachloride	5.000E+04	2.610E+10	1.990E+10	5.000E+02	9.200E+08	6.920E+08
Hexachorobutadiene	3.200E+01	1.670E+07	1.270E+07	3.200E-01	5.880E+05	4.430E+05
Phenol	5.800E+03	3.020E+09	2.310E+09	5.800E+01	1.070E+08	8.030E+07

Worst Case: Stationary Ship With a 70km Impact Area, 10 Days Wet Deposition, Stability Class D and Wind Speed of 1.5m/s

Acute Criteria Are Based on Deposition Rates at Plume Centerline

Chronic Criteria Are Based on Deposition Rates at an Offset Distance of 100m from the Plume Centerline

Maximum Feed Concentrations Are Based on 3 Incinerators With Feed Rates of 175 l/m Per Incinerator

20m Values for Maximum Feed Concentrations Correspond to Average Over the First 20m of the Water Column

0.5m Values for Maximum Feed Concentrations Correspond to Average Over the First 0.5m of the Water Column

TABLE 6.7. Allowable Concentrations of Contaminants for Intermediate Case Conditions Based on Acute and Chronic Water Quality Criteria

CONTAMINANT	ACUTE CRITERIA ug/l	ALLOWABLE CONTAMINANT CONCENTRATIONS IN WASTE: ACUTE CONCENTRATIONS 20m mg/l	ACUTE CONCENTRATIONS .5m mg/l	CHRONIC CRITERIA ug/l	CHRONIC CONCENTRATIONS 20m mg/l	CHRONIC CONCENTRATIONS .5m mg/l
Aluminum	1.500E+03	9.800E+05	5.520E+05	2.000E+02	2.590E+05	1.450E+05
Arsenic	6.900E+01	4.510E+04	2.540E+04	3.600E+01	4.670E+04	2.610E+04
Cadmium	4.300E+01	2.810E+04	1.580E+04	9.300E+00	1.210E+04	6.730E+03
Chlorine	1.630E+04	1.060E+07	6.000E+06	1.630E+04	2.110E+07	1.180E+07
Chromium III	1.030E+04	6.730E+06	3.790E+06	1.030E+04	1.340E+07	7.460E+06
Chromium VI	1.100E+03	7.180E+05	4.050E+05	5.000E+01	6.480E+04	3.620E+04
Copper	2.900E+00	1.890E+03	1.070E+03	2.900E+00	3.760E+03	2.100E+03
Lead	1.400E+02	9.140E+04	5.150E+04	5.600E+00	7.260E+03	4.050E+03
Mercury	2.100E+00	1.370E+03	7.730E+02	2.500E-02	3.240E+01	1.810E+01
Nickel	1.400E+02	9.140E+04	5.150E+04	7.100E+00	9.200E+03	5.140E+03
Selenium	4.100E+02	2.680E+05	1.510E+05	5.400E+01	7.000E+04	3.910E+04
Silver	2.300E+00	1.500E+03	8.470E+02	2.300E-02	2.980E+01	1.670E+01
Thallium	2.130E+00	1.390E+03	7.840E+02	2.000E-02	2.590E+01	1.450E+01
Tin	7.000E-01	4.570E+02	2.580E+02	7.000E-01	9.070E+02	5.070E+02
Zinc	1.700E+02	1.110E+05	6.260E+04	5.800E+01	7.520E+04	4.200E+04
Cyanide	1.000E+00	6.530E+02	3.680E+02	1.000E-02	1.300E+01	7.240E+00
Dioxin	1.000E-02	6.580E+06	3.710E+06	1.000E-05	1.310E+04	7.300E+03
DDT	1.300E-01	8.490E+05	4.790E+05	1.000E-03	1.300E+04	7.240E+03
PCBs	1.000E+01	6.580E+09	3.710E+09	3.000E-02	3.920E+07	2.190E+07
Dichlorethane	1.130E+05	7.380E+11	4.160E+11	1.130E+03	1.460E+10	8.180E+09
Trichloroethane	3.120E+04	2.040E+11	1.150E+11	3.120E+02	4.040E+09	2.260E+09
Tetrachoroethane	9.020E+03	5.890E+10	3.320E+10	9.000E+01	1.170E+09	6.520E+08
Hexachloroethane	9.400E+02	6.140E+09	3.460E+09	9.400E+00	1.220E+08	6.800E+07
Chlorobenzenes	1.600E+02	1.040E+09	5.890E+08	1.300E+02	1.680E+09	9.410E+08
Halomethanes	1.200E+04	7.830E+10	4.420E+10	6.400E+03	8.290E+10	4.630E+10
Carbon Tetrachloride	5.000E+04	3.260E+11	1.840E+11	5.000E+02	6.480E+09	3.620E+09
Hexachorobutadiene	3.200E+01	2.090E+08	1.180E+08	3.200E-01	4.150E+06	2.320E+06
Phenol	5.800E+03	3.790E+10	2.130E+10	5.800E+01	7.520E+08	4.200E+08

Intermediate Case: Ship Moving Along a 20km Path With a 70km Impact Area, 2 Days Wet Deposition, Stability Class D and Wind Speed of 6m/s

Acute Criteria Are Based on Deposition Rates at Plume Centerline

Chronic Criteria Are Based on Deposition Rates at an Offset Distance of 100m from the Plume Centerline

Maximum Feed Concentrations Are Based on 3 Incinerators With Feed Rates of 175 l/m Per Incinerator

20m Values for Maximum Feed Concentrations Correspond to Average Over the First 20m of the Water Column

0.5m Values for Maximum Feed Concentrations Correspond to Average Over the First 0.5m of the Water Column

6.2 COMPARISON OF MODEL OUTPUT WITH ATMOSPHERIC MEASUREMENTS

Modeled and measured values were compared using data obtained during the operation of incinerator ships (Weitkamp et al. 1984). Specific information was not available on the stack characteristics, so the default values in the INSEA model were used for making quantitative comparisons.

The observations of plume rise supported the modeling algorithms in INSEA. The cross sections of the HCl plume obtained with a LIDAR showed that the plume consistently rose upward from the ship. The plume rise of 300 to 600 m reported during June and July 1983 corresponds well with the plume rise heights predicted by INSEA. These results show no evidence of entrainment of the incinerator plume in the ship's aerodynamic wake.

The removal rates of HCl using INSEA for 10 time periods from three ships (VESTA, VULCANUS, and MATTHIAS II) are plotted on the left side of Figure 6.1. The plotted dry deposition removal rates are based on the recommended values of air/sea deposition velocities for the low (0.5 cm/s), middle (3.0 cm/s), and high (30.0 cm/s) values. These plots assume no wet removal and neutral stability. The 10 m/s wind speed was a typical value for these time periods. The dry deposition rates are sufficient to explain only the smallest of the measured HCl removal rates. Although Weitkamp et al. treat this smallest dry deposition rate as an outlier, the INSEA model results suggest that dry deposition was the principal for removal of HCl.

The very high removal rates observed for HCl may be the result of processes such as chemical reactions, gravitational settling of water droplets containing HCl, scavenging of HCl by ocean spray, and scavenging of HCl by precipitation. Figure 6.1 shows that gravitational settling in the INSEA model is not sufficient to explain the higher measured removal rates. Scavenging by water droplets is sufficient to duplicate the observed removal rates with the INSEA model.

The concentrations of HCl at the ocean surface as a function of downwind distance was computed with INSEA for slightly unstable atmospheric conditions, 6 m/s winds, and mean source strength of 1400 g/s reported for July 19, 1983.

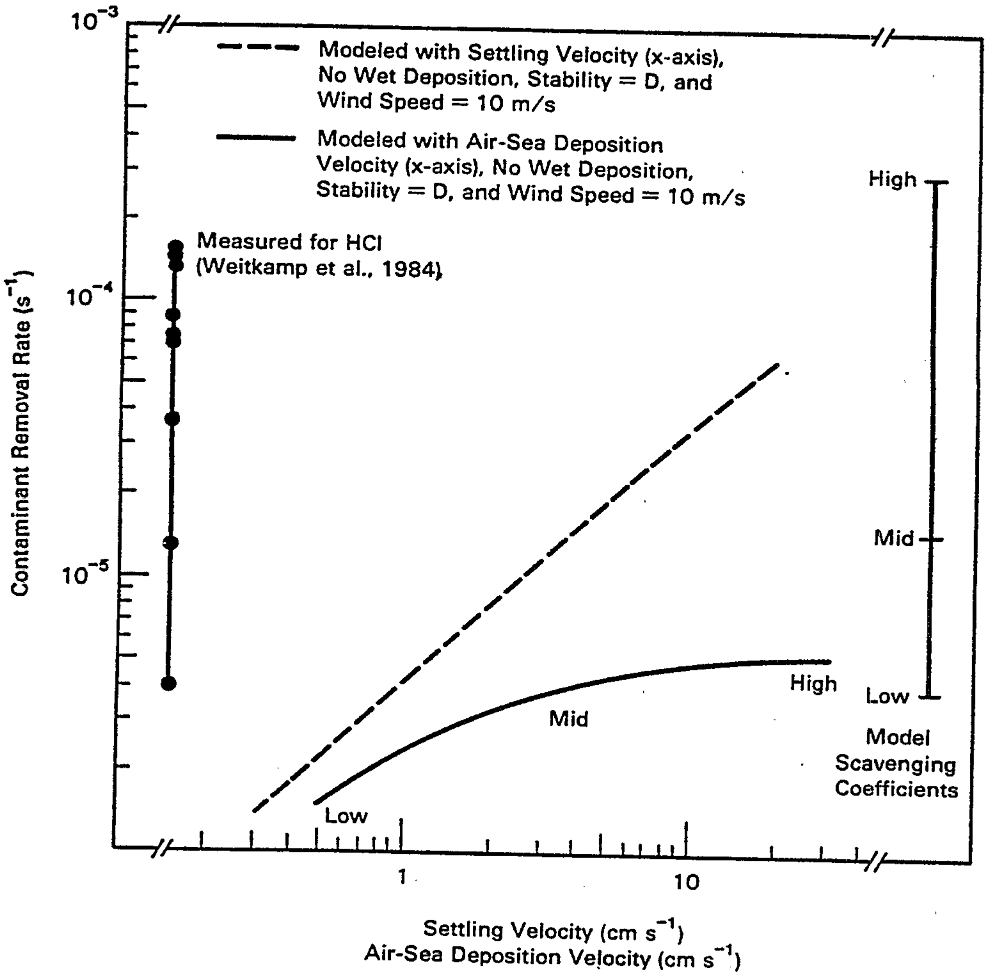


FIGURE 6.1. Comparison of HCl Removal Rates

A middle value of the air/sea deposition velocity was used along with the observed HCl removal rates. These results are plotted in Figure 6.2 along with average HCl concentrations measured under different weather conditions between May 1979 and July 1982. The INSEA model predicts values that are quite close to those measured over the longer time period. The scatter corresponds to expected range of observed HCl removal rates.

These comparisons of the INSEA model outputs with data from incinerator operations demonstrate that the INSEA model can be used with some confidence in characterizing atmospheric transport, dispersion and deposition processes.

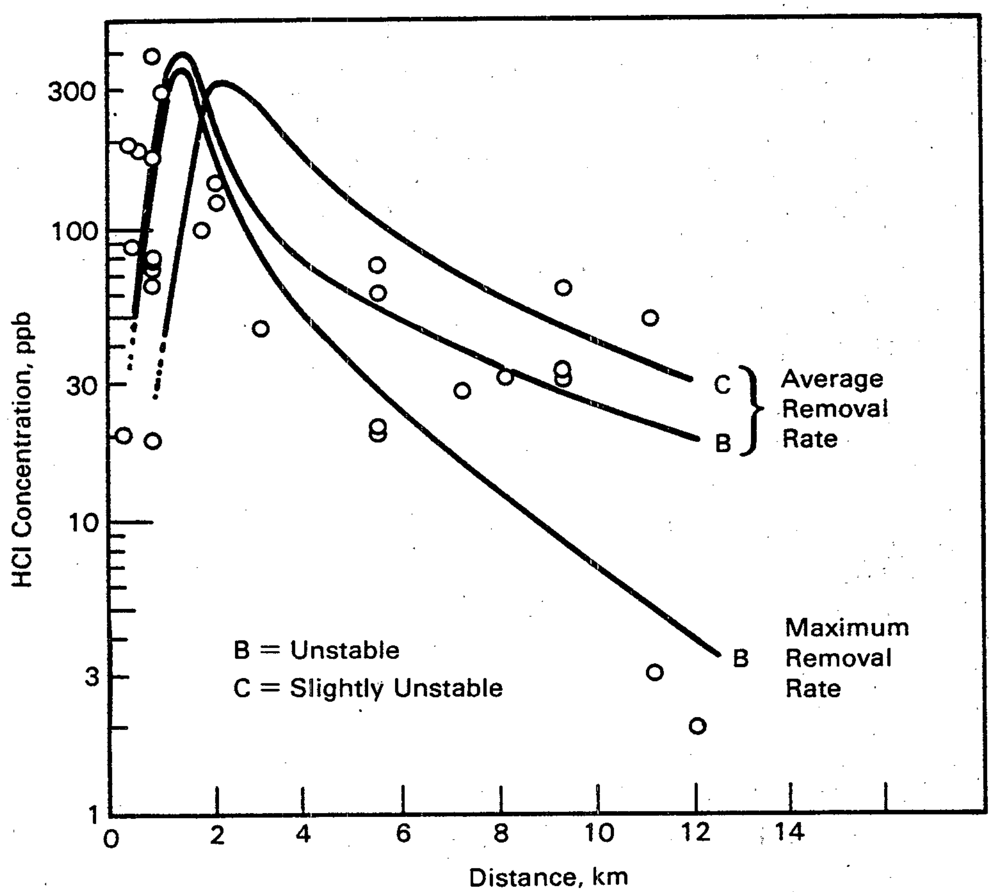


FIGURE 6.2. Average HCl Concentrations Versus Distance [circles are measured and curves are modeled based on conditions for July 19, 1983 (Weitkamp 1984).]

6.3 SENSITIVITY OF INSEA TO INITIAL MIXING LAYER

Six tests were performed to evaluate the sensitivity of INSEA to the selection of the initial mixing layer. Ocean concentrations were compared using initial mixing depths of 10 m, 1 m, 0.1 m, 0.01 m, 0.001 m and 0.0001 m with a total depth of 20 m. All other INSEA input parameters were the same for the initial mixing depth tests. Each test was run for a 5-day period with a 1.5 m/s wind, regional current of 10 cm/sec and for a distance of 45 km downwind of the incinerator ship.

Results of the initial mixing layer sensitivity tests are shown in Table 6.8. Ocean concentrations in ug/l/unit emission are provided for each of the six tests at 1-km intervals downwind of the incinerator ship for the surface layer, 12 m and 20 m depths. Computed ocean concentrations are very similar for initial mixing depths of 0.1 m, 0.01 m, 0.001 m and 0.001m, varying by no more than 0.4 ug/l. Computed ocean concentrations are lower in the surface layer for the 1-m and 10-m initial mixing depths when compared with the smaller initial mixing depths. These lower surface concentrations for the larger initial mixing layer depths are due to the greater volume of water that the incinerator emissions are initially mixed into after deposition on the sea surface. For the 1-m initial mixing depth the ocean concentrations quickly approach those of the smaller initial mixing depths after 1 km downwind, whereas for the 10-m initial mixing depth the ocean concentrations approach those of the smaller initial mixing depths after a distance of 10 km downwind of the incinerator ship.

Based on these initial mixing layer tests it was found that the INSEA model is not very sensitive to the selection of the initial mixing depth for depths of 1 m or less. For initial mixing depths of greater than 1 m the computed near-surface concentrations are lower due to the larger volume of water that the incinerator emissions are initially mixed, and the concentrations below the surface layer are larger because the incinerator emissions are mixed downward faster. Therefore, it is recommended that users of the INSEA model select an initial mixing layer depth of 1 m or less.

TABLE 6.8. Results of INSEA Sensitivity Tests on Selection of Initial Mixing Depth

DISTANCE DOWNWIND km	SURFACE LAYER 10m Test mg/l	1m Test mg/l	.1m Test mg/l	.01m Test mg/l	.001m Test mg/l	.0001m Test mg/l	12 METER DEPTH 10m Test mg/l	1m Test mg/l	.1m Test mg/l	.01m Test mg/l	.001m Test mg/l	.0001m Test mg/l	20 METER DEPTH 10m Test mg/l	1m Test mg/l	.1m Test mg/l	.01m Test mg/l	.001m Test mg/l	.0001m Test mg/l
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	3.20	5.00	4.60	4.60	4.60	0.00	0.00	0.11	0.11	0.11	0.11	0.00	0.00	0.00	0.00	0.00	0.00
2	1.40	3.80	3.30	3.70	3.70	3.70	0.51	0.17	0.31	0.36	0.36	0.36	0.04	0.01	0.01	0.01	0.01	0.01
3	2.10	3.20	3.30	3.30	3.30	3.30	1.00	0.47	0.64	0.65	0.65	0.65	0.15	0.04	0.05	0.05	0.05	0.05
4	2.10	3.00	3.00	3.00	3.00	3.00	1.20	0.77	0.87	0.86	0.86	0.86	0.29	0.09	0.11	0.11	0.11	0.11
5	1.70	2.80	2.80	2.80	2.80	2.80	1.20	0.98	1.10	1.00	1.00	1.00	0.46	0.17	0.20	0.20	0.20	0.20
6	2.00	2.60	2.70	2.70	2.70	2.70	1.40	1.10	1.20	1.20	1.20	1.20	0.66	0.28	0.33	0.32	0.32	0.32
7	2.00	2.50	2.50	2.50	2.50	2.50	1.50	1.20	1.30	1.30	1.30	1.30	0.79	0.46	0.44	0.44	0.44	0.44
8	1.70	2.40	2.40	2.40	2.40	2.40	1.50	1.30	1.30	1.30	1.30	1.30	0.92	0.54	0.57	0.57	0.57	0.57
9	1.90	2.30	2.30	2.40	2.40	2.40	1.50	1.40	1.40	1.40	1.40	1.40	1.10	0.66	0.70	0.70	0.70	0.70
10	1.90	2.30	2.30	2.30	2.30	2.30	1.60	1.50	1.50	1.50	1.50	1.50	1.10	0.78	0.81	0.82	0.82	0.82
11	1.70	2.20	2.20	2.20	2.20	2.20	1.60	1.50	1.50	1.50	1.50	1.50	1.20	0.89	0.91	0.91	0.91	0.91
12	1.80	2.10	2.10	2.10	2.10	2.10	1.60	1.50	1.50	1.50	1.50	1.50	1.30	0.98	1.00	1.00	1.00	1.00
13	1.80	2.10	2.10	2.10	2.10	2.10	1.60	1.50	1.50	1.50	1.50	1.50	1.40	1.10	1.10	1.10	1.10	1.10
14	1.70	2.00	2.00	2.00	2.00	2.00	1.60	1.60	1.60	1.60	1.60	1.60	1.40	1.10	1.20	1.20	1.20	1.20
15	1.70	2.00	2.00	2.00	2.00	2.00	1.60	1.60	1.60	1.60	1.60	1.60	1.50	1.20	1.20	1.20	1.20	1.20
16	1.70	2.00	1.90	1.90	1.90	1.90	1.60	1.60	1.60	1.60	1.60	1.60	1.50	1.30	1.30	1.30	1.30	1.30
17	1.70	1.90	1.90	1.90	1.90	1.90	1.60	1.60	1.60	1.60	1.60	1.60	1.50	1.30	1.30	1.30	1.30	1.30
18	1.70	1.90	1.90	1.90	1.90	1.90	1.70	1.60	1.60	1.60	1.60	1.60	1.50	1.40	1.40	1.30	1.30	1.30
19	1.70	1.90	1.90	1.90	1.90	1.90	1.70	1.60	1.60	1.60	1.60	1.60	1.60	1.40	1.40	1.40	1.40	1.40
20	1.70	1.80	1.80	1.80	1.90	1.90	1.70	1.60	1.60	1.60	1.70	1.70	1.60	1.40	1.40	1.40	1.40	1.40
21	1.70	1.80	1.80	1.80	1.80	1.80	1.70	1.60	1.60	1.70	1.70	1.70	1.60	1.50	1.50	1.50	1.50	1.50
22	1.70	1.80	1.80	1.80	1.80	1.80	1.70	1.60	1.70	1.70	1.70	1.70	1.60	1.50	1.50	1.50	1.50	1.50
23	1.70	1.80	1.80	1.80	1.80	1.80	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.50	1.50	1.50	1.50	1.50
24	1.70	1.80	1.80	1.80	1.80	1.80	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.50	1.60	1.60	1.60	1.60
25	1.70	1.80	1.80	1.80	1.80	1.80	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.60	1.60	1.60	1.60
26	1.70	1.80	1.80	1.80	1.80	1.80	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.60	1.60	1.60	1.60
27	1.70	1.80	1.80	1.80	1.80	1.80	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.60	1.60	1.60
28	1.70	1.80	1.80	1.80	1.80	1.80	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.60	1.60	1.60
29	1.70	1.70	1.80	1.80	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.60	1.60	1.60
30	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.60	1.60	1.60
31	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.60	1.60	1.60
32	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.60	1.60	1.60
33	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.60	1.60	1.60
34	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.70	1.70	1.70
35	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.70	1.70	1.70	1.70
36	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
37	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
38	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.70	1.70	1.70
39	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.60	1.60	1.60	1.60	1.60
40	1.70	1.60	1.60	1.60	1.60	1.60	1.70	1.60	1.60	1.60	1.60	1.60	1.70	1.60	1.60	1.60	1.60	1.60
41	1.70	1.60	1.60	1.60	1.60	1.60	1.70	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60
42	1.60	1.50	1.50	1.50	1.50	1.50	1.60	1.50	1.50	1.50	1.50	1.50	1.60	1.50	1.50	1.50	1.50	1.50
43	1.50	1.40	1.40	1.40	1.40	1.40	1.50	1.50	1.40	1.40	1.40	1.40	1.50	1.40	1.40	1.40	1.40	1.50
44	1.40	1.30	1.30	1.30	1.30	1.30	1.40	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
45	1.20	1.10	1.10	1.10	1.10	1.10	1.20	1.20	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10

APPENDIX A

INSEA CODE LISTING

APPENDIX A

INSEA Code Listing

INSEA was written in Microsoft FORTRAN77 Version 3.3 for the DOS Operating System. The following is a complete listing of the source code.

```
      PROGRAM INSEA

C  PROGRAM DEVELOPED FOR U.S. E.P.A.
C  UNDER CONTRACT NO. 68-01-6986

C  PURPOSE:
C  ESTIMATE THE MAXIMUM FEED CONCENTRATION OF TOXIC WASTES INTO AN
C  INCINERATOR AT SEA THAT WILL NOT VIOLATE AQUATIC CRITERIA

C  AUTHORS:  L.W. VAIL  AND J.G. DROPPO JR
C  GEOSCIENCES DEPARTMENT
C  BATTELLE PACIFIC NORTHWEST LABORATORIES
C  P.O. BOX 999
C  RICHLAND, WASHINGTON 99352

$     INCLUDE: 'INSEA.INC'
      LOGICAL LREAD
      REAL RREAD
      EXTERNAL LREAD,RREAD
      LOGICAL PLOTC,ECHOP,TABLEP,SELECT,MORE
      CHARACTER*78 TITLE2

C  READ CONFIGURATION

      CALL CONFIG

C  OPEN FILE TO SAVE INTERACTIVE RUN STREAM

      OPEN (UNIT=IOECHO,FILE=FILE2,STATUS='UNKNOWN')
      LECHO = .TRUE.
      CALL SPACE (1)
      CALL OUT ('                INSEA - INCINERATION AT SEA MODEL$')
      CALL SPACE (1)

C  READ DEFAULT VALUES

      CALL PROMPT ('TITLE OF RUN$',TITLE2,.FALSE.)
      TITLE = TITLE2(1:40)

      CALL DEFAUL

C  PARAMETER SELECTION

      CALL LIST (IOECHO)
```

```
      SELECT = LREAD('CHANGE PARAMETERS$')

      IF (SELECT) THEN

100      CALL CHANGE
         MORE = LREAD('CHANGE ANOTHER PARAMETER$')
         IF (MORE) GOTO 100

      ENDIF

C  SIMULATION

      IF (SELECT) CALL LIST (IOECHO)

      WRITE (*,120) MAXCOL,MAXLAY
      WRITE (IOECHO,120) MAXCOL,MAXLAY
      DO 105 I=1,MAXLAY
         WRITE (*,115) I,DD(I)
         WRITE (IOECHO,115) I,DD(I)
105      CONTINUE

110   HRS = RREAD('NUMBER OF HOURS TO BE SIMULATED$')

      CALL RUN

C  PRINT CRITERIA TABLE, PRINT ECHO FILE, PLOT CONCENTRATIONS

      TABLEP = LREAD('PRINT FEED RATE TABLE$')

      IF (TABLEP) CALL TPRINT

      ECHOP = LREAD('PRINT ECHO FILE$')

      IF (ECHOP) CALL EPRINT

      PLOTC = LREAD('PLOT AQUATIC CONCENTRATION DATA$')

      IF (PLOTC) CALL CPLOT

      MORE = LREAD('CONTINUE SIMULATION$')

      IF (MORE) GOTO 110

C  FINISH

      STOP
115   FORMAT (' LAYER',I3,' THICKNESS OF LAYER ',F5.2,' METERS')
120   FORMAT (' NUMBER OF COLUMNS IN OCEAN GRID =',I3,/' NUMBER OF LAYER
     &S IN OCEAN GRID    =',I3)
      END
```

```
      SUBROUTINE AIRLWV
$     INCLUDE: 'INSEA.INC'

      DIMENSION FRAC(MXXCOL),STORED(MXXCOL)

C  WIND PROFILES BASED ON USTAR, ZO

C  Set Stability Class Index . . .

      KSK = KS
      IF (KS.GT.3) KSK = KS+1
      IF (KS.GT.7) KSK = 7

C  Define distances . . .

      DISTIN = REACH/MAXCOL
      DIST(1) = 200.
      DO 100 I=2,MAXCOL
100      DIST(I) = DIST(I-1)+DISTIN

      DO 105 ID=1,MAXCOL
         DEP(ID) = 0.0
105      DEPTOT(ID) = 0.0

C  DEFINE PARAMETERS
      WINMIN = 0.5
      ITIME = 0
      SOUR = FLOAT(NSS)*QP
      AIRTME = 3600.0
      CON1 = SQRT(2.*PI)

C  DEFINE WIND SPEEDS

      WIND = WSPD

C  CALM DEFINED AS WINMIN M/S DRIFT

      WIND = MAX(WIND,WINMIN)
      WSPD = WIND

      PREP = 1.0
      CALL WINDC (KS,WIND,ANHGT,USTAR,ZO)
      CALL DRYMAX (USTAR,WIND,VD)
      IF (VD.LE.0..OR.DEPVEL.LE.0.) THEN

C  GRAVITATIONAL FALLOUT/ZERO DRY REMOVAL

          DEPVEL = -1.0*DEPVEL
          IF (DEPVEL.GT..10) THEN
             WRITE (*,145)
             WRITE (IOECHO,145)
          ENDIF
```

```
          WRITE (*,135) ' Deposition velocity = ',DEPVEL,' m/s'
          WRITE (IOECHO,135) ' Deposition velocity = ',DEPVEL,' m/s'
       ELSE

C   COMBINE AIR AND SURFACE DRY DEPOSITION TERMS

          DEPVEL = 1./(1./VD+1./DEPVEL)
          WRITE (*,135) ' Combined air/sea deposition velocity = ',DEPVEL
     &    ,' m/s'
          WRITE (IOECHO,135) ' Combined air/sea deposition velocity = ',D
     &    EPVEL,' m/s'
       ENDIF
       WRITE (*,135) ' for friction velocity, U* = ',USTAR,' m/s'
       WRITE (*,135) ' and roughness length, zo  = ',ZO,'m.'
       WRITE (IOECHO,135) ' for friction velocity, U* = ',USTAR,' m/s'
       WRITE (IOECHO,135) ' and roughness length, zo  = ',ZO,'m.'

       IF (ICASE.EQ.0) THEN

C   STATIONARY SHIP OPERATION PLUME RISE

          CALL WINDP (KS,UNEW,HPP,USTAR,ZO)
          CALL PLMRS (KSK,UNEW,PREP,ANHGT,DH,HE)
          IF (HE.GT.HL) HE = HL

C   DH=PLUME RISE
C   HE=EFFECTIVE STACK HEIGHT

          PHGT = HE

C   EXTRAPOLATE WIND SPEED UP TO PLUME HEIGHT OR 200 M.
C   WHICH EVER IS LOWER

          IF (HE.GT.200.) PHGT = 200.
          CALL WINDP (KS,WIND,PHGT,USTAR,Z0)
          CALL SHIPLV

          depall = 0.0
          DO 110 J=1,MAXCOL
             depall = depall+deptot(j)
110          CONTINUE

          WRITE (IOECHO,135) ' Stationary operation with ',he,' m plume r
     &    ise.'
          WRITE (IOECHO,135) ' Wind speed at plume height =  ',wind,' m/s
     &    '
          WRITE (IOECHO,135) ' Wind speed at 10 m = ',wspd,' m/s'
       ELSE

C   SHIP OPERATION ALONG A LINE

C   Check Line Source Reach . . .
```

```
      REAC2 = REACH-XLENG
      IF (REAC2.LT.0.0) THEN

C  CHECK IF SHIP PATH IS LESS THAN REACH

         WRITE (IOECHO,*) ' ERROR - Ship path greater than reach '
         WRITE (*,*) ' ERROR - Ship path greater than reach '
         STOP
      ENDIF

C  Define Speeds . . .

      CALL WINDP (KS,UNEW,HPP,USTAR,ZO)

      SSPDR = MAX(SSPD,UNEW+SPDMIN)
      SSPDL = MAX(SSPD,UNEW-SPDMIN)

      IF (SSPD.EQ.0.0) THEN
         RTR = 0.5
         RTL = 0.5
      ELSE
         TR = XLENG/SSPDR
         TL = XLENG/SSPDL
         RTR = TR/(TR+TL)
         RTL = TL/(TR+TL)
      ENDIF

      WSPL = SSPDL+UNEW
      WSPR = SSPDR-UNEW

C  Plume Rise . . .

      CALL PLMRS (KSK,WSPL,PREP,ANHGT,DHL,HEL)
      HEL = MIN(HEL,HL)
      HEXL = MIN(200.,HEL)
      CALL PLMRS (KSK,WSPR,PREP,ANHGT,DHR,HER)
      HER = MIN(HER,HL)
      HEXR = MIN(200.,HER)
      CALL WINDP (KS,WINDL,HEXL,USTAR,ZO)
      CALL WINDP (KS,WINDR,HEXR,USTAR,ZO)

C  Define initial ship direction and parameters . . .

      DO 115 J=1,MAXCOL
         STORED(J) = 0.0
115      CONTINUE

      XLEN = XLENG/1000.
      TDIS = XLEN
      DIRC = -1.0
      CALL SHIPLV
      NDCOLS = MAX(1.0,(XLENG/REACH)*MAXCOL)
```

```
      DO 120 J=1,MAXCOL
         DO 120 I=MAX(J-NDCOLS+1,1),J
            STORED(J) = STORED(J)+RTR*DEPTOT(I)
120         CONTINUE

      DIRC = 1.0
      CALL SHIPLV

      DO 125 J=1,MAXCOL
         DO 125 I=MAX(J-NDCOLS+1,1),J
            STORED(J) = STORED(J)+RTL*DEPTOT(I)
125         CONTINUE

      depall = 0.0
      DO 130 J=1,MAXCOL
         DEPTOT(J) = STORED(J)/NDCOLS
         depall = depall+deptot(j)
130      CONTINUE

      WRITE (IOECHO,140) ' Ship moves right at ',SSPDR,' m/s, ',her,
     &    'm plume rise'
      WRITE (IOECHO,140) ' Ship moves left at  ',SSPDL,' m/s, ',hel,
     &    'm plume rise'
      WRITE (IOECHO,135) ' Wind speed for plume height (right)  =  ',
     &   windr,' m/s'
      WRITE (IOECHO,135) ' Wind speed for plume height (left)   =  ',
     &   windl,' m/s'

      ENDIF
      write (ioecho,*) depall,(deptot(j),j=1,maxcol)
      ITIME = 1
      RETURN
135   FORMAT (A,G10.3,A)
140   FORMAT (A,G10.3,A,G10.3,A)
145   FORMAT (' WARNING - DEPOSITION VELOCITY OUT OF RANGE FOR INSEA MOD
     &EL')
      END
```

```
      SUBROUTINE CHANGE
$     INCLUDE: 'INSEA.INC'
      INTEGER MATCH
      EXTERNAL MATCH
      CHARACTER*78 CSTAB
      PARAMETER (NUMPAR=24)
      CHARACTER*3 PLIST(NUMPAR)
      DATA PLIST/'HEI','VEL','TEM',
     &           'PAT','DRY','WET',
     &           'NUM','DIF','DIS',
     &           'LAT','OFF','SHI ',
     &           'WIN','STA','POI',
     &           'LIN','AIR',
     &           'MIX','MIN','LEN',
     &           'HEL','DIA','GRI','REG'/
      JUMP = MATCH('Enter Parameter Keyword (or HELP)$',PLIST,NUMPAR)
      GOTO (100,105,110,115,120,125,130,135,140,145,150,155,160,165,170,
     &175,180,185,190,195,200,205,210,215), JUMP

100   HPP = RREAD('HEIGHT OF STACK IN METERS$')
      RETURN

105   VSP = RREAD('EXIT VELOCITY OF STACK EMISSIONS IN METERS/SEC$')
      RETURN

110   TSP = RREAD('TEMPERATURE OF STACK EMISSIONS IN DEGREES C$')+273.
      RETURN

115   XLENG = RREAD('PATH LENGTH OF LINE SOURCE IN KILOMETERS$')*1000.0
      RETURN

120   DEPVEL = RREAD('DRY DEPOSITION VELOCITY IN METERS/SEC$')
      RETURN

125   SCAVC = RREAD('WET SCAVENGING COEFFICIENT IN 1/SEC$')
      RETURN

130   NSS = IREAD('NUMBER OF INCINERATORS$')
      RETURN

135   DIFFUS = RREAD('DIFFUSION COEFFICIENT IN SQ. METERS/SEC$')
      RETURN

140   DISPER = RREAD('DISPERSIVITY IN METERS$')
      RETURN

145   RLAT = RREAD('LATITUDE IN DEGREES$')
      RETURN

150   YE = RREAD('OFFSET DISTANCE FROM PLUME CENTERLINE IN METERS$')
      RETURN
```

```
155   SSPD = RREAD('SHIP SPEED IN KNOTS$')*0.5148
      RETURN

160   WSPD = RREAD('WIND SPEED IN METERS/SEC$')
      RETURN

165   CALL PROMPT ('STABILITY CLASS A,B,C,D,E,F$',CSTAB,.FALSE.)
      IT = ICHAR(CSTAB(1:1))
      IF (IT.GE.97) IT = IT-32
      IT = IT-64
      IF (IT.LT.1.OR.IT.GT.6) THEN
         CALL OUT ('INVALID STABILITY CLASS$')
         GOTO 165
      ENDIF
      RKS = FLOAT(IT)
      RETURN

170   RICASE = 0.0
      RETURN

175   RICASE = 1.0
      RETURN

180   TEMP = RREAD('AIR TEMPERATURE IN DEGREES C$')+273.
      RETURN

185   HL = RREAD('MIXING HEIGHT$')
      RETURN

190   SPDMIN = RREAD('MINIMUM AIR SPEED PAST STACK IN METERS/SEC$')
      RETURN

195   REACH = RREAD('LENGTH OF OCEAN SIMULATED IN KILOMETERS$')*1000.0
      RETURN

200   CALL LIST (IOECHO)
      RETURN

205   DP = RREAD('DIAMETER OF STACK IN METERS$')
      RETURN

210   CALL LOG
      RETURN

215   DRIFT = RREAD('REGIONAL CURRENT VELOCITY IN METERS/SEC$')
      RETURN

      END
```

```
      SUBROUTINE CONFIG
$     INCLUDE: 'INSEA.INC'
      OPEN (UNIT=1,FILE='CONFIG.FIL',STATUS='OLD')
      READ (1,100) FILE1
      READ (1,100) FILE2
      READ (1,100) FILE3
      READ (1,100) FILE4
      READ (1,100) FILE5
      READ (1,100) FILE6
      CLOSE (UNIT=1)
      OPEN (UNIT=1,FILE=FILE5,STATUS='OLD')
      READ (1,*) MAXCOL,MAXLAY,(DD(I),I=1,MAXLAY)
      MAXLAP = MAXLAY+1
      CGRID = 'DEFAULT
      ANHGT = 10.0
      NSS = INT(RNSS)
      CLOSE (UNIT=1)
      RETURN
100   FORMAT (A20)
      END
```

```
      SUBROUTINE CPLOT
$     INCLUDE: 'INSEA.INC'
      PARAMETER (SECDY=86400.0)
      PARAMETER (SECHR=3600.0)
      INTEGER XXXX,YYYY
      REAL DDD(MXXCOL)

      IF (MAXLAY.EQ.1) THEN
         CALL OUT (' ONLY ONE LAYER IN GRID$')
         CALL OUT (' VERTICAL PROFILE IMPOSSIBLE$')
      ENDIF

      OPEN (UNIT=IOPRNT,FILE=FILE3,STATUS='UNKNOWN')
      IOPLOT = IOPRNT
      S = TIME
      IDAY = INT(S/SECDY)
      S = MOD(S,SECDY)
      IHR = INT(S/SECHR)

      CMAX = 0.0
      DO 100 I=1,MAXCOL
         CMAX = MAX(CMAX,T(1,I))
100      CONTINUE

      DMAX = 0.0
      DO 105 I=1,MAXLAY
         DMAX = DMAX+DD(I)
105      CONTINUE

      DDD(1) = DD(1)*0.5
      DO 110 I=2,MAXLAY
         DDD(I) = DDD(I-1)+(DD(I)+DD(I-1))*0.5
110      CONTINUE

      TEMPHI = 100
      TEMPLO = 0
      TEMPIN = 20
      BEGPLT = 0
      ENDPLT = 100
      TIMEIN = 10
      NXT = 5
      NYT = 10

      WRITE (IOPLOT,135) TITLE,IDAY,IHR,CMAX,DMAX
      WRITE (IOPLOT,140)

C  TICKS

      DO 115 I=1,NXT+1
         IT = NINT(6000.0-(I-1)*5000.0/NXT)
         WRITE (IOPLOT,145) IT,IT-175,INT(TEMPHI-(I-1)*TEMPIN)
115      CONTINUE
```

```
C  TICKS

      DO 120 I=1,NYT+1
         IT = NINT(7000.0-(I-1)*6000.0/NYT)
         WRITE (IOPLOT,150) IT,IT-50,INT(BEGPLT+(I-1)*TIMEIN)
120      CONTINUE

      WRITE (IOPLOT,155)

125   II = IREAD('INPUT NUMBER OF WATER COLUMN TO BE PLOTTED$')
      IF (II.GT.MAXCOL.OR.II.LE.0) THEN
         CALL OUT ('BAD COLUMN NUMBER$')
         GOTO 125
      ENDIF
      IPEN = IPEN+1
      WRITE (IOPLOT,160) IPEN,5300-IPEN*200

      XX = 0.2+(REACH*(II-1))/(MAXCOL*1000.)
      WRITE (IOPLOT,165) XX
      DO 130 I=1,MAXLAY
         XXXX = NINT(7000-(DDD(I)/DMAX)*6000)
         YYYY = NINT(1000+5000*T(I,II)/CMAX)
         IF (I.EQ.1) THEN
            WRITE (IOPLOT,170) YYYY,XXXX
         ELSE
            WRITE (IOPLOT,175) YYYY,XXXX
         ENDIF
130      CONTINUE
      WRITE (IOPLOT,*) ' PU;'

      LMORE = LREAD('PLOT ANOTHER COLUMN$')
      IF (LMORE) GOTO 125

      CLOSE (UNIT=IOPRNT)
      RETURN
135   FORMAT (' SP1;DT',/,' PA2500,7500;DI1,0;LB(Concentration/CMAX)%',/
     &,' PU7000,6750;DI1,0;',/,' LBINSEA Incineration at Sea ',/,' CP0,-
     &1;LB',A40,/,' CP0,-1;LBVertical Concentration Profile',/' CP0,-1;L
     &B',I3,' days ',I2,' hrs ',/,' CP0,-1;LBCMAX =',G10.3,' (ug/l)/(gm/
     &s)',/,' CP0,-1;LBDMAX =',G10.3,' meters',/' CP0,-1;LBDistance from
     & origin in km',/,' PA200,4700;DI0,-1;LB(Depth/DMAX)%')
140   FORMAT (' SP2;PU,PA1000,1000;YT;',/,' PD,PA1000,7000,PA6000,7000;X
     &T;PU;')
145   FORMAT (' PU;PA',I4,',7000;XT;PU;PA,',I4,',7200;DI1,0;LB',I3)
150   FORMAT (' PU;PA1000,',I4,';YT;PU;PA600,',I4,';D1,0;LB',I3)
155   FORMAT (' PU;PA0,0;')
160   FORMAT (' SP',I2,';,PA;PU8000,',I4,/)
165   FORMAT ('DI1,0;LB',F5.2)
170   FORMAT (' PA;PU',I5,',',I5,';PD;')
175   FORMAT (' PA;PD',I5,',',I5,';PU;')
      END
```

```
      SUBROUTINE DEBUG (FLAG)
$     INCLUDE: 'INSEA.INC'
      CHARACTER*4 FLAG
      IF (FLAG.EQ.'DEPT') THEN
         WRITE (IOECHO,*) ' DEBUG DATA  DEPTH'
         DO 100 I=1,MAXLAY
            WRITE (IOECHO,*) ' LAYER : ',I,' DEPTH : ',DD(I)
100         CONTINUE
      ENDIF
      IF (FLAG.EQ.'VELO') THEN
         WRITE (IOECHO,*) ' DEBUG DATA  VELOCITY'
         DO 105 I=1,MAXLAY
            WRITE (IOECHO,*) ' LAYER : ',I,' VELOCITY : ',VEL(I)
105         CONTINUE
      ENDIF
      IF (FLAG.EQ.'CLOC') THEN
         WRITE (IOECHO,*) ' DEBUG DATA  CLOCK'
         DO 110 I=1,MAXLAY
            WRITE (IOECHO,*) ' LAYER : ',I,' FUNTS : ',FUNDTS(I)
110         CONTINUE
      ENDIF
      IF (FLAG.EQ.'DISP') THEN
         WRITE (IOECHO,*) ' DEBUG DATA  DISPERSION'
         DO 115 I=1,MAXLAY
            WRITE (IOECHO,*) ' LAYER : ',I,' DISP: ',DISP(I)
115         CONTINUE
      ENDIF
      IF (FLAG.EQ.'ATMO') THEN
         WRITE (IOECHO,*) ' DEBUG DATA  ATMOSPHERIC'
         DO 120 I=1,MAXCOL
            WRITE (IOECHO,*) ' COLUMN : ',I,' DIST : ',DIST(I),' FLUX :
     &      ',FLUX(I)
120         CONTINUE
      ENDIF
      RETURN
      END
```

```
      SUBROUTINE DEFAUL
$     INCLUDE: 'INSEA.INC'
      CHARACTER*65 CASE

C  SELECT DEFAULT MENU

      OPEN (UNIT=IODEFL,FILE=FILE6,STATUS='OLD')

100   CALL OUT ('                DEFAULT CASE MENU$')
      CALL OUT ('=============================================$')
      CALL SPACE (1)
      NCASES = 0

C  READ/WRITE NAMES OF DEFAULT DATA SETS IN FILE

      DO 105 I=1,25
         READ (IODEFL,120,END=110) CASE
         READ (IODEFL,*,END=110) DISPER,DIFFUS,DEPMIX,DFACT,REACH,RLAT,S
     &   SPD,XINC,WSPD,YE,SPDMIN,RKS,HPP,VSP,TSP,QP,HL,RICASE,XLENG,RNSS
     &   ,TEMP,SCAVC,DEPVEL,DP
         NCASES = NCASES+1
         WRITE (*,125) I,CASE
         WRITE (IOECHO,125) I,CASE
105      CONTINUE

110   REWIND IODEFL

      CALL SPACE (1)
      ICASE = IREAD('SELECT CASE NUMBER$')

      IF (ICASE.GT.0.AND.ICASE.LE.NCASES) THEN

C  SKIP DOWN TO CHOOSEN DATA SET

         DO 115 I=1,ICASE-1
            READ (IODEFL,120) CASE
            READ (IODEFL,*) DISPER,DIFFUS,DEPMIX,DFACT,REACH,RLAT,SSPD,X
     &      INC,WSPD,YE,SPDMIN,RKS,HPP,VSP,TSP,QP,HL,RICASE,XLENG,RNSS,T
     &      EMP,SCAVC,DEPVEL,DP
115         CONTINUE

C  READ IN CHOOSEN DATA SET

         READ (IODEFL,120) CASE
         READ (IODEFL,*) DISPER,DIFFUS,DEPMIX,DFACT,REACH,RLAT,SSPD,XINC
     &   ,WSPD,YE,SPDMIN,RKS,HPP,VSP,TSP,QP,HL,RICASE,XLENG,RNSS,TEMP,SC
     &   AVC,DEPVEL,DP
      ELSE
         GOTO 100
      ENDIF
      CLOSE (UNIT=IODEFL)
```

```
      OPEN (UNIT=IODEFL,FILE=FILE5,STATUS='OLD')
      READ (IODEFL,*) MAXCOL,MAXLAY,(DD(I),I=1,MAXLAY)
      MAXLAP = MAXLAY+1
      CGRID = 'DEFAULT
      CLOSE (UNIT=IODEFL)

      TIME = 0.0
      ANHGT = 10.0
      NSS = INT(RNSS)
      RETURN
120   FORMAT (A65)
125   FORMAT (' CASE  ',I2,2X,A65)
      END
```

```
      SUBROUTINE DRIVER
$     INCLUDE: 'INSEA.INC'
      TSTEPE = HRS*3600.0
      TMAX = TSTEPE*0.05
      ENDTIM = TIME+TSTEPE
      TSTEP = RELBIG
      TCOUT = 0.0
      TCIN = 0.0
      DO 100 I=1,MAXLAP
         TN(I) = FUNDTS(I)*PRTHRU(I)
         IF (TN(I).EQ.0.0) TN(I) = FUNDTS(I)
         TSTEP = MIN(TSTEP,TN(I))
100      CONTINUE

C  subtract tstep's; if ripe, CONVCT & CONDCT

105   IF (TIME+TSTEP.LT.ENDTIM) THEN
         TSTEP = RELBIG
         DO 110 I=1,MAXLAP
            TSTEP = MIN(TSTEP,TN(I))
110         CONTINUE

C  FIND MINIMUM TIME TO NEXT MOVE

         DO 130 I=1,MAXLAP
            TN(I) = TN(I)-TSTEP
            IF (TN(I).LE.1.0E-20) THEN

C  IF I=MAXLAP INCLUDE  FLUXES

               IF (I.EQ.MAXLAP) THEN

C  ADD FLUX

                  DO 115 II=1,MAXCOL
                     TCIN = TCIN+FLUX(II)
                     T(1,II) = T(1,II)+FLUX(II)/DD(1)
115                  CONTINUE
                  IF (MAXLAY.NE.1) CALL DSPER

C  AVERAGE CONC

                  TCSTOR = 0.0
                  DO 120 JJ=1,MAXLAY
                     DO 120 II=1,MAXCOL
                        AVEC(JJ,II) = T(JJ,II)/HRS+AVEC(JJ,II)
                        TCSTOR = TCSTOR+T(JJ,II)*DD(JJ)
120                     CONTINUE

               ELSE
```

```
C  CONVECT APPROPRIATE ROW

                    TCOUT = T(I,MAXCOL)*DD(I)+TCOUT
                    DO 125 K=MAXCOL,2,-1
                       T(I,K) = T(I,K-1)
125                    CONTINUE

C  INCOMING WATER IS PURE I.E. T=0

                    T(I,1) = 0.0
                 ENDIF

C  REASSIGN TIME TO NEXT MOVE TO FUNDEMENTAL TIME STEP

                 TN(I) = FUNDTS(I)
              ENDIF
130           CONTINUE

C  WRITE SIMULATION TIME

           CALL WCLOCK (TIME+TSTEP)

C  UPDATE CLOCK

           TIME = TIME+TSTEP
           GOTO 105
        ELSE
           DO 135 I=1,MAXLAP
              TN(I) = TN(I)-(ENDTIM-TIME)
              PRTHRU(I) = 1.0-TN(I)/FUNDTS(I)
135           CONTINUE
           TIME = ENDTIM
           CALL WCLOCK (TIME)
        ENDIF

C  PRINT OUTPUT

        WRITE (IOECHO,*) 'Mass balance error',(TCIN-TCOUT-TCSTOR)/TCIN
        WRITE (IOECHO,*) 'Mass IN   (grams) ',TCIN
        WRITE (IOECHO,*) 'Mass OUT           ',TCOUT
        WRITE (IOECHO,*) 'Mass STORED        ',TCSTOR
        WRITE (IOECHO,*) 'Ocean concentrations in micrograms/liter/unit em
       &ission:'

        NTIMES = INT(MAXCOL*0.19999)+1
        I = 1
        DO 140 J=1,NTIMES
           J1 = (J-1)*5+1
           J2 = J*5
           DO 141 K=1,MAXLAY
           WRITE (IOECHO,145) K,J1,J2,(T(K,II)*1000.0,II=J1,J2)
141        CONTINUE
```

```
140      CONTINUE
      CALL SLINE (1)
      RETURN
145   FORMAT (' LAYER:',I2,' COL',I2,'TO',I2,5(1X,E10.2))
      END
```

```
      SUBROUTINE DRYMAX (USTAR,WIND,VD)
C   SUBPROGRAM ABSTRACT:  DRYMAX / VER 02-18-86
C   THE SUBROUTINE DRYMAX PROVIDES AN UPPER
C   VALUE FOR THE DRY DEPOSITION VELOCITY BASED ON
C   THE MOMEMTUM FLUX THROUGH AIR

C   JG DROPPO VERSION

      VD = USTAR*USTAR/WIND
      RETURN
      END
```

```
      SUBROUTINE DSPER
C   *************************************************************
$     INCLUDE: 'INSEA.INC'
      J = 2
      TSTEPI = 3600.0/J
      DELTCI = 1.0/TSTEPI
C  set up B vector in matrix
      DO 100 I=1,MAXLAY
         RHS(I) = -DELTCI*DD(I)
         B(I) = -A(I)-C(I)+RHS(I)
100      CONTINUE
C  decomposition
      I = 1
      ALPHAI(1) = 1.0/B(1)
105   IF (I.GT.MAXLAY-1) GOTO 110
      BETA(I) = C(I)*ALPHAI(I)
      I = I+1
      ALPHAI(I) = 1.0/(B(I)-A(I)*BETA(I-1))
      GOTO 105
C  solver

110   DO 145 I1=1,MAXCOL
         DO 115 K=1,MAXLAY
            YC(K) = T(K,I1)
115         CONTINUE
         DO 135 IL=1,J
            DO 120 I=1,MAXLAY
               YC(I) = YC(I)*RHS(I)
120            CONTINUE
C  YC(1) = YC(1)-TEMPT*A(1)
C  YC(MAXLAY) = YC(MAXLAY)-TEMPB*C(MAXLAY)
C  forward substitution
            YC(1) = YC(1)*ALPHAI(1)
            DO 125 I=2,MAXLAY
               YC(I) = (YC(I)-A(I)*YC(I-1))*ALPHAI(I)
125            CONTINUE
C  back substitution
            DO 130 I=MAXLAY-1,1,-1
               YC(I) = YC(I)-BETA(I)*YC(I+1)
130            CONTINUE
135         CONTINUE
C  for steady state
         DO 140 K=1,MAXLAY
            T(K,I1) = YC(K)
140         CONTINUE

145      CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EPRINT
$     INCLUDE: 'INSEA.INC'
      CHARACTER*78 LINE

C  PRINT ECHO FILE

      CLOSE (UNIT=IOECHO)
      OPEN (UNIT=IOECHO,FILE=FILE2,STATUS='OLD')
      OPEN (UNIT=IOPRNT,FILE=FILE1)
100   READ (IOECHO,110,END=105) LINE
      WRITE (IOPRNT,110) LINE
      GOTO 100
105   CLOSE (UNIT=IOECHO)
      CLOSE (UNIT=IOPRNT)
      OPEN (UNIT=IOECHO,FILE=FILE2,STATUS='UNKNOWN')
      RETURN
110   FORMAT (A78)
      END
```

```
      INTEGER FUNCTION INDEXR(STR1,STR2)
      CHARACTER*78 STR1
      CHARACTER*1 STR2
      DO 100 I=1,78
         IF (STR1(I:I).EQ.STR2) THEN
            INDEXR = I
            RETURN
         ENDIF
100      CONTINUE
      INDEXR = 0
      RETURN
      END
```

```
      INTEGER FUNCTION IREAD(STRING)
C   THIS ROUTINE WRITES THE STRING 'STRING' AND PROMPTS THE
C   USER FOR AN INTEGER.  THE ENTIRE SEQUENCE IS ECHOED TO
C   LOGICAL UNIT IOECHO, IF LECHO IS TRUE.

      CHARACTER*78 ANS
      CHARACTER*43 STRING
      CHARACTER*1 IOKAY(10)
      EXTERNAL INDEXR

      DATA IOKAY/'1','2','3','4','5','6','7','8','9','0'/
      IREAD = 0
100   CALL PROMPT (STRING,ANS,.FALSE.)
      NTERMS = INDEXR(ANS,' ')
      I1 = 1
      IF (ANS(1:1).EQ.'-') I1 = 2
      DO 110 I=I1,NTERMS
         DO 105 J=1,10
            IF (IOKAY(J).EQ.ANS(I:I)) THEN
               IREAD = IREAD*10+(ICHAR(ANS(I:I))-48)
               GOTO 110
            ENDIF
105         CONTINUE
         IF (ANS(I:I).EQ.' ') GOTO 115
         CALL OUT (' INPUT ERROR, TRY AGAIN (integer)$')
         GOTO 100
110      CONTINUE
115   IF (ANS(1:1).EQ.'-') IREAD = -IREAD
      END
```

```
      SUBROUTINE LIST (IO)
$     INCLUDE: 'INSEA.INC'
      CHARACTER*1 CSTAB

C  LIST PARAMETERS

      WRITE (*,100)
      WRITE (IO,100)

      WRITE (*,105) TITLE
      WRITE (IO,105) TITLE

C  SHIP PARAMETERS

      IF (RICASE.EQ.0.) THEN

         WRITE (*,110)
         WRITE (IO,110)

      ELSE

         WRITE (*,115) SSPD/0.5148,XLENG*0.001
         WRITE (IO,115) SSPD/0.5148,XLENG*0.001

      ENDIF

C  INCINERATOR PARAMETERS

      WRITE (*,120) NSS,HPP,VSP,TSP,DP,SPDMIN
      WRITE (IO,120) NSS,HPP,VSP,TSP,DP,SPDMIN

C  ATMOSPHERIC PARAMETERS

      CSTAB = CHAR(INT(RKS)+64)
      WRITE (*,125) CSTAB,WSPD,TEMP-273.0,HL,SCAVC,DEPVEL,YE
      WRITE (IO,125) CSTAB,WSPD,TEMP-273.0,HL,SCAVC,DEPVEL,YE

C  OCEAN PARAMETERS

      WRITE (*,130) DRIFT,DIFFUS,DISPER,RLAT,REACH*0.001,CGRID
      WRITE (IO,130) DRIFT,DIFFUS,DISPER,RLAT,REACH*0.001,CGRID

      RETURN
100   FORMAT (1H1)
105   FORMAT (//,20X,'PARAMETER LIST',/,10X,'TITLE: ',A40,/,' **********
     &********* SHIP PARAMETERS ********************')
110   FORMAT (' POInt source')
115   FORMAT (' LINe source',/,' SHIp speed',T35,F3.0,T45,'KNOTS',/,' PA
     &Th length of line source',T35,F4.1,T45,'KILOMETERS')
120   FORMAT (' **************** INCINERATOR PARAMETERS ***************
     &*',/,' NUMber of incinerators',T35,I2,/' HEIght of stack',T35,F4.1
     &,T45,'METERS',/' VELocity of stack emission',T35,F6.0,T45,'METERS/
```

```
     &SEC',/' TEMperature of stack emissions',T35,F5.0,T45,'DEGREES C',/
     &' DIAmeter of stack',T35,F4.1,T45,'METERS',/' MINimum air speed pa
     &st stack',F6.1,T45,'METERS/SEC')
125   FORMAT (' ***************** ATMOSPHERIC PARAMETERS ***************
     &*',/,' STAbility class',T35,A1,/,' WINd speed',T35,F5.1,T45,'METER
     &S/SEC',/' AIR temperature',T35,F5.0,T45,'DEGREES C',/' MIXing heig
     &ht',T35,F5.0,T45,'METERS',/' WET scavenging coefficient',T35,G8.2,
     &T45,'1/SEC',/' DRY deposition velocity',T35,G8.2,T45,'METERS/SEC',
     &/' OFFset from plume centerline',T35,F5.0,T45,'METERS')
130   FORMAT (' ******************* OCEAN PARAMETERS *****************
     &**',/,' REGional current velocity',T35,G7.2,T45,'METERS/SEC',/' DI
     &Ffusion coefficient',T35,G7.2,T45,'SQ. METERS/SEC',/' DISpersivity
     &',T35,G7.2,T45,'METERS',/' LATitude ',T35,F3.0,T45,'DEGREES',/' LE
     &Ngth of ocean simulated',T35,F3.0,T45,'KILOMETERS',/,' GRId spacin
     &g',T35,A12)
      END
```

```
      SUBROUTINE LOG
C   ******************************************************************
C   ROUTINE PROMPTS USER FOR: (1) NUMBER OF LAYERS; (2) THICKNESS OF
C   EACH LAYER;

$     INCLUDE: 'INSEA.INC'
      LOGICAL SAME,LREAD,MORE
      EXTERNAL LREAD,IREAD,RREAD
      CGRID = 'USER DEFINED'
100   MAXLAY = ABS(IREAD('NUMBER OF HORIZONTAL LAYERS IN OCEAN GRID$'))
      MAXLAP = MAXLAY+1
      IF (MAXLAP.GT.MXXLAY) THEN
         CALL OUT ('NUMBER OF LAYERS EXCEEDS MAXIMUM ALLOWABLE$')
         GOTO 100
      ENDIF

C   get thickness of each layer

      SAME = LREAD('SAME THICKNESS FOR ALL LAYERS$')
      IF (SAME) THEN
105      TEMPX = ABS(RREAD('THICKNESS IN METERS$'))
         IF (TEMPX.LE.0.0) THEN
            CALL OUT ('INPUT ERROR, THICKNESS > 0$')
            GOTO 105
         ENDIF
         DO 110 I=1,MAXLAY
            DD(I) = TEMPX
110         CONTINUE
      ELSE
         DO 120 I=1,MAXLAY
115         WRITE (*,140) I
            WRITE (IOECHO,140) I
            DD(I) = ABS(RREAD('THICKNESS IN METERS$'))
            IF (DD(I).LE.0.0) THEN
               CALL OUT ('INPUT ERROR, THICKNESS > 0$')
               GOTO 115
            ENDIF
120         CONTINUE
      ENDIF

C   WRITE THICKNESSES

      DO 125 I=1,MAXLAY
         WRITE (*,135) I,DD(I)
125      CONTINUE

130   MAXCOL = IREAD('NUMBER OF VERTICAL COLUMNS IN OCEAN GRID$')
      IF (MAXCOL.GT.MXXCOL) THEN
         CALL OUT ('NUMBER OF COLUMNS EXCEEDS MAXIMUM$')
         GOTO 130
      ENDIF
```

```
      RETURN
135   FORMAT (' LAYER ',I2,' THICKNESS ',F5.2,' METERS')
140   FORMAT (' LAYER ',I2)
      END
```

```
      LOGICAL FUNCTION LREAD(STRING)
C  THIS ROUTINE WRITES THE STRING 'STRING' AND PROMPTS THE
C  USER FOR A BOOLEAN.  THE ENTIRE SEQUENCE IS ECHOED TO
C  LOGICAL UNIT IOECHO, IF LECHO IS TRUE.

      CHARACTER*78 ANS
      CHARACTER*43 STRING
100   CALL PROMPT (STRING,ANS,.TRUE.)
      IF (ANS(1:1).EQ.'Y'.OR.ANS(1:1).EQ.'y') THEN
         LREAD = .TRUE.
         RETURN
      ENDIF
      IF (ANS(1:1).EQ.'N'.OR.ANS(1:1).EQ.'n') THEN
         LREAD = .FALSE.
         RETURN
      ENDIF
      CALL OUT ('INPUT ERROR, TRY AGAIN (Y/N)$')
      GOTO 100
      END
```

```
      FUNCTION MATCH (STRING,LIST,NFILL)

C  THIS ROUTINE WRITES THE STRING 'STRING' AND PROMPTS THE
C  USER FOR A LITERAL AND THEN FINDS WHICH ELEMENT OF LIST
C  'LIST' THE STRING IS.

      CHARACTER*3 LIST(NFILL),TEST
      CHARACTER*78 ANS
      CHARACTER*43 STRING
100   CALL PROMPT (STRING,ANS,.FALSE.)

C  MAKE UPPER CASE

      DO 105 I=1,3
         IT = ICHAR(ANS(I:I))
         IF (IT.GE.97) ANS(I:I) = CHAR(IT-32)
105      CONTINUE

C  CHECK NAME

      TEST = ANS(1:3)
      DO 110 MATCH=1,NFILL
         IF (TEST.EQ.LIST(MATCH)) RETURN
110      CONTINUE
      CALL OUT ('INPUT ERROR, TRY AGAIN$')
      GOTO 100
      END
```

```
      SUBROUTINE OUT (STRING)
C  *************************************************************
C  THIS ROUTINE WRITES THE STRING 'STRING'.
$     INCLUDE: 'IOUNIT.INC'
      EXTERNAL INDEXR
      CHARACTER*78 STR1
      CHARACTER*78 STRING
      STR1 = ' '
      NN = INDEXR(STRING,'$')-1
      STR1(1:NN) = STRING(1:NN)
      WRITE (*,100) STR1
      WRITE (IOECHO,100) STR1
      RETURN
100   FORMAT (1H ,A78)
      END
```

```
      SUBROUTINE PAUSE (SEGMNT)
C  PAUSE FOR USER RESPONSE
      CHARACTER*4 SEGMNT
      CHARACTER*1 KEY
      WRITE (*,100) SEGMNT
      READ (*,105) KEY
      RETURN
100   FORMAT (/,1X,'     press <RETURN> to continue ',A4,/)
105   FORMAT (A1)
      END
```

```
      SUBROUTINE PGSIG (X,XY,KST,SY,SZ)
C  D. B. TURNER, ENVIRONMENTAL APPLICATIONS BRANCH
C  METEOROLOGY LABORATORY, ENVIRONMENTAL PROTECTION AGENCY
C  RESEARCH TRIANGLE PARK, N C 27711
C  (919) 549 - 8411, EXTENSION 4565
C  VERTICAL DISPERSION PARAMETER VALUE, SZ DETERMINED BY
C  SZ = A * X ** B WHERE A AND B ARE FUNCTIONS OF BOTH STABILITY
C  AND RANGE OF X.
      DIMENSION XA(7), XB(2), XD(5), XE(8), XF(9), AA(8), BA(8), AB(3),
     &BB(3), AD(6), BD(6), AE(9), BE(9), AF(10), BF(10)
      DATA XA /.5,.4,.3,.25,.2,.15,.1/
      DATA XB /.4,.2/
      DATA XD /30.,10.,3.,1.,.3/
      DATA XE /40.,20.,10.,4.,2.,1.,.3,.1/
      DATA XF /60.,30.,15.,7.,3.,2.,1.,.7,.2/
      DATA AA /453.85,346.75,258.89,217.41,179.52,170.22,158.08,122.8/
      DATA BA /2.1166,1.7283,1.4094,1.2644,1.1262,1.0932,1.0542,.9447/
      DATA AB /109.30,98.483,90.673/
      DATA BB /1.0971,0.98332,0.93198/
      DATA AD /44.053,36.650,33.504,32.093,32.093,34.459/
      DATA BD /0.51179,0.56589,0.60486,0.64403,0.81066,0.86974/
      DATA AE /47.618,35.420,26.970,24.703,22.534,21.628,21.628,23.331,
     &24.26/
      DATA BE /0.29592,0.37615,0.46713,0.50527,0.57154,0.63077,0.75660,
     &0.81956,0.8366/
      DATA AF /34.219,27.074,22.651,17.836,16.187,14.823,13.953,13.953,
     &14.457,15.209/
      DATA BF /0.21716,0.27436,0.32681,0.41507,0.46490,0.54503,0.63227,
     &0.68465,0.78407,0.81558/
      GOTO (100,115,130,135,140,155,170), KST
C  STABILITY A (10)
100   TH = (24.167-2.5334*ALOG(XY))/57.2958
      IF (X.GT.3.11) GOTO 185
      DO 105 ID=1,7
         IF (X.GE.XA(ID)) GOTO 110
105      CONTINUE
      ID = 8
110   SZ = AA(ID)*X**BA(ID)
      GOTO 195
C  STABILITY B (40)
115   TH = (18.333-1.8096*ALOG(XY))/57.2958
      IF (X.GT.35.) GOTO 185
      DO 120 ID=1,2
         IF (X.GE.XB(ID)) GOTO 125
120      CONTINUE
      ID = 3
125   SZ = AB(ID)*X**BB(ID)
      GOTO 190
C  STABILITY C (70)
130   TH = (12.5-1.0857*ALOG(XY))/57.2958
      SZ = 61.141*X**0.91465
      GOTO 190
```

```
C  D DAY TIME
135   TH = (8.3333-0.72382*ALOG(XY))/57.2958
      SZ = 30.9057*X**0.8273
      GOTO 190
C  STABILITY D (80)
140   TH = (8.3333-0.72382*ALOG(XY))/57.2958
      DO 145 ID=1,5
         IF (X.GE.XD(ID)) GOTO 150
145      CONTINUE
      ID = 6
150   SZ = AD(ID)*X**BD(ID)
      GOTO 190
C  STABILITY E (110)
155   TH = (6.25-0.54287*ALOG(XY))/57.2958
      DO 160 ID=1,8
         IF (X.GE.XE(ID)) GOTO 165
160      CONTINUE
      ID = 9
165   SZ = AE(ID)*X**BE(ID)
      GOTO 190
C  STABILITY F (140)
170   TH = (4.1667-0.36191*ALOG(XY))/57.2958
      DO 175 ID=1,9
         IF (X.GE.XF(ID)) GOTO 180
175      CONTINUE
      ID = 10
180   SZ = AF(ID)*X**BF(ID)
      GOTO 190
185   SZ = 5000.
      GOTO 195
190   IF (SZ.GT.5000.) SZ = 5000.
195   SY = 465.116*XY*SIN(TH)/COS(TH)
C  465.116 = 1000. (M/KM) / 2.15
      RETURN
      END
```

```
      SUBROUTINE PLMRS (KST,U,PL,HANE,DELH,H)
$     INCLUDE: 'INSEA.INC'
      IOPT = 1
      VS = VSP
      TS = TSP
      D = DP
C  MODIFY WIND SPEED BY POWER LAW PROFILE IN ORDER TO TAKE INTO
C  ACCOUNT THE INCREASE OF WIND SPEED WITH HEIGHT.
C  ASSUME WIND MEASUREMENTS ARE REPRESENTATIVE FOR HEIGHT=HANE.
C  THT IS THE PHYSICAL STACK HEIGHT
      THT = HPP
C  POINT SOURCE HEIGHT NOT ALLOWED TO BE LESS THAN 1 METER.
      IF (THT.LT.1.) THT = 1.
C  U - WIND SPEED AT HEIGHT 'HANE'
C  PL - POWER FOR THE WIND PROFILE
C  UPL - WIND AT THE PHYSICAL STACK HEIGHT
      UPL = U*(THT/HANE)**PL
C  WIND SPEED NOT ALLOWED TO BE LESS THAN 1 METER/SEC.
      IF (UPL.LT.1.) UPL = 1.
      BUOY = 2.45153*VS*D**2
C  TEMP- THE AMBIENT AIR TEMPERATURE FOR THIS HOUR
      DELT = TS-TEMP
      F = BUOY*DELT/TS
C  CALCULATE  H PRIME WHICH TAKES INTO ACCOUNT STACK DOWNWASH
C  BRIGGS(1973) PAGE 4
      HPRM = THT
C  IF IOPT=0, THEN NO STACK DOWNWASH COMPUTATION
      IF (IOPT.EQ.0) GOTO 100
      DUM = VS/UPL
      IF (DUM.LT.1.5) HPRM = THT+2.*D*(DUM-1.5)
C  'HPRM' IS BRIGGS' H-PRIME
      IF (HPRM.LT.0.) HPRM = 0.
100   CONTINUE
C  CALCULATE PLUME RISE AND ADD H PRIME TO OBTAIN EFFECTIVE
C  STACK HEIGHT.
C  PLUME RISE CALCULATION
      IF (KST.GT.5) GOTO 110
C  PLUME RISE FOR UNSTABLE CONDITIONS
      IF (TS.LT.TEMP) GOTO 115
      IF (F.GE.55.) GOTO 105
C  DETERMINE DELTA-T FOR BUOYANCY-MOMENTUM CROSSOVER(F<55)
C  FOUND BY EQUATING BRIGGS(1969) EQ 5.2, P 59 WITH
C  COMBINATION OF BRIGGS(1971) EQUATIONS 6 AND 7, P 1031
C  FOR F<55.
      DTMB = 0.0297*TS*VS**0.33333/D**0.66667
      IF (DELT.LT.DTMB) GOTO 115
C  DISTANCE OF FINAL BUOYANT RISE(0.049 IS 14*3.5/1000)
C  BRIGGS(1971) EQUATION 7,F<55, AND DIST TO FINAL RISE IS
C  3.5 XSTAR DISTF IN KILOMETERS
      DISTF = 0.049*F**0.625
C  COMBINATION OF BRIGGS(1971) EQUATIONS 6 AND 7, P 1031 FOR
C  F<55.
```

```
      DELH = 21.425*F**0.75/UPL
      GOTO 125
C  DETERMINE DELTA-T FOR BUOYANCY-MOMENTUM CROSSOVER(F>55)
C  FOUND BY EQUATING BRIGGS(1969) EQ 5.2, P 59 WITH
C  COMBINATION OF BRIGGS(1971) EQUATIONS 6 AND 7, P 1031
C  FOR F>55.
105   DTMB = 0.00575*TS*VS**0.66667/D**0.33333
      IF (DELT.LT.DTMB) GOTO 115
C  DISTANCE OF FINAL BUOYANT RISE (0.119 IS 34*3.5/1000)
C  BRIGGS(1971) EQUATION 7, F>55, AND DIST TO FINAL RISE
C  IS 3.5 XSTAR. DISTF IN KILOMETERS
      DISTF = 0.119*F**0.4
C  COMBINATION OF BRIGGS(1971) EQUATIONS 6 AND 7, P 1031
C  FOR F>55.
      DELH = 38.71*F**0.6/UPL
      GOTO 125
C  PLUME RISE FOR STABLE CONDITIONS.
110   DTHDZ = 0.02
      IF (KST.GT.6) DTHDZ = 0.035
      S = 9.80616*DTHDZ/TEMP
      IF (TS.LT.TEMP) GOTO 120
C  DETERMINE DELTA-T FOR BUOYANCY-MOMENTUM CROSSOVER(STABLE)
C  FOUND BY EQUATING BRIGGS(1975) EQ 59, PAGE 96 FOR STABLE
C  BUOYANCY RISE WITH BRIGGS(1969) EQ 4.28, PAGE 59 FOR
C  STABLE MOMENTUM RISE.
      DTMB = 0.019582*TEMP*VS*SQRT(S)
      IF (DELT.LT.DTMB) GOTO 120
C  STABLE BUOYANT RISE FOR WIND CONDITIONS.(WIND NOT ALLOWED
C  LOW ENOUGH TO REQUIRE STABLE RISE IN CALM CONDITIONS.)
C  BRIGGS(1975) EQ 59, PAGE 96.
      DELH = 2.6*(F/(UPL*S))**0.333333
C  COMBINATION OF BRIGGS(1975) EQ 48 AND EQ 59. NOTE DISTF
C  IN KM.
      DISTF = 0.0020715*UPL/SQRT(S)
      GOTO 125
C  UNSTABLE-NEUTRAL MOMENTUM RISE
C  BRIGGS(1969) EQUATION 5.2, PAGE 59 NOTE: MOST ACCURATE
C  WHEN VS/U>4; TENDS TO OVERESTIMATE RISE WHEN VS/U<4
C  (SEE BRIGGS(1975) P 78, FIG 4.)
115   DELH = 3.*VS*D/UPL
      DISTF = 0.
      GOTO 125
C  STABLE MOMENTUM RISE
120   DHA = 3.*VS*D/UPL
C  BRIGGS(1969) EQUATION 4.28, PAGE 59
      DELH = 1.5*(VS*VS*D*D*TEMP/(4.*TS*UPL))**0.333333/S**0.166667
      IF (DHA.LT.DELH) DELH = DHA
125   H = HPRM+DELH
      RETURN
      END
```

```
      SUBROUTINE PROMPT (STRING,ANS,LOGPMT)

C  THIS ROUTINE WRITES STRING AND READS RESPONSE.

$     INCLUDE: 'IOUNIT.INC'
      CHARACTER*78 ANS
      CHARACTER*43 STRING
      CHARACTER*1 BLANK
      CHARACTER*45 PSTR
      LOGICAL LOGPMT
      EXTERNAL INDEXR

C  PUT APPROPRIATE PROMPT IN PSTR

      BLANK = ' '
      PSTR = '
      NN = INDEXR(STRING,'$')-1
      PSTR(1:NN) = STRING
      IF (LOGPMT) THEN
         PSTR(40:45) = '(Y/N)>'
      ELSE
         PSTR(45:45) = '>'
      ENDIF

C  BLANK OUT INPUT BUFFER

      ANS = ' '

C  WRITE PROMPT

100   WRITE (*,120) PSTR
      WRITE (IOECHO,120) PSTR

C  READ RESPONSE INTO INPUT BUFFER

      READ (*,125,END=100) ANS
      WRITE (IOECHO,125) ANS

C  MOVE FIRST NON-BLANK RESPONSE TO FIRST ENTRY OF INPUT BUFFER

      DO 115 I=1,30
         IF (ANS(1:1).EQ.BLANK) THEN
            DO 105 J=1,29
               ANS(J:J) = ANS(J+1:J+1)
105            CONTINUE
            ANS(30:30) = BLANK
         ELSE
            IF (ANS(1:4).EQ.'QUIT') GOTO 110
            IF (ANS(1:4).EQ.'quit') GOTO 110
            IF (ANS(1:4).EQ.'BYE ') GOTO 110
            IF (ANS(1:4).EQ.'bye ') GOTO 110
            IF (ANS(1:4).EQ.'EXIT') GOTO 110
```

```
          IF (ANS(1:4).EQ.'STOP') GOTO 110
          IF (ANS(1:4).EQ.'exit') GOTO 110
          IF (ANS(1:4).EQ.'stop') GOTO 110
          RETURN
110       CLOSE (UNIT=IOECHO)
          STOP
        ENDIF
115     CONTINUE

C  IF BLANK RESPONSE RETRY

      GOTO 100
120   FORMAT (1X,A45,\)
125   FORMAT (A30)
      END
```

```
      REAL FUNCTION RREAD(STRING)

C  THIS ROUTINE WRITES THE STRING 'STRING' AND PROMPTS THE
C  USER FOR A REAL.  THE ENTIRE SEQUENCE IS ECHOED TO LOGI-
C  CAL UNIT IOECHO, IF LECHO IS TRUE.

      CHARACTER*78 ANS
      CHARACTER*43 STRING
      CHARACTER*1 IOKAY(10)
      LOGICAL LBDP,LADP,LAEX,LTEST,LSIGN,LBDF
      DATA IOKAY/'1','2','3','4','5','6','7','8','9','0'/
100   CALL PROMPT (STRING,ANS,.FALSE.)
      RREAD = 0.0
      EXP = 0.0
      LBDP = .TRUE.
      LADP = .FALSE.
      LAEX = .FALSE.
      LTEST = .TRUE.
      RTENTH = 0.10
      LSIGN = .FALSE.
      LBDF = .TRUE.
      I1 = 1
      IF (ANS(1:1).EQ.'-'.OR.ANS(1:1).EQ.'+') I1 = 2
      DO 120 I=I1,30

C  BEFORE DECIMAL POINT

         IF (LBDP) THEN
            DO 105 J=1,10
               IF (IOKAY(J).EQ.ANS(I:I)) THEN
                  RREAD = RREAD*10+(ICHAR(ANS(I:I))-48)
                  GOTO 120
               ENDIF
105            CONTINUE
            IF (ANS(I:I).EQ.'.') THEN
               LBDP = .FALSE.
               LADP = .TRUE.
               GOTO 120
            ELSEIF (ANS(I:I).EQ.'E'.OR.ANS(I:I).EQ.'e') THEN
               LAEX = .TRUE.
               LADP = .FALSE.
               LBDP = .FALSE.
               GOTO 120
            ELSEIF (ANS(I:I).EQ.' ') THEN
               GOTO 125
            ELSE
               CALL OUT ('INPUT ERROR, TRY AGAIN (real)$')
               GOTO 100
            ENDIF
         ENDIF

C  AFTER DECIMAL POINT
```

```
          IF (LADP) THEN
             DO 110 J=1,10
                IF (IOKAY(J).EQ.ANS(I:I)) THEN
                   RREAD = RREAD+(ICHAR(ANS(I:I))-48)*RTENTH
                   RTENTH = RTENTH*0.10
                   GOTO 120
                ENDIF
110             CONTINUE
             IF (ANS(I:I).EQ.'E'.OR.ANS(I:I).EQ.'e') THEN
                LADP = .FALSE.
                LAEX = .TRUE.
                GOTO 120
             ELSEIF (ANS(I:I).EQ.' ') THEN
                GOTO 125
             ELSE
                CALL OUT (' INPUT ERROR, TRY AGAIN (0..9, E, e$')
                GOTO 100
             ENDIF
          ENDIF

C  AFTER EXPONENTIAL

          IF (LAEX) THEN
             IF (LTEST) THEN
                LTEST = .FALSE.
                IF (ANS(I:I).EQ.'+'.OR.ANS(I:I).EQ.'-') THEN
                   IF (ANS(I:I).EQ.'-') LSIGN = .TRUE.
                   GOTO 120
                ENDIF
             ENDIF
             DO 115 J=1,10
                IF (IOKAY(J).EQ.ANS(I:I)) THEN
                   EXP = EXP*10+(ICHAR(ANS(I:I))-48)
                   GOTO 120
                ENDIF
115             CONTINUE
             IF (ANS(I:I).EQ.' ') THEN
                GOTO 125
             ELSE
                CALL OUT (' INPUT ERROR, TRY AGAIN (Exx ?)$')
                GOTO 100
             ENDIF
          ENDIF
120       CONTINUE
125    IF (ANS(1:1).EQ.'-') RREAD = -RREAD
       IF (LSIGN) THEN
          RREAD = RREAD*10.0**(-EXP)
       ELSE
          RREAD = RREAD*10.0**(EXP)
       ENDIF
       RETURN
       END
```

```
      SUBROUTINE RUN
$     INCLUDE: 'INSEA.INC'
      VFP = VSP*PI*0.25*DP*DP
      KS = RKS
      ICASE = RICASE
      NSS = RNSS
      DO 100 J=1,MAXLAY
         DO 100 I=1,MAXCOL
            AVEC(J,I) = 0.0
100         CONTINUE
      IF (TIME.EQ.0.0) THEN
         DO 105 I=1,MAXCOL
            DO 105 J=1,MAXLAY
               T(J,I) = 0.0
105            CONTINUE
         TDIS = 0.0
         CALL DEBUG ('DEPT')
         CALL VELOCI
         CALL DEBUG ('VELO')

C  CLOCK PARAMETERS

         DO 110 I=1,MAXLAY
            IF (VEL(I)+DRIFT.GT.0.0) THEN
               FUNDTS(I) = REACH/(MAXCOL*(VEL(I)+DRIFT))
            ELSE
               FUNDTS(I) = RELBIG
            ENDIF
            PRTHRU(I) = 0.0
110         CONTINUE
         FUNDTS(MAXLAP) = 3600.0
         IF(FUNDTS(1).LT.3600.0) THEN
            CALL OUT('SURFACE LAYER MOVES MORE FREQUENTLY THAN$')
            CALL OUT('ATMOSPHERIC DEPOSITION$')
            CALL OUT('THIS MAY BIAS RESULTS$')
         ENDIF

         ISTEP = 3600
         CALL DEBUG ('CLOC')

C  DEFINE DISPERSION TERMS

         IF (MAXLAY.NE.1) THEN
            DO 115 I=1,MAXLAY
               DISP(I) = DISPER*VEL(I)+DIFFUS
115            CONTINUE
            DO 120 I=2,MAXLAY-1
               A(I) = 2*SQRT(DISP(I)*DISP(I-1)/(DD(I)*DD(I-1)))
               C(I) = 2*SQRT(DISP(I+1)*DISP(I)/(DD(I)*DD(I+1)))
120            CONTINUE
            A(MAXLAY) = 2*SQRT(DISP(MAXLAY)*DISP(MAXLAY-1)/(DD(MAXLAY)*D
     &      D(MAXLAY-1)))
```

```
      C(1) = 2*SQRT(DISP(2)*DISP(1)/(DD(1)*DD(2)))
   ENDIF
   CALL DEBUG ('DISP')
   CALL AIRLWV
   LNEW = .FALSE.
   CALL OUT ('START SIMULATION::$')
ELSE
   CALL OUT ('CONTINUE SIMULATION::$')
ENDIF
CALL DRIVER
RETURN
END
```

```
      SUBROUTINE SHIPLV
$     INCLUDE: 'INSEA.INC'

      CHARACTER*13 RR,RL
      RR = ' MOVING RIGHT'
      RL = ' MOVING LEFT '
      IF(ICASE.EQ.1) THEN
C
           SET LINE SOURCE PARAMETERS

           IF(DIRC.EQ.1.0) THEN
C
           SHIP MOVES TO LEFT

              HE = HEL
              WIND = WINDL
              IF (ITIME.EQ.0) WRITE(IOECHO,105) RL
           ELSE
C
           SHIP MOVES TO RIGHT

              HE = HER
              WIND = WINDR
              IF (ITIME.EQ.0) WRITE(IOECHO,105) RR
          ENDIF
      ELSE
          IF (ITIME.EQ.0) WRITE(IOECHO,105)
      ENDIF
C
      Deposition Computation . . .

      FRAC = 1.0
      XSTP = DIST(2)-DIST(1)
      DREM = 0
      DO 100 ID = 1,MAXCOL
           CDIS = DIST(ID)/1000.
           FRAL = FRAC
C
           COMPUTE FOR DISTANCES OF 200 M OR GREATER

           IF (CDIS.GE.0.200) THEN
                CALL PGSIG (CDIS,CDIS,KSK,SYT,SZT)
                HL8 = .8*HL
                IF (SZT.GE.HL8) SZT = HL8
                YFAC = EXP(-0.5*YE*YE/(SYT*SYT))
                XTEST = -0.5*HE*HE/(SZT*SZT)
                IF (XTEST.GT.-35.) THEN
                  ZFAC = EXP(-0.5*HE*HE/(SZT*SZT))
                ELSE
                  ZFAC = 0.0
                ENDIF
```

```
                IF (ID.EQ.1) THEN
                    DREM = CDIS*1000./SZT*ZFAC
                ELSE
                    DREM = DREM+XSTP/SZT*ZFAC
                ENDIF
                FWET = (EXP(-SCAVC*DIST(ID)/WIND))
                FDRY = (EXP(-.7979*DREM*DEPVEL/WIND))
                FRAC = FDRY*FWET
                CONSUR = FRAL*SOUR*CON1/(SZT*SYT*WIND)*ZFAC*YFAC
                DEP(ID) = (FRAL*SCAVC*SOUR/(CON1*SYT*WIND)*YFAC
     +                 +CONSUR*DEPVEL)*AIRTME
                DEPTOT(ID) = DEP(ID)
                IF (ITIME.EQ.0) WRITE(IOECHO,110)
     +          DIST(ID),CONSUR,DEPTOT(ID),FDRY,FWET,FRAC
            ELSE
                WRITE (*,*)' CHECK CDIS IN SHIPLV'
            ENDIF
100         CONTINUE
      RETURN
105   FORMAT(' Table of Atmospheric Values:',A
     +/'  DIST(M)    SURC(G/M3) D(G/M2/HR)   DRYF   WETF  TOTAL')
110   FORMAT(1X,3G11.4,3F7.4)

      END


      SUBROUTINE SLINE (N)
C  ****************************************************************
$     INCLUDE: 'IOUNIT.INC'
      IF (N.LT.1.OR.N.GT.10) N = 1
      DO 100 I=1,N
         WRITE (*,105)
         WRITE (IOECHO,105)
100      CONTINUE
      RETURN
105   FORMAT (70('*'))
      END
```

```
C   ***************************************************************
      SUBROUTINE SPACE (N)
C   ***************************************************************
$     INCLUDE: 'IOUNIT.INC'
      DO 100 I=1,N
         WRITE (*,105)
         WRITE (IOECHO,105)
100      CONTINUE
      RETURN
105   FORMAT (/)
      END
```

```
      SUBROUTINE TPRINT
C  INSEA VERSION 041186
$     INCLUDE: 'INSEA.INC'
      LOGICAL CONTIN
      CHARACTER*20 NAME
      CHARACTER*70 STITLE
      CHARACTER*7 TYP(2)
      TYP(2) = 'CHRONIC'
      TYP(1) = ' ACUTE '
C  PRINT TABLE OF ALLOWABLE FEED RATES
      FEEDRA = RREAD('Enter Incinerator Feed Rate (l/min)$')
      ICALL = 0
      CFACT = 1.0E9/FEEDRA/60./24.
100   RMAXC = 0.0
      RMAXAC = 0.0
      TOTALD = 0.0
105   CALL OUT ('Specify Water Concentration as:$')
      CALL OUT ('  1  Average of Entire Domain$')
      CALL OUT ('  2  Maximum Surface$')
      CALL OUT ('  3  Average Surface$')
      CALL OUT ('  4  User Specified$')
      ICASE = IREAD('Enter Selection$')
      IF (ICASE.LE.0.OR.ICASE.GE.5) GOTO 105
      TOTALD = 0.0
      IF (ICASE.EQ.2) THEN
         DO 110 I=1,MAXCOL
            RMAXAC = MAX(RMAXAC,AVEC(1,I))
110         CONTINUE
      ELSEIF (ICASE.EQ.3) THEN
         DO 115 I=1,MAXCOL
            RMAXAC = AVEC(1,I)+RMAXAC
115         CONTINUE
         RMAXAC = RMAXAC/MAXCOL
      ELSEIF (ICASE.EQ.1) THEN
         DO 120 I=1,MAXLAY
            TOTALD = TOTALD+DD(I)
120         CONTINUE
         DO 125 J=1,MAXLAY
            FACT = DD(J)/TOTALD
            DO 125 I=1,MAXCOL
               RMAXAC = RMAXAC+AVEC(J,I)*FACT
125            CONTINUE
         RMAXAC = RMAXAC/MAXCOL
      ELSE
         ML = IREAD('NUMBER OF LAYERS TO AVERAGE OVER$')
         MC = IREAD('NUMBER OF COLUMNS TO AVERAGE OVER$')
         DO 130 J=1,ML
            TOTALD = TOTALD+DD(J)
130         CONTINUE
         DO 135 J=1,ML
            FACT = DD(J)/TOTALD
            DO 135 I=1,MC
```

```
            RMAXAC = RMAXAC+AVEC(J,I)*FACT
135         CONTINUE
         RMAXAC = RMAXAC/MC
      ENDIF
      IF (RMAXAC.EQ.0.0) THEN
         CALL OUT ('NO TABLE; ZERO CONCENTRATIONS$')
         RETURN
      ENDIF
      ICASEP = ICASE
140   CALL OUT ('CRITERIA TO BE USED$')
      CALL OUT ('  1  ACUTE$')
      CALL OUT ('  2  CHRONIC$')
      ICASE = IREAD('SELECTION$')
      IF (ICASE.LE.0.OR.ICASE.GT.2) GOTO 140
      OPEN (UNIT=IOSTND,FILE=FILE4,STATUS='OLD')
      OPEN (UNIT=IOPRNT,FILE=FILE1,STATUS='UNKNOWN')
      IF (ICALL.EQ.0) CALL LIST (IOPRNT)
      ICALL = 1
      READ (IOSTND,155) STITLE
      WRITE (IOPRNT,160) TITLE
      WRITE (IOPRNT,165) TYP(ICASE)
      I = 0
145   READ (IOSTND,170,END=150) NAME,STANDA,STANDC,DESTRC
      I = I+1
      QMXA = (STANDA/(RMAXAC*(1.0-DESTRC/100.0)))*0.0000864
      QMXC = QMXA*STANDC/STANDA
      IF (ICASE.EQ.1) WRITE (IOPRNT,175) NAME,STANDA,QMXA*CFACT,DESTRC
      IF (ICASE.EQ.2) WRITE (IOPRNT,175) NAME,STANDC,QMXC*CFACT,DESTRC
      GOTO 145
150   WRITE (IOPRNT,180)
      IF (ICASEP.EQ.1) WRITE (IOPRNT,*) ' Average over entire domain'
      IF (ICASEP.EQ.2) WRITE (IOPRNT,*) ' Maximum surface concentration'
      IF (ICASEP.EQ.3) WRITE (IOPRNT,*) ' Average surface concentration'
      IF (ICASEP.EQ.4) WRITE (IOPRNT,*) ' Average over specified domain'
      IF (ICASE.EQ.1) WRITE (IOPRNT,185) 'acute',FEEDRA
      IF (ICASE.EQ.2) WRITE (IOPRNT,185) 'chronic',FEEDRA
      WRITE (IOPRNT,*) ' ',STITLE
      IF (YE.GT.0.0) THEN
         WRITE (IOPRNT,190) '  Based on deposition computed at an offset
     &    distance of ',YE,' m'
      ELSE
         WRITE (IOPRNT,190) '  Based on deposition computed at plume cen
     &   terline'
      ENDIF
      CLOSE (UNIT=IOSTND)
      CLOSE (UNIT=IOPRNT)
      CONTIN = LREAD('ANOTHER TABLE$')
      IF (CONTIN) GOTO 100
      RETURN
155   FORMAT (A70)
160   FORMAT ('1TITLE: ',A40)
165   FORMAT (' ',60('-')/,27X,A,4X,'MAXIMUM',/'  CONTAMINANT',14X,'STAN
```

```
     &DARD    FEED CONC',2X,'DESTRUCTION',/,'     NAME',19X,'(ug/l)',6X,
     &'(mg/l)    EFFICIENCY',/,' ',60('='))
170   FORMAT (A20,3F10.0)
175   FORMAT (2X,A20,'  ',G11.3,'  ',G11.3,'    ',F7.4)
180   FORMAT (' ',60('-'))
185   FORMAT ('  Computed using ',A,' criteria and feed rate of ',G10.4,
     &' l/min')
190   FORMAT (A,F7.0,A)
      END
```

```
      SUBROUTINE VELOCI
C  ROUTINE TO CALCULATE VELOCITY PROFILES IN A WATER COLUMN
C  DUE TO WIND SHEAR .

$     INCLUDE: 'INSEA.INC'
      EQUIVALENCE (ZA,ANHGT)
      EQUIVALENCE (WSPEED,WSPD)
      EQUIVALENCE (TAU,SHR)
      PARAMETER (AMU = 1.768E-5)
      PARAMETER (ARHO = 1.3534)
      PARAMETER (WRHO = 1025.75)
      PARAMETER (WMU = 1.6E-3)
      PARAMETER(OMEGA=0.729E-04)

C  CALCULATE SHEAR STRESS AT WATER SURFACE
C  IF WIND SPEED IS LESS THAN 6 M/SEC, SOLVE FOR SURFACE SHEAR
C  USING VON KARMAN EXPRESSION.  OTHERWISE, SOLVE USING EKMAN
C  EXPRESSION.

C  VON KARMAN EXPRESSION IS SOLVED ITERATIVELY USING NEWTON'S
C  METHOD.  INITIAL VALUE OF SURFACE SHEAR USED IS 0.001 KG/M-SEC**2.
C  100 ITERATIONS ARE ALLOWED FOR SOLUTION.

      IF (WSPEED.NE.0.0) THEN
         IF (WSPEED.LT.6.0) THEN

C  VON KARMAN SOLUTION FOR SHEAR

C  INITIAL VALUES FOR ITERATIVE SOLUTION

            SHR1 = 0.001
            BB = ZA*ARHO/AMU
            A1 = SQRT(SHR1/ARHO)

C  LOOP THROUGH ITERATIVE SOLUTION

            DO 100 I=1,100
               V1 = 5.5*A1+(5.75*A1*ALOG10(A1*BB))

C  CHECK FOR CONVERGENCE.  SOLUTION GOOD IF LESS THAN 0.1% DIFFERENCE

               IF (ABS((WSPEED-V1)/WSPEED).LT.0.001) THEN
                  SHR = ARHO*A1**2.
                  GOTO 105
               ENDIF
               V1PRM = 8.0+5.75*(ALOG10(BB)+ALOG10(A1))
               A2 = ((WSPEED-V1)/V1PRM)+A1
               A1 = A2
100            CONTINUE

C  IF THROUGH LOOP THEN SOLUTION NOT REACHED.  WRITE OUT ERROR
```

```
C  MESSAGE

            CALL OUT ('*VEL DID NOT CONVERGE AFTER 100 ITERATIONS$')
            GOTO 105
         ELSE

C  EKMAN SOLUTION


            SHR = 2.6E-03*ARHO*WSPEED*WSPEED
         ENDIF

105      CONTINUE

C  CHECK FOR ERROR AND STOP IF ERROR

         IF (TAU.EQ.0.) THEN
            CALL OUT ('TAU = 0.0$')
            STOP
         ENDIF

C  WRITE OUT SHEAR RESULTS

         IF (WSPEED.LT.6.) THEN
            WRITE (IOECHO,*) 'WIND SHEAR CALCULATED USING METHOD OF VON
     &      KARMAN'
         ELSE
            WRITE (IOECHO,*) 'WIND SHEAR CALCULATED USING METHOD OF EKMA
     &      N$'
         ENDIF

C  A IS EDDY VISCOSITY.  CALCULATE 2 WAYS DEPENDING ON WIND SPPEED

         IF (WSPEED.LT.6.) AA = 0.1*1.02*WSPEED**3.
         IF (WSPEED.GE.6.) AA = 0.1*4.3*WSPEED*WSPEED

C  CALCULATE WATER VELOCITY AT SURFACE DUE TO WIND SHEAR

         VO = TAU/(SQRT(WRHO*AA*2.*OMEGA*SIN(RLAT*0.017453293)))

C  D IS DEPTH OF FRICTIONAL RESISTANCE

         DFR = PI*SQRT(AA/(WRHO*OMEGA*SIN(RLAT*0.017453293)))

C  LOOP THROUGH DEPTH OF WATER COLUMN AND CALCULATE
C  WATER VELOCITY

         DTOT = DD(1)*0.5
         DO 110 I=1,MAXLAY
            IF (DTOT.GT.DFR) THEN
               VEL(I) = 0.0
            ELSE
```

```
            VEL(I) = VO*EXP(-PI*DTOT/DFR)
            DTOT = DTOT+DD(I+1)
         ENDIF
110      CONTINUE
     ELSE
       DO 115 I=1,MAXLAY
         VEL(I) = 0.0
115      CONTINUE
     ENDIF
     RETURN
     END
```

```
C  *****************************************************
      SUBROUTINE WCLOCK (SCLKS)
$     INCLUDE: 'IOUNIT.INC'
      PARAMETER (SECDY=86400.0)
      PARAMETER (SECHR=3600.0)
      PARAMETER (SECMN=60.0)
      S = SCLKS
      IDAY = INT(S/SECDY)
      S = MOD(S,SECDY)
      IHR = INT(S/SECHR)
      S = MOD(S,SECHR)
      IMIN = INT(S/SECMN)
      S = MOD(S,SECMN)
      WRITE (*,100) IDAY,IHR,IMIN,S
      RETURN
100   FORMAT (1H+,'      SIMULATION TIME:',I6,' days ',I2,' hrs ',I2,' m
     &in ',F5.2,' sec')
      END
```

```
      SUBROUTINE WINDC (KS,U,ANHGT,USTAR,ZO)

C  SUBPROGRAM ABSTRACT:  WINDC / VER 02-18-1986
C  THIS SUBROUTINE WITH WINDP ALLOWS
C  COMPUTATION OF THE WIND SPEED FOR VARIOUS
C  HEIGHTS OVER A WATER SURFACE.  WINDP DOES A
C  WIND HEIGHT CORRECTION BASED ON USTAR AND ZO
C  COMPUTED IN THIS ROUTINE, JG DROPPO

C  NOTE: U is wind speed at 10m.

      DIMENSION OV(6),PM(3)
      DATA OV/ -.6,-.28,-.03,0.0,.12,.3/
      DATA PM/ 0.2,0.4,0.7/
      NIR = 10
C  Define intial values for turbulence parameters
      USTAR = U*(.0012)**.5
      ZO = .0144*USTAR*USTAR/9.8
      OVRL = OV(KS)
C  Compute new wind speed
      IF (KS.LT.4) THEN
         PHIM = PM(KS)
         U1 = -2*ALOG(.5*(1+1/PHIM))
         U2 = -1*ALOG(.5*(1+1/PHIM/PHIM))
         U3 = 2*ATAN(1/PHIM)-3.1415/2
         DO 100 I=1,NIR
            UNEW = USTAR/.4*(ALOG(ANHGT/ZO)+U1+U2+U3)
            STAR = USTAR*(1+(U-UNEW)/(U+UNEW)*2)
            IF (STAR.LE.0.0) THEN
               USTAR = USTAR*0.9
            ELSE
               USTAR = STAR
            ENDIF
            ZO = .0144*USTAR*USTAR/9.8
100         CONTINUE
      ELSE
         DO 105 I=1,NIR
            UNEW = (USTAR/.4)*(ALOG(ANHGT/ZO)+5.0*ANHGT*OVRL)
            STAR = USTAR*(1+(U-UNEW)/(U+UNEW)*2)
            IF (STAR.LE.0.0) THEN
               USTAR = USTAR*0.9
            ELSE
               USTAR = STAR
            ENDIF
            ZO = .0144*USTAR*USTAR/9.8
105         CONTINUE
      ENDIF
      RETURN
      END
```

```
      SUBROUTINE WINDP (KS,UNEW,PHGT,USTAR,ZO)
C  SUBPROGRAM ABSTRACT:  WINDP / VER 02-18-1986
C  WINDP IS A SUBROUTINE FOR COMPUTING THE
C  WIND SPEED FOR AS A FUNCTION OF HEIGHT
C  OVER A WATER SURFACE.  THIS USES WIND HEIGHT
C  CORRECTION BASED ON USTAR AND ZO, JG DROPPO

      DIMENSION OV(6),PM(3)
      DATA OV/ -.6,-.28,-.03,0.0,.12,.3/
      DATA PM/ 0.2,0.4,0.7/
      OVRL = OV(KS)
C  Compute new wind speed
      IF (KS.LT.4) THEN
         PHIM = PM(KS)
         U1 = -2*ALOG(.5*(1+1/PHIM))
         U2 = -1*ALOG(.5*(1+1/PHIM/PHIM))
         U3 = 2*ATAN(1/PHIM)-3.1415/2
         UNEW = USTAR/.4*(ALOG(PHGT/ZO)+U1+U2+U3)
      ELSE
         UNEW = (USTAR/.4)*(ALOG(PHGT/ZO)+5.0*PHGT*OVRL)
      ENDIF
      RETURN
      END
```

APPENDIX B

ECHO.FIL FILE

APPENDIX B

ECHO.FIL FILE

The ECHO.FIL file provides a copy of the interactive session. This provides the user the ability to clearly document their modeling activities. The following file was generated by the example run discussed in Section 2.3.

```
                    INSEA - INCINERATION AT SEA MODEL

TITLE OF RUN                                  >example
          DEFAULT CASE MENU

===============================================


CASE  1  Point Source, Centerline Values, Precipitation Conditions
CASE  2  Point Source, Centerline Values, Non-precipitation Conditions
CASE  3  Point Source, Offset From Centerline Values, Precipitation Condit
CASE  4  Point Source, Offset From Centerline Values, Non-precipitation Co
CASE  5  Line Source, Centerline, Precipitation Conditions
CASE  6  Line Source, Centerline, Non-precipitation Conditions
CASE  7  Line Source, Offset From Centerline Values, Precipitation Conditi
CASE  8  Line Source, Offset From Centerline Values, Non-precipitation Con

SELECT CASE NUMBER                            >3


               PARAMETER LIST
     TITLE: example
******************* SHIP PARAMETERS ********************
POInt source
**************** INCINERATOR PARAMETERS ****************
NUMber of incinerators             3
HEIght of stack                   12.0      METERS
VELocity of stack emission          15.     METERS/SEC
TEMperature of stack emissions    1429.     DEGREES C
DIAmeter of stack                  3.2      METERS
MINimum air speed past stack   1.5          METERS/SEC
**************** ATMOSPHERIC PARAMETERS ****************
STAbility class                   D
WINd speed                          1.5     METERS/SEC
AIR temperature                     10.     DEGREES C
MIXing height                      500.     METERS
WET scavenging coefficient         .15E-03  1/SEC
```

```
DRY deposition velocity            .30E-01  METERS/SEC
OFFset from plume centerline       100.     METERS
******************** OCEAN PARAMETERS ********************
REGional current velocity         .00      METERS/SEC
DIFfusion coefficient             .50E-03  SQ. METERS/SEC
DISpersivity                      .00      METERS
LATitude                          26.      DEGREES
LENgth of ocean simulated         10.      KILOMETERS
GRId spacing                      DEFAULT
CHANGE PARAMETERS                       (Y/N)>y
Enter Parameter Keyword (or HELP)           >wind
WIND SPEED IN METERS/SEC                    >2.0
CHANGE ANOTHER PARAMETER                (Y/N)>n


                PARAMETER LIST
         TITLE: example
******************* SHIP PARAMETERS ********************
POInt source
**************** INCINERATOR PARAMETERS *****************
NUMber of incinerators             3
HEIght of stack                   12.0      METERS
VELocity of stack emission           15.    METERS/SEC
TEMperature of stack emissions   1429.      DEGREES C
DIAmeter of stack                  3.2      METERS
MINimum air speed past stack   1.5          METERS/SEC
***************** ATMOSPHERIC PARAMETERS ****************
STAbility class                   D
WINd speed                          2.0     METERS/SEC
AIR temperature                     10.     DEGREES C
MIXing height                      500.     METERS
WET scavenging coefficient         .15E-03  1/SEC
DRY deposition velocity            .30E-01  METERS/SEC
OFFset from plume centerline       100.     METERS
******************** OCEAN PARAMETERS *******************
REGional current velocity         .00      METERS/SEC
DIFfusion coefficient             .50E-03  SQ. METERS/SEC
DISpersivity                      .00      METERS
LATitude                          26.      DEGREES
LENgth of ocean simulated         10.      KILOMETERS
GRId spacing                      DEFAULT
NUMBER OF COLUMNS IN OCEAN GRID = 70
NUMBER OF LAYERS IN OCEAN GRID    = 14
LAYER  1 THICKNESS OF LAYER  1.00 METERS
LAYER  2 THICKNESS OF LAYER  1.00 METERS
LAYER  3 THICKNESS OF LAYER  1.00 METERS
LAYER  4 THICKNESS OF LAYER  1.00 METERS
LAYER  5 THICKNESS OF LAYER  1.00 METERS
LAYER  6 THICKNESS OF LAYER  1.00 METERS
LAYER  7 THICKNESS OF LAYER  1.00 METERS
LAYER  8 THICKNESS OF LAYER  1.00 METERS
```

```
LAYER  9 THICKNESS OF LAYER  1.00 METERS
LAYER 10 THICKNESS OF LAYER  1.00 METERS
LAYER 11 THICKNESS OF LAYER  1.00 METERS
LAYER 12 THICKNESS OF LAYER  1.00 METERS
LAYER 13 THICKNESS OF LAYER  1.00 METERS
LAYER 14 THICKNESS OF LAYER  1.00 METERS
NUMBER OF HOURS TO BE SIMULATED          >240
 DEBUG DATA  DEPTH
 LAYER :              1 DEPTH :        1.0000000
 LAYER :              2 DEPTH :        1.0000000
 LAYER :              3 DEPTH :        1.0000000
 LAYER :              4 DEPTH :        1.0000000
 LAYER :              5 DEPTH :        1.0000000
 LAYER :              6 DEPTH :        1.0000000
 LAYER :              7 DEPTH :        1.0000000
 LAYER :              8 DEPTH :        1.0000000
 LAYER :              9 DEPTH :        1.0000000
 LAYER :             10 DEPTH :        1.0000000
 LAYER :             11 DEPTH :        1.0000000
 LAYER :             12 DEPTH :        1.0000000
 LAYER :             13 DEPTH :        1.0000000
 LAYER :             14 DEPTH :        1.0000000
WIND SHEAR CALCULATED USING METHOD OF VON       KARMAN
 DEBUG DATA  VELOCITY
 LAYER :              1 VELOCITY :   2.019621E-002
 LAYER :              2 VELOCITY :   1.652817E-002
 LAYER :              3 VELOCITY :   1.352632E-002
 LAYER :              4 VELOCITY :   1.106966E-002
 LAYER :              5 VELOCITY :   9.059187E-003
 LAYER :              6 VELOCITY :   7.413855E-003
 LAYER :              7 VELOCITY :   6.067347E-003
 LAYER :              8 VELOCITY :   4.965394E-003
 LAYER :              9 VELOCITY :   4.063577E-003
 LAYER :             10 VELOCITY :   3.325549E-003
 LAYER :             11 VELOCITY :   2.721562E-003
 LAYER :             12 VELOCITY :   2.227271E-003
 LAYER :             13 VELOCITY :   1.822753E-003
 LAYER :             14 VELOCITY :   1.491704E-003
 DEBUG DATA  CLOCK
 LAYER :              1 FUNTS :       7073.4610000
 LAYER :              2 FUNTS :       8643.2510000
 LAYER :              3 FUNTS :      10561.4200000
 LAYER :              4 FUNTS :      12905.2800000
 LAYER :              5 FUNTS :      15769.3100000
 LAYER :              6 FUNTS :      19268.9400000
 LAYER :              7 FUNTS :      23545.2400000
 LAYER :              8 FUNTS :      28770.5600000
 LAYER :              9 FUNTS :      35155.5100000
 LAYER :             10 FUNTS :      42957.4600000
 LAYER :             11 FUNTS :      52490.8700000
 LAYER :             12 FUNTS :      64140.0000000
 LAYER :             13 FUNTS :      78374.3900000
```

```
LAYER :              14 FUNTS :      95767.7600000
DEBUG DATA  DISPERSION
LAYER :               1 DISP:   5.000000E-004
LAYER :               2 DISP:   5.000000E-004
LAYER :               3 DISP:   5.000000E-004
LAYER :               4 DISP:   5.000000E-004
LAYER :               5 DISP:   5.000000E-004
LAYER :               6 DISP:   5.000000E-004
LAYER :               7 DISP:   5.000000E-004
LAYER :               8 DISP:   5.000000E-004
LAYER :               9 DISP:   5.000000E-004
LAYER :              10 DISP:   5.000000E-004
LAYER :              11 DISP:   5.000000E-004
LAYER :              12 DISP:   5.000000E-004
LAYER :              13 DISP:   5.000000E-004
LAYER :              14 DISP:   5.000000E-004
Combined air/sea deposition velocity =   .142E-02 m/s
for friction velocity, U* =   .546E-01 m/s
and roughness length, zo  =   .439E-05m.
Table of Atmospheric Values:
```

200.0	.0000	.3676E-10	1.0000	.9876	.9876
342.9	.0000	.9695E-05	1.0000	.9789	.9789
485.7	.0000	.2591E-03	1.0000	.9702	.9702
628.6	.0000	.9265E-03	1.0000	.9616	.9616
771.4	.0000	.1671E-02	1.0000	.9531	.9531
914.3	.0000	.2250E-02	1.0000	.9447	.9447
1057.	.0000	.2625E-02	1.0000	.9363	.9363
1200.	.1401E-44	.2833E-02	1.0000	.9280	.9280
1343.	.3934E-39	.2924E-02	1.0000	.9198	.9198
1486.	.9349E-35	.2939E-02	1.0000	.9116	.9116
1629.	.2952E-31	.2904E-02	1.0000	.9036	.9036
1771.	.2107E-28	.2840E-02	1.0000	.8956	.8956
1914.	.4879E-26	.2758E-02	1.0000	.8876	.8876
2057.	.4737E-24	.2667E-02	1.0000	.8798	.8798
2200.	.2319E-22	.2571E-02	1.0000	.8720	.8720
2343.	.6563E-21	.2475E-02	1.0000	.8643	.8643
2486.	.1191E-19	.2380E-02	1.0000	.8566	.8566
2629.	.1499E-18	.2287E-02	1.0000	.8490	.8490
2771.	.1393E-17	.2198E-02	1.0000	.8415	.8415
2914.	.1004E-16	.2113E-02	1.0000	.8341	.8341
3057.	.5589E-16	.2031E-02	1.0000	.8267	.8267
3200.	.2461E-15	.1954E-02	1.0000	.8194	.8194
3343.	.9383E-15	.1880E-02	1.0000	.8121	.8121
3486.	.3158E-14	.1810E-02	1.0000	.8049	.8049
3629.	.9529E-14	.1744E-02	1.0000	.7978	.7978
3771.	.2613E-13	.1681E-02	1.0000	.7907	.7907
3914.	.6587E-13	.1622E-02	1.0000	.7837	.7837
4057.	.1540E-12	.1565E-02	1.0000	.7768	.7768
4200.	.3371E-12	.1511E-02	1.0000	.7699	.7699
4343.	.6950E-12	.1460E-02	1.0000	.7631	.7631
4486.	.1359E-11	.1412E-02	1.0000	.7563	.7563
4629.	.2531E-11	.1366E-02	1.0000	.7496	.7496

4771.	.4516E-11	.1322E-02	1.0000	.7430	.7430
4914.	.7746E-11	.1280E-02	1.0000	.7364	.7364
5057.	.1282E-10	.1240E-02	1.0000	.7299	.7299
5200.	.2054E-10	.1202E-02	1.0000	.7234	.7234
5343.	.3195E-10	.1166E-02	1.0000	.7170	.7170
5486.	.4837E-10	.1132E-02	1.0000	.7107	.7107
5629.	.7142E-10	.1098E-02	1.0000	.7044	.7044
5771.	.1031E-09	.1067E-02	1.0000	.6981	.6981
5914.	.1456E-09	.1036E-02	1.0000	.6920	.6920
6057.	.2018E-09	.1007E-02	1.0000	.6858	.6858
6200.	.2747E-09	.9794E-03	1.0000	.6798	.6798
6343.	.3676E-09	.9526E-03	1.0000	.6737	.6737
6486.	.4845E-09	.9269E-03	1.0000	.6678	.6678
6629.	.6293E-09	.9022E-03	1.0000	.6619	.6619
6771.	.8066E-09	.8785E-03	1.0000	.6560	.6560
6914.	.1021E-08	.8557E-03	1.0000	.6502	.6502
7057.	.1277E-08	.8337E-03	1.0000	.6444	.6444
7200.	.1580E-08	.8125E-03	1.0000	.6387	.6387
7343.	.1936E-08	.7922E-03	1.0000	.6331	.6331
7486.	.2348E-08	.7725E-03	1.0000	.6275	.6275
7629.	.2823E-08	.7536E-03	1.0000	.6219	.6219
7771.	.3366E-08	.7353E-03	1.0000	.6164	.6164
7914.	.3981E-08	.7176E-03	1.0000	.6110	.6110
8057.	.4673E-08	.7006E-03	1.0000	.6055	.6055
8200.	.5447E-08	.6841E-03	1.0000	.6002	.6002
8343.	.6307E-08	.6682E-03	1.0000	.5949	.5949
8486.	.7257E-08	.6527E-03	1.0000	.5896	.5896
8629.	.8301E-08	.6378E-03	1.0000	.5844	.5844
8771.	.9441E-08	.6234E-03	1.0000	.5792	.5792
8914.	.1068E-07	.6094E-03	1.0000	.5741	.5741
9057.	.1202E-07	.5959E-03	1.0000	.5690	.5690
9200.	.1347E-07	.5828E-03	1.0000	.5640	.5640
9343.	.1502E-07	.5701E-03	1.0000	.5590	.5590
9486.	.1667E-07	.5577E-03	1.0000	.5540	.5540
9629.	.1843E-07	.5458E-03	1.0000	.5491	.5491
9771.	.2030E-07	.5341E-03	1.0000	.5442	.5442
9914.	.2228E-07	.5229E-03	1.0000	.5394	.5394
.1006E+05	.2429E-07	.5119E-03	1.0000	.5346	.5346

Stationary operation with 500. m plume r ise.
Wind speed at plume height = 2.41 m/s
Wind speed at 10 m = 2.00 m/s

9.312927E-002	3.675564E-011	9.694654E-006	2.590923E-004	9.265162E-004
1.671293E-003	2.250367E-003	2.624593E-003	2.832879E-003	2.924382E-003
2.938808E-003	2.904311E-003	2.839843E-003	2.757876E-003	2.666522E-003
2.571013E-003	2.474691E-003	2.379662E-003	2.287216E-003	2.198110E-003
2.112748E-003	2.031308E-003	1.953817E-003	1.880209E-003	1.810359E-003
1.744108E-003	1.681278E-003	1.621684E-003	1.565140E-003	1.511465E-003
1.460484E-003	1.412029E-003	1.365944E-003	1.322081E-003	1.280300E-003
1.240472E-003	1.202478E-003	1.166205E-003	1.131549E-003	1.098413E-003
1.066707E-003	1.036348E-003	1.007258E-003	9.793657E-004	9.526032E-004
9.269082E-004	9.022229E-004	8.784925E-004	8.556669E-004	8.336988E-004
8.125443E-004	7.921617E-004	7.725130E-004	7.535618E-004	7.352742E-004

```
  7.176186E-004  7.005650E-004  6.840855E-004  6.681538E-004  6.527450E-004
  6.378359E-004  6.234046E-004  6.094298E-004  5.958924E-004  5.827736E-004
  5.700560E-004  5.577230E-004  5.457590E-004  5.341489E-004  5.228788E-004
  5.119345E-004
START SIMULATION::

Ocean concentrations in micrograms/liter/unit emission:
LAYER: 1 COL 1TO 5    .27E-07    .71E-02    .19E+00    .76E+00    .16E+01
LAYER: 2 COL 1TO 5    .22E-07    .58E-02    .16E+00    .64E+00    .14E+01
LAYER: 1 COL 6TO10    .25E+01    .34E+01    .42E+01    .50E+01    .58E+01
LAYER: 2 COL 6TO10    .22E+01    .30E+01    .38E+01    .46E+01    .53E+01
LAYER: 1 COL11TO15    .65E+01    .71E+01    .77E+01    .83E+01    .89E+01
LAYER: 2 COL11TO15    .60E+01    .67E+01    .73E+01    .79E+01    .85E+01
LAYER: 1 COL16TO20    .94E+01    .99E+01    .10E+02    .11E+02    .11E+02
LAYER: 2 COL16TO20    .91E+01    .96E+01    .10E+02    .11E+02    .11E+02
LAYER: 1 COL21TO25    .12E+02    .12E+02    .13E+02    .13E+02    .13E+02
LAYER: 2 COL21TO25    .11E+02    .12E+02    .12E+02    .13E+02    .13E+02
LAYER: 1 COL26TO30    .14E+02    .14E+02    .14E+02    .15E+02    .15E+02
LAYER: 2 COL26TO30    .13E+02    .14E+02    .14E+02    .14E+02    .15E+02
LAYER: 1 COL31TO35    .15E+02    .16E+02    .16E+02    .16E+02    .16E+02
LAYER: 2 COL31TO35    .15E+02    .15E+02    .16E+02    .16E+02    .16E+02
LAYER: 1 COL36TO40    .16E+02    .16E+02    .16E+02    .16E+02    .16E+02
LAYER: 2 COL36TO40    .16E+02    .16E+02    .16E+02    .16E+02    .16E+02
LAYER: 1 COL41TO45    .16E+02    .16E+02    .16E+02    .16E+02    .16E+02
LAYER: 2 COL41TO45    .16E+02    .16E+02    .16E+02    .16E+02    .16E+02
LAYER: 1 COL46TO50    .16E+02    .15E+02    .15E+02    .15E+02    .14E+02
LAYER: 2 COL46TO50    .15E+02    .15E+02    .15E+02    .15E+02    .14E+02
LAYER: 1 COL51TO55    .14E+02    .14E+02    .13E+02    .13E+02    .13E+02
LAYER: 2 COL51TO55    .14E+02    .14E+02    .13E+02    .13E+02    .12E+02
LAYER: 1 COL56TO60    .12E+02    .12E+02    .12E+02    .11E+02    .11E+02
LAYER: 2 COL56TO60    .12E+02    .12E+02    .11E+02    .11E+02    .11E+02
LAYER: 1 COL61TO65    .11E+02    .10E+02    .99E+01    .96E+01    .94E+01
LAYER: 2 COL61TO65    .10E+02    .10E+02    .98E+01    .95E+01    .93E+01
**********************************************************************
PRINT FEED RATE TABLE                      (Y/N)>y
Enter Incinerator Feed Rate (l/min)             >175
Specify Water Concentration as:
  1  Average of Entire Domain
  2  Maximum Surface
  3  Average Surface
  4  User Specified

Enter Selection                                 >1
CRITERIA TO BE USED
  1  ACUTE
  2  CHRONIC
SELECTION                                       >2
ANOTHER TABLE                              (Y/N)>n
PRINT ECHO FILE                            (Y/N)>n
PLOT AQUATIC CONCENTRATION DATA            (Y/N)>n
CONTINUE SIMULATION                        (Y/N)>n
```

APPENDIX C

STANDARD.DAT FILE

APPENDIX C

STANDARD.DAT FILE

The STANDARD.DAT File contains the names, chronic standards, acute standards, and destruction efficiencies for each constituent of concern. By using an editor this file can be modified to add, delete, or alter the present standards data.

CRITERIA PROVIDED BY EPA			
Aluminum	1500.	200.	0.0
Arsenic	69.	36.	0.0
Cadmium	43.	9.3	0.0
Chlorine	16300.	16300.	0.0
Chromium III	10300.	10300.	0.0
Chromium VI	1100.	50.	0.0
Copper	2.9	2.9	0.0
Lead	140.	5.6	0.0
Mercury	2.1	0.025	0.0
Nickel	140.	7.1	0.0
Selenium	410.	54.	0.0
Silver	2.3	0.023	0.0
Thallium	2.13	0.02	0.0
Tin	0.7	0.7	0.0
Zinc	170.	58.	0.0
Cyanide	1.0	0.01	0.0
Dioxin	.01	0.00001	99.9999
DDT	.13	0.001	99.99
PCBs	10.	0.03	99.9999
Dichloroethane	113000.	1130.	99.99
Trichloroethane	31200.	312.	99.99
Tetrachloroethane	9020.	90.	99.99
Hexachloroethane	940.	9.4	99.99
Chlorobenzenes	160.	130.	99.99
Halomethanes	12000.	6400.	99.99
Carbon Tetrachloride	50000.	500.	99.99
Hexachlorobutadiene	32.	.32	99.99
Phenol	5800.	58.0	99.99

APPENDIX D

DEFAULT.DAT FILE

APPENDIX D

DEFAULT.DAT FILE

The DEFAULT.DAT File contains the names and parameter values for each of the default cases. This file can be tailored to the user's specific area of interest. The data is read in the following manner. For each case read

- o default case descriptor format(a65)
- o default case parameters - free formmatted read of following variables
  1 - dispersivity
  2 - diffusion coefficient
  3 - not used
  4 - not used
  5 - length of ocean simulated
  6 - latitude
  7 - ship speed
  8 - not used
  9 - wind speed
  10 - offset distance from centerline
  11 - minimum speed of air past stack
  12 - stability class (1-6)
  13 - height of stack
  14 - velocity of stack emissions
  15 - temperature of stack emissions
  16 - not used
  17 - height of mixing layer
  18 - 0 = point source 1 = line source
  19 - path length of line source
  20 - number of incinerators
  21 - air temperature
  22 - scavenging coefficient
  23 - deposition velocity
  24 - diameter of stack

```
Point Source, Centerline Values, Precipitation Conditions
0.0E-5,5.0E-4,0.5,1.1,10000.,26,1.5,0.1,1.5,0.0,1.5,4.0,12.0,15.2,1429.,
1.0,500,0.0,5000,3,283,1.5E-4,0.03,3.2
Point Source, Centerline Values, Non-precipitation Conditions
0.0E-5,5.0E-4,0.5,1.1,10000.,26,1.5,0.1,1.5,0.0,1.5,4.0,12.0,15.2,1429.,
1.0,500,0.0,5000,3,283,0.0,0.03,3.2
Point Source, Offset From Centerline Values, Precipitation Conditions
0.0E-5,5.0E-4,0.5,1.1,10000.,26,1.5,0.1,1.5,100,1.5,4.0,12.0,15.2,1429.,
1.0,500,0.0,5000,3,283,1.5E-4,0.03,3.2
Point Source, Offset From Centerline Values, Non-precipitation Conditions
0.0E-5,5.0E-4,0.5,1.1,10000.,26,1.5,0.1,1.5,100,1.5,4.0,12.0,15.2,1429.,
1.0,500,0.0,5000,3,283,0.0,0.03,3.2
Line Source, Centerline, Precipitation Conditions
0.0E-5,5.0E-4,0.5,1.1,20000.,26,1.5,0.1,1.5,0.0,1.5,4.0,12.0,15.2,1429.,
1.0,500,1.0,5000,3,283,1.5E-4,0.03,3.2
```

Line Source, Centerline, Non-precipitation Conditions
0.0E-5,5.0E-4,0.5,1.1,20000.,26,1.5,0.1,1.5,0.0,1.5,4.0,12.0,15.2,1429.,
1.0,500,1.0,5000,3,283,0.0,0.03,3.2
Line Source, Offset From Centerline Values, Precipitation Conditions
0.0E-5,5.0E-4,0.5,1.1,20000.,26,1.5,0.1,1.5,100,1.5,4.0,12.0,15.2,1429.,
1.0,500,1.0,5000,3,283,1.5E-4,0.03,3.2
Line Source, Offset From Centerline Values, Non-precipitation Conditions
0.0E-5,5.0E-4,0.5,1.1,20000.,26,1.5,0.1,1.5,100,1.5,4.0,12.0,15.2,1429.,
1.0,500,1.0,5000,3,283,0.0,0.03,3.2

APPENDIX E

<u>GRID.DAT FILE</u>

APPENDIX E

GRID.DAT FILE

The GRID.DAT contains the default specifications for the grid spacing data. This file can be modified to alter the defualt specifications. The file is free formatted with the following variables:

- number of columns in the ocean grid
- number of layers in the ocean grid
- thickness of each ocean layer

The following is the current GRID.DAT file.

70,14,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,2,2,2,2,2,4,

APPENDIX F

CONFIG.FIL FILE

APPENDIX F

CONFIG.FIL FILE

The CONFIG.FIL file contains the name of the devices used in INSEA. By editing this file you can reconfigure the program for your hardware. For instance, if your plotter is connected to the COM2 port, simply change the COM1 in the CONFIG.FIL file to COM2.

PRN	PRINTER
ECHO.FIL	ECHO FILE
COM1	PLOTTER
STANDARD.DAT	AQUATIC CRITERIA STANDARDS FILE
GRID.DAT	GRID SPACING FILE
DEFAULT.DAT	DEFAULT CASES DEFINITION FILE

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