# INCINERATION-AT-SEA

# RESEARCH STRATEGY

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U.S. Environmental Protection Agency
Office of Water

TABLE OF CONTENTS

## 1.0 INTRODUCTION

### 1.1 Previous Research

The Environmental Protection Agency (EPA) has been involved in ocean incineration research for over 10 years. Starting in 1974, a series of 4 research burns have been conducted under EPA permits to gather scientific information about the incineration of liquid hazardous wastes at sea and to evaluate ocean incineration as an alternative to various land based disposal options. These research burns were conducted under the authority of the Marine Protection, Research, and Sanctuaries Act of 1972, as amended, and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention).

The major objective of these research burns was to determine if the incinerator could be operated efficiently and could attain the minimum acceptable destruction efficiently (DE) required for the particular waste being incinerated. This determination was necessary because the permits were defined by incinerator operating conditions rather than being specific to the toxicities of the emissions. Environmental monitoring has been conducted and the emissions have been analyzed for specific products of incomplete combustion. Plumes have been followed and sampled by ships and planes in an effort to trace the dispersion of the emissions over the ocean, and marine water samples have been collected for analysis of possible emission constituents. Caged marine organisms have been exposed in the incinerator area to determine if any effects could be observed. No products of incomplete combustion (dioxins or furans) were identified in the emission samples and no potential toxic emission products were observed at elevated levels in the environment.

During these past ten years, the scientific community has developed several different methods for sampling incinerator emissions for DE. These basic procedures have been used in the ocean incineration research burns. The complexities of sampling at sea and the peculiarities of ocean incinerators has led to the use of modifications of the accepted land based methods. The research burn results indicated that incineration at sea could be a viable technology for destroying hazardous wastes. However, the previous studies did not address a number of questions and issues which have subsequently emerged. This research strategy is proposed to address these questions.

### 1.2 Relationship of This Strategy to Other Agency Activities

On May 22, 1984, the Agency decided not to grant special (i.e. operational) incineration-at-sea permits as requested by Chemical Waste Management and Ocean Combustion Services. That decision was based on:

(a) deficiencies in available information considered by the Agency in determining the need for incineration at sea;

(b) the lack of specific EPA regulations for incineration at sea; and

(c) the fact that the research permits recommended by EPA's Hearing Officer after a public hearing in Brownsville, Texas had never been the subject of a tentative determination, of a public hearing, or of public comment.

While the requested special permits were denied, future use of incineration at sea was not ruled out. Rather, EPA deferred permit issuance until completion of a more deliberative approach for ocean incineration. To that end, EPA began development of a research strategy that would respond to the needs of the program and to propose specific regulations for ocean incineration.

EPA is currently developing specific regulations by applying the Agency's experience with land-based incineration facilities and ocean incineration vessels. In addition, as a Contracting Party to the London Dumping Convention (LDC), EPA is bound by the LDC "Regulations for the Control of Incineration of Waste and Other Matter at Sea" (Regulations) and is required "to take full account of" the "Technical Guidelines" implementing the Regulations to the extent the requirements of the Marine Protection, Research, and Sanctuaries Act (MPRSA) are not relaxed. The Agency also considered extensive public comments on the "Tentative Determination To Issue Special and Research Permits to Chemical Waste Management" (48 FR 48986, October 21, 1983) in preparing the proposed regulations.

In recognition of the questions regarding: the environmental efficacy of incinerating liquid wastes at sea; the environmental and human health risks involved in the process; the risks involved in transportation and loading activities that support incineration at sea, particularly the risk of a catastrophic spill; the need for incineration at sea; and public acceptance of incineration at sea to support this hazardous waste disposal option, the Agency has also initiated an "Incineration Study" in addition to this research strategy.

The Agency's Incineration Study is to provide an analysis of the technical, economic, and environmental benefits of, and problems with, incineration as a means of disposing of combustible liquid hazardous wastes. Both land-based and at-sea incineration are being assessed with respect to capability, risks and economics in

order to make comparisons between the two technologies. Currently available data is being used in this effort. Other technologies with potential for treating or disposing of combustible liquid hazardous wastes such as pyrolysis and wet oxidation, are also being assessed.

The analysis included in the Incineration Study will discuss the risks of land-based and at-sea incineration, the efficacy of the technology, and the capacity of existing incineration facilities to meet present and future demand for incineration under different regulatory scenarios. The regulatory scenarios that will be examined include potential restrictions on land disposal and deep-well injection of hazardous wastes, the use of hazardous wastes in industrial boilers, and the elimination of the small hazardous waste generator exemption. The risk of spills from ocean-going vessels will also be addressed.

The Incineration Study should put into perspective the risks and uncertainties of ocean incineration as compared to the available land-baed alternatives using the technical information currently available. This research strategy is being designed to allow EPA to obtain more detailed data which will be needed to more accurately evaluate these risks.

### 1.3 Development of This Research Strategy and Future Plans

The research strategy is designed to address the issues of concern and provide a strategy for organizing the research necessary to determine the human health and environmental risks of at sea incineration.

Legal, policy, regulatory and procedural issues are not within the scope of this strategy. Only the risks of incinerator operation are included because the risks related to issues such as spills, fugitive emissions, etc., are being evaluated in the Agency's overall "Incineration Study." Long-term environmental monitoring is also not addressed in this research strategy but is the subject of another document being developed by EPA.

In July 1984, a scientific working group which included scientists from EPA's Office of Research and Development who have been deeply involved in the Agency's incineration program, met to prepare a strategy for gathering the information to address the major scientific issues of concern.

The scientific work group was asked to develop a strategy to meet the following three objectives:

1. Define the major technical and operational issues related to incineration at sea permits and of concern to EPA, the public and the scientific community;

2. Provide the incineration at sea industry with a scientifically valid program design for gathering information to address these issues; and

3. Provide the Agency with a basis for making future decisions on ocean incineration permit applications.

Major scientific/technical issues generated by the public regarding ocean-based hazardous waste incineration were organized under four headings. These four headings serve as an organizational framework for the research strategy (Table 1).

The working group was directed to develop a research strategy which would address the information needs of as many of the issues as possible. The work group developed a strategy with each member contributing in his own area of expertise. The research strategy does not address long-term environmental monitoring or many of the issues covered in the "incineration study." Only research is addressed.

The draft strategy was circulated and was the focus of a public meeting held in Washington, D.C., on November 13, 1984. The comments received from the public on the draft strategy were then the focus of another EPA Task Force meeting on December 19, where the draft strategy was modified and the current document developed.

EPA plans to have this document and the actual subsequent research plans for the strategy reviewed by qualified scientists prior to implementation. The reports resulting from this work will also be reviewed by a qualified scientific group.

## 2.0 OVERALL STRATEGY

### 2.1 Summary of the Research Strategy

The major focus for the research strategy is the development of a rational, scientifically defensible, methodology for an updated environmental risk assessment of hazardous waste incineration at sea. The alternative approach of monitoring an area around the site before, during, and after incineration to measure environmental concentration of pollutants and ecological effects will not generate an acceptable environmental risk assessment. Risk assessment is a confidence-bounded estimate of the probability of unacceptably altering the aquatic environment as a result of hazardous waste incineration at sea. The estimate is derived from a comparison of the predicted organism exposure concentrations of pollutants with concentrations that cause adverse biological effects.

TABLE 1

The specific issues that were developed from public comments are grouped under the few major headings of emissions, exposure, effects and site selection.

1.0 Emissions

1.1 General Issues

1.1.1 What are the emissions from ocean incineration?

1.1.2 What is the relationship between emissions and incinerator specifications, operating conditions and waste feedstock characteristics?

1.1.3 What are acceptable parameters for continuous monitoring which are related to emissions?

1.1.4 What effect does the addition of control technologies have on emissions?

1.2 Specific Issues

1.2.1 What are the types and quantities of products of incomplete combustion (PICs) generated by the types of wastes and incinerator operating characteristics proposed for operational and research burns at sea?

1.2.2 What are alternative parameters (e.g., total unburned hydrocarbons or total organochlorides) for monitoring total PIC emissions?

1.2.3 Is it necessary to identify and measure all PICs as well as principal organic hazardous constituents (POHCs)?

1.2.4 What happens to PIC production during upset (clogged burner, etc.) conditions?

1.2.5 What are the sampling protocols, detection limits and quality assurance requirements for monitoring ocean incineration emissions?

1.2.6 What sampling procedure should be used to obtain a representative sample of the entire stack?

1.2.7 Within the regulatory window, what is the relationship between destruction and combustion efficiencies over a range of conditions of $CO_2$, CO, etc.?

1.2.8 Should destruction efficiency (DE) be measured continuously, throughout all burns?

1.2.9 Should combustion efficiency (CE) be based on total carbon in waste, and not just the oxidized emissions?

1.2.10 What is the relationship between PIC production and destruction/combustion efficiency?

1.2.11 What performance standards and specifications should be met during ocean incineration burns?

1.2.12 What are the organic compounds found in the plume when it reaches ambient temperatures and what are their concentration levels?

1.2.13 What are the emission levels of metals and chloride during ocean incineration?

1.2.14 Should research protocols be tested with non-toxic substances prior to burns involving liquid organic hazardous wastes?

## 2.0 Exposure

### 2.1 General Issues

2.1.1 How do we measure and model transport and dispersion of the plume generated during ocean incineration?

2.1.2 How do we verify model predictions?

2.1.3 To what extent do these substances in the plume persist in the atmosphere and enter the microlayer and water column?

2.1.4 To what extent is the biota exposed to these substances?

## 2.2 Specific Issues

2.2.1 What is the potential for uptake, concentration and transport by each of the following: eddies, slicks (microlayers), particles, bubbles, winds, waves, thermoclines, currents, and precipitation (wet deposition)?

2.2.2 How is the rate of uptake and residence time of emissions components in the microlayer measured?

2.2.3 Are plume spiking (e.g., with perfluorocarbons) and tracking needed?

# 3.0 Effects

## 3.1 General Issues

3.1.1 What biological and ecological effects result from exposure to ocean incineration emissions?

3.1.2 What human health effects result from ocean incineration?

## 3.2 Specific Issues

3.2.1 To what extent do emission components which accumulate in the surface microlayer cause adverse impacts in the microlayer?

3.2.2 To what extent do emission components bioaccumulate in food chain organisms exposed to the microlayer and water column?

3.2.3 What are the aquatic organism acute and chronic toxicities of specific emission components and byproducts and how do they compare to the toxicities of the dispersed and the undispersed plumes?

3.2.4 What levels of emissions cause behavioral or sublethal population and ecosystem effects?

3.2.5 What species can be used as indicators of adverse impacts (e.g., the Mussel-watch Program) at incineration sites?

3.2.6 How can current models for predicting human and ecological effects from ocean incineration be improved?

## 4.0 Siting

### 4.1 General Issues

4.1.1 What are characteristics of a site which make it suitable for incineration?

4.1.2 How can the long-term assimilative capacity of a site for incinerator emissions be assessed?

### 4.2 Specific Issues

4.2.1 What are criteria to identify areas with "redundant" ecosystems as candidate sites for incineration?

4.2.2 What parameters should be measured to determine the capacity of a site to handle additional incineration without causing adverse impacts?

4.2.3 What additional information is needed at undesignated sites?

Given the scientific concerns regarding previous research, EPA has developed this research strategy based upon what appears to be the three most important issues that need to be addressed (area 1 and 2 below) to develop an adequate risk assessment for incineration at sea, and tests that may need to follow (area 3). These areas are:

Area 1 - Methods development for aquatic toxicology tests and emissions sampling

Methods need to be developed for determining the aquatic toxicity of incinerator emissions. This will involve the development of a system for removing a known volume of emissions from an incinerator with subsequent incorporation of these emissions into seawater which would then be subjected to various bioassays to determine its toxicity to various standard laboratory aquatic test organisms. If possible, preliminary toxicity tests will be conducted using emissions from a land-based hazardous waste incinerator to field test the system and obtain information describing the possible toxic effects of real incinerator emissions (range finding).

Tests also need to be conducted at either a land-based or at-sea incinerator to determine the need for stack traversal while collecting high temperature, low particulate emissions for subsequent chemical characterization or toxicity testing.

Area 2 - Monitoring of incineration-at-sea operations

During incineration-at-sea operations, emissions need to be collected for chemical characterization and toxicity testing. Environmental sampling during these operations is also needed to determine if emissions can be detected in the environment near the incinerator and if environmental effects can be detected. This sampling is also needed to modify/verify emission transport models.

Area 3 - Additional research

Studies will be needed to evaluate the environmental impacts of alternative incineration-at-sea technologies and wastes. Other studies which may be conducted include detailed studies of transport and fate of emissions in the air and water column, toxicity studies using organisms indigenous to burn sites, and long range chronic studies of emission toxicity and bioaccumulation.

There is a substantial difference between a risk assessment based on a specific hazardous substance and the planned risk assessment based on hazardous waste emissions from an incinerator. The

TABLE 2

RESEARCH STRATEGY

| Area 1<br>Methods Development and Range Finding | Area 2<br>Use of New Methods At-Sea (Research Burn) | Area 3<br>Additional Tests and Research to Update Risk Assessment (Yearly) |
|---|---|---|
| ° Develop emissions sampling technique for toxicity testing. | ° Baseline and environmental monitoring. | ° Emissions transport testing in lab situation. |
| ° Develop appropriate toxicity tests. | ° Emissions sampling for chemical analysis. | ° Toxicity testing with other organisms and various methods of exposure and exposure times. |
| ° Determine appropriate emissions sampling procedure for subsequent chemical characterization and toxicity testing. | ° Emissions sampling for toxicity tests. | ° Area 2 tests using other vessels in research or trial burns. |
| ° Obtain toxicity data from a land-based incinerator if possible. | ° Transport model development and verification. | ° Area 2 tests using other wastes. |
| | ° Risk assessment. | ° Other tests as required. |

TIME

planned assessment is much more complex because the emissions are difficult to sample at high temperatures, may be in 2 phases (gas and scrubber water), and only poorly characterized. The emitted material is potentially a complex mixture composed of small amounts of the original waste material, partly destroyed original material, and new compounds generated during the incineration phase or during the cooling of the emitted gases in air or in scrubber waters.

Even if the emissions can be fully quantified and characterized, this will not yield the needed toxicity and environmental exposure information. Incinerator emissions are complex materials with potentially additive, synergistic, or subtractive interactions of toxicological properties. The approach of defining the composition of the emissions and developing a toxicity data base for each constituent would require extensive chemical analysis and long, expensive toxicity testing. Instead, EPA plans to chemically analyze the emissions in an effort to identify the most abundant substances present and to treat the emissions as a complex mixture to conduct a risk assessment based upon the toxicity of the mixture itself.

To obtain the needed toxicity information, methodology will be developed to trap the emission and introduce it in a controlled manner into laboratory aquatic systems to create a known dilution of emissions in sea water. The emissions will be directly introduced into a water media which will subsequently be used to dose aquatic laboratory test systems.

When this methodology has been developed, some preliminary tests on standard test animals, which have documented tolerances to a wide range of toxic substances, will be conducted at an onshore facility. Additional tests at a land-based hazardous waste incinerator may be conducted as a preliminary assessment of the aquatic toxicity of emissions which may be expected during at-sea incineration operations.

An at-sea research burn would then be conducted where the newly developed emission toxicity sampling and bioassay procedures would be used. Emission samples would also be collected for chemical analysis, and environmental samples would be collected for plume fate and transport model verification.

The field measurement program is also designed to respond to EPA concerns and issues raised by the public and scientific community on incinerator destruction efficiency variability during normal operation of the incinerator, the characterization of the emissions, and the fate of the emissions leaving the stack. Simultaneously, a control area of the site region will be monitored for background information.

Because very small amounts of unburned waste material may pass through the incinerator, EPA plans to burn polychlorinated biphenyls (PCBs) as the first waste material to be subjected to a research burn. This will enable EPA to use the large existing toxicity data base for PCBs for comparison to the toxicity data obtained from the proposed tests. The PCB waste material can also be more easily characterized than a complex waste composed of several toxic constituents.

By combining the results of the emission bioassay dose-response tests and the plume transport and exposure models, EPA intends to estimate the potential impact of the emissions on the environment (risk assessment). Field samples collected during the research burn from control and plume areas will be used in an attempt to verify the existence of impacts in the plume touchdown area.

Risk assessments will be conducted at several stages in the strategy at a series of exposure conditions. This will allow derivation of a risk assessment for operation of incinerator vessels at some prescribed level of efficiency. The risk assessment process will be tiered as appropriate to examine acute, chronic, and genotoxic effects of a range of spatial and temporal environmental concentrations.

Data and risk assessments generated from implementation of this strategy will be useful for decision making on incineration-at-sea permits and for incineration site management.

Specific activities anticipated to occur in each of these three areas of this strategy are briefly outlined below.

## 2.2 Area 1 - Method development for aquatic toxicity tests and emissions sampling

- Toxicity Test Sampling System Development

This will require the design, development and fabrication of an emission sampling system which can draw hot emissions from an incinerator system and incorporate the emissions to a volume of synthetic sea water.

This system must be capable of removing organics from the emissions and will subsequently collect HCl and water vapor. Its development will therefore require consideration of the extra volume of water which will be collected and the need for pH and oxygen adjustments that may be needed prior to use in bioassays.

° Sampling System Performance Testing

There will be an initial testing of the system using an easily accessible combustion chamber such as a small-scale incinerator or fuel oil burner.

Emissions will be collected from the exhaust duct using the newly developed sampling system. The water from the system will then be subjected to a series of lab tests to evaluate the usefulness of the overall sampling system. Emissions may need to be spiked with water vapor, HCl, and organic substances to approximate real incinerator emissions.

Tests will be performed to evaluate the effect of the collection procedure on the quality of the sample water. These tests will include:

- the effect of, and necessary counter-measures for, the decreased salinity due to collection of water vapors
- the effect of, and necessary counter-measures for, the the decreased pH due to HCl collection
- the effect of temperature during sampling
- the effect of particulates collected during sampling
- the effect of, and necessary counter-measures for, changes in buffering capacity due to the collection procedures and substances collected

Tests shall also be performed to determine the appropriate species and bioassay endpoints which will become the major focus of future bioassay tests. The species and endpoints to be considered will include:

- fish embryo/larvae tests for hatch viability and growth. Test durations of 48 and 96 hours will be considered
- molluscan larvae 48-hour growth tests and shell development success
- crustacean larvae (mysids and grass shrimp) survival and growth at 48 and 96 hours
- zooplankton (nauplii or juvenile copepods) survival at 48 and 96 hours
- phytoplankton growth for 48 and 96 hours

Additional consideration will be given to the necessary handling procedures of the sample bioassay water between collection and use. These will include evaluation of the need for immediate use versus acceptable storage and transport procedures.

When the sampling and bioassay procedures are developed, preliminary field testing may be conducted at a land-based hazardous waste incinerator if available. Samplers at this type of facility will present some of the same sampling conditions as an at-sea incinerator and the emissions themselves should be similar. Emissions collection can be conducted at a land-based incinerator and the methods for exposing test animals to the emissions can be tested. This approach will allow range finding tests to be conducted and will permit the field testing of the overall procedure while avoiding the complications of conducting an at-sea research burn.

Fuel oil will be burned during part of these tests for "blank" information since many PCB wastes contain fuel oil, and samples will also be collected while PCBs are being incinerated.

° Incinerator Emission Sampling Point/Points Determination

A series of tests will be conducted to examine the need for traversing a section of the incinerator stack while collecting emissions for subsequent chemical characterization or toxicity testing. These tests may be conducted during an at-sea research burn, on shore at a land based hazardous waste incinerator, during a fuel oil dockside burn of an at-sea incinerator, or at a combination of the three locations based upon the availability of a suitable location for the tests.

The incinerator stack or duct will be sampled for determination of combustion efficiency using a traverse across the stack or duct. Velocity, CO, $CO_2$, and $O_2$ will be measured using EPA Methods 1 through 3. Three full traverses will be conducted with measurements taken at each cross-sectional sampling point.

Additional tests at the land-based hazardous waste incinerator or during an at-sea research burn when PCBs are being destroyed, will again include sampling the single point and traverse sampling points, but this time a modified Method 5 procedure will be used for organics collection. The samples will be analyzed for PCBs (as will the PCB fuel), and destruction efficiency will be calculated. Particulate samples will be collected at each individual point in the traverse and weighed for determination of the variability in particulate loadings across the stack.

The results of the particulate CE and DE single-point and traverse analyses will be compared to determine the need for traversing stacks in future studies. If CE should show a constantly low value at a specific sampling point, this point will be used for the single-point DE determination. If this point shows equivalent or lower DE than the traverse samples, then it may be used by EPA in future tests as a worst case. If the single point and traverse CE's and DE's are not statistically different, traversal may not be required in future tests.

The oxygen concentrations in the gas at the stack sampling points of an at-sea incinerator will also be useful in determining if ambient air is intruding down into the stack to the sampling level. The analysis will allow EPA to determine if the sampling ports in the stack should be lowered, moving them farther from the exit plane of the stack.

## 2.3 Area 2 - Monitoring of incineration-at-sea operations

### A - Emission Characterization

- Emissions will be collected for subsequent chemical characterization. Samples will be collected using either the EPA Modified Method 5 (MM5) Sampling System or Source Assessment Sampling System (SASS) for semivolatile organic analyses, and the Volatile Organic Sampling Train (VOST) for volatile organic analyses. Sampling points in the stack will be determined based upon the results of the "Area 1" studies.

  Emission samples will be analyzed using gas chromatography/mass spectroscopy (GC/MS), gas chromatography/ electron capture (GC/EC) and other methods to identify and quantify the most abundant compounds observed in GC/MS scan chromatograms (including PCBs, dioxins, furans and other chlorinated organics).

- Emissions samples will be collected for subsequent total organohalogen (TOX) analysis using a GC/Hall Detector technique.

- Total unburned hydrocarbons, plus CO, $CO_2$ and $O_2$ will be monitored continuously.

- Emissions will be collected for determination of particulate levels at various points across the stack.

° Sampling will occur during normal operation of the incinerator (including upsets if they occur).

B - Exposure and Effects

° Incineration Research Site Selection

Prior to the implementation of the ocean research burn of hazardous waste, an environmentally acceptable site will be selected specifically for the burn.

Information will be collected on the geographic, physical, chemical, and biological characteristics of the research site. Physical information will include data on currents, hydrology, and meteorology.

° Environmental Control Sampling

Immediately prior to an at-sea research burn (on the order of days) and during the burn, an environmental control study will be conducted at the site.

- Chemical concentration data will be collected on samples of biota living in surface waters at the site (neuston), as well as in the air and water to establish background concentrations of any emission related contaminants.

- Air samples will be collected and analyzed for several types of substances. Air will be sampled for organic substances using a high volume filtering system which uses polyurethane foam plugs to trap organics. HCl in air will be measured using a real-time HCl analyzer, such as a Geomet HCl analyzer, which has the needed sensitivity.

- Water samples will be collected using several procedures. One procedure will be a high volume polyurethane foam plug filtering system for organics collection and the other will be a syringe sampling method for sulfurhexafluoride ($SF_6$) or perfluorinated hydrocarbon (PFH) determination. Water bottles will be used to collect water for pH, alkalinity, temperature, salinity, chlorophyll, and ATP determinations.

- Neuston will be collected using standard neuston nets, and the catch will be taxonomically identified into major groups and analyzed for organic residues.

- Background $SF_6$ or PFH levels (plume tracers) will be measured in air using either a continuous monitor or a grab sample - GC/EC procedures.

- Chemical analysis of the samples will be conducted using the previously described methods for waste and emissions samples and will be conducted after the emissions samples have been analyzed.

° Environmental Sampling in the Research Burn Area

Samples will be collected during the research burn in the vicinity of the incinerator vessel.

- Samples of air, water and biota will be collected in the plume area.

- Chemical analysis of the environmental samples will be the same as for the control samples and will not be conducted until the substances present in the emissions samples are identified. The environmental samples will then be analyzed specifically for these substances.

- Air samples for HCl and $SF_6$ or PFH analysis will be collected in the plume.

° Transport Model Development

Appropriate atmospheric and aquatic transport models will be selected to predict transport of the emissions over and in the water to the point where they are indistinguishable from the background.

° Transport Model Verification

The results of the environmental sampling during the research burn cruise will be used to verify the transport models.

° The atmospheric transport models will be empirically calibrated with the HCl in the plume and emission plume markers such as $SF_6$ and PFH.

° In addition, limiting atmospheric conditions for incineration will be identified, and best- and worst-case scenarios of environmental exposure determined.

° Biological Effects Assessment

The impact of emissions on biological processes in the marine environment will be assessed from laboratory studies conducted with stack emissions that have been collected during the ocean research burn. These emissions will be collected using the procedures developed in Area 1 of this strategy.

- Test organisms will be obtained for bioassays and will include the standard test species for which we have extensive comparative toxicological data.

- Test organisms will be exposed to concentrations of the emissions including the expected/measured range of water column concentrations.

- To insure that the toxicological data developed for this plan are quality-assured and meet the requirements of good laboratory practice, the following standard test protocols will be used:

  a. ASTM Standard Practice for Conduct of Acute Toxicity Tests with Fishes and Invertebrates.

  b. ASTM Standard Practice for the Conduct of Acute and Chronic Tests with the Mysid Shrimp, Mysidopsis bahia.

  c. ASTM Standard Practice for the Conduct of Early Life Stage Tests with Fishes.

  d. OPTS Interlaboratory Calibration Studies with Oyster Larvae.

  e. OPTS Interlaboratory Calibration Studies with Penaeid Shrimp.

  f. OPTS Interlaboratory Calibration Studies with Marine Algae.

- Estimates of the potential bioaccumulation of toxic pollutants in the emissions will be predicted from estimated trophic level productivity structure activity and the log of the octanol-water equilibrium partition coefficient for the substances identified in the emissions and, depending on these results, direct measures of tissue residues will be attempted on chronically-exposed species as dictated by tissue sample size and analytical detection levels.

## 2.4 Area 3 - Additional tests

- Tests can be conducted to determine the transport properties of emissions through various media including air, microlayer, surface water, deep water and sediments.
- Emissions toxicity tests can be conducted using indigenous organisms from incineration sites, and more complicated toxicity tests could be developed and used.
- Tests for bioaccumulation in indigenous species and food chains can be investigated.
- Areas 2 and 3 type tests can be conducted using various waste materials.
- Areas 2 and 3 type tests can be conducted using different incineration vessels or other incinerator designs.
- Tests can be conducted to determine if cooling of emissions in the plume or scrubber changes their chemical composition.
- Tests can be conducted to determine the effects of possible incinerator upset conditions on DE, CE, and emission composition.
- Tests can be conducted to determine the physical form and characteristics of substances in the emissions (i.e., particulate, droplet, and gaseous form).
- Tests can be conducted for additional verification of the applicability of current emissions sampling methods (particularly the Modified Method 5 procedure for organic substance collection) when sampling at high temperature and acid conditions.

## 3.0 RATIONALE FOR SPECIFIC PLAN COMPONENTS

### 3.1 Emission Characterization Considerations

#### 3.1.1 Overview

One of the essential elements to an understanding of the impacts from ocean incineration is an accurate determination of the types and quantities of substances emitted from the incineration system. These include unburned waste materials and substances formed inside the incinerator as products of incomplete combustion.

Another essential element is an understanding of the combustion process to the extent that easily monitored substances/parameters can be realistically used as surrogates for continuously measuring all the substances being emitted from the incinerator.

EPA has been increasing its knowledge and understanding of both these issues for many years regarding on-shore and ocean incineration. Methods have been developed for collecting/analyzing/monitoring samples for constituents in addition to the several emission gas constituents currently being used to continuously monitor incineration to ensure proper operation.

EPA's emissions analysis and monitoring techniques are continuously evolving and have been developed and used largely at land-based incinerators or other types of on-shore combustion facilities.

Questions have been raised as to whether the newest, state-of-the-art techniques for emissions sampling, analysis, and monitoring have been used on ocean incinerators, and whether these procedures are actually applicable or necessary to ocean incinerators due to the high stack gas temperatures, high HCl concentrations, cyclonic flow in the short stacks, and low particulate levels.

Several ocean incineration research burns have been completed in the past. During each burn, testing for destruction efficiency of the major waste components was done using the best technology available at that time. Certain issues have not been fully addressed during previous incineration burns and the associated analytical studies. In retrospect, there are three main technical areas which are now viewed as deficient. These areas are described separately below.

A. Rigorous Testing of Performance According to Best Available EPA Methods:

EPA has not fully applied the Agency's most rigorous stack sampling methods such as stack traversing with isokinetic collection of emissions during past research burns. Also, the previous evaluations were only designed to test for compliance of earlier incineration-at-sea requirements for 99.9 or 99.99 percent destruction efficiency (DE), and some were insufficient in sampling time duration to show whether the land-based regulatory requirements for DRE of 99.9 to 99.9999 percent were being met, or whether any significant quantification of particulate matter emission was accomplished. Although the previous work which EPA has reviewed is accepted as valid and accurate, public comments and recent or proposed revisions to Agency policy now dictate that the above deficiencies in this area should be addressed through additional research and testing. The additional research tests would include longer (e.g., 8 hours versus 2 hours) sampling, fully traversing the stack(s) isokinetically (or providing suitable justification that traversing is not necessary), and quantifying the particulate matter.

B. A Complete Chemical Characterization of All Incinerator Emissions:

Previous work with incinerator ships concentrated on destruction efficiencies but failed to quantify fully the amount of all the other substances in the stack emissions. Although a similar deficiency exists in most of EPA's land-based incinerator performance data, recent comments request that the Agency close this data gap in any future incineration tests whether for land or at-sea incinerator performance.

EPA recognizes that identification and quantification of "all stack effluents" rather than just the major PCB and selected emission substances may be impractical in terms of the cost and time. However, the analytical search should be expanded to the greatest practical extent.

C. Potential for Changes in Stack Effluent Chemical Composition Upon Leaving the Stack:

Previous at-sea incinerator performance evaluations did not evaluate the potential for further chemical changes

(e.g., chemical reformation or recombination of molecules, etc.) in scrubbers or within the stack effluent gases upon leaving the stack exit plane and entering the cooler atmosphere immediately above or downstream of the ship. Such studies have also not been conducted for land-based incinerators; however, EPA agrees that this is an area which merits investigation, particularly for those incinerators which discharge hot effluents directly into the atmosphere. Although it is likely that hazardous compounds passing through the incinerator hot zones become disassociated, oxidized, and separated such that they will not further change or recombine, a test of the "permanency" of separation and its "stability" would be a significant piece of information to demonstrate incineration effectiveness.

In response to the data needs described above and elsewhere, a series of at-sea incineration research burns should be conducted to provide sufficient amounts of emission contaminants for various tests to (1) demonstrate the destruction efficiency of designated organic compounds, (2) demonstrate particulate collection and quantification in stack emissions, (3) demonstrate the production and survival of other chemical compounds during the incineration process, (4) demonstrate whether reactive products are produced in the plume as cooling occurs, (5) aid in plume model validation studies and biological testing, and (6) demonstrate the effects of liquid scrubbers on stack emissions. The following sections address these data needs.

### 3.1.2 Development of Emissions Sampling Methods

In order to characterize adequately the emissions from at-sea incineration of hazardous waste, a test burn should first be conducted to determine the optimum sampling and analysis procedures.

EPA's land-based RCRA and TSCA trial burn procedures and stack sampling procedures require that the incinerator effluents be sampled isokinetically at a number of individual points (typically 12 points) across each of two perpendicular diameters of the stack. While this elaborate and costly procedure is not absolutely known to be necessary (versus single-point readings), it nevertheless has been required on all land-based incinerator trial burn testing.

Recently, EPA has reviewed the need for traversing by examining the typical turbulence/mixing/Reynolds number levels in most incinerator stacks. They found that, in most cases, the flow patterns are extremely turbulent and rarely laminar. If good mixing and uniformity across any diameter of stack effluents can be verified, then traversing should not be necessary. Because of the large stack diameters, the extreme heat, and the necessity for personnel to be in unsafe locations during some of the traverse procedures, traversing during waste burning at sea is both hazardous to personnel and costly. This strategy suggests conducting traverse/single point comparison tests on at-sea incinerators with the alternate use of dockside nonhazardous fuel (diesel oil) stack emissions testing if these tests cannot be conducted at sea.

This at-sea or dockside emissions testing will provide meaningful information on the variation across stack diameters of velocity, CO, $CO_2$, $O_2$, THC, NO, etc. It will also provide information showing the relationship of the particulates obtained from single-point samples at all the traverse points. These parameters will help to determine if variations are significant and therefore justify requiring traversing during sampling. Alternatively, should these tests identify a point of "worst emissions," the option for placing a single-point probe at these points may be considered during waste burns. Traverse vs. single point DE tests may be conducted at a land-based hazardous waste incinerator for the collection of data to supplement the dockside data.

EPA has reviewed data submitted by a permit applicant which shows clearly the combustion products for an oil burn would be similar to an actual hazardous waste burn, except for the chlorine content of a chlorinated waste. The chlorine content may be in the 3 percent (by weight and volume) range. Therefore, it appears that data from an oil burn would be representative, in a fluid dynamics/flow pattern sense, of the flow of hazardous waste emissions from an incinerator stack under the same velocity and net flow rate conditions, etc.

The recognized EPA methods for collecting organic substances for DE determination include the Modified Method 5 (MM5) train for organic sampling, the Source Assessment Sampling System (SASS) train, which is a larger version of the MM5 capable of collecting five times the organic sample as the MM5, and the Volatile Organic Sampling Train (VOST). Both the MM5 and the SASS trains collect organic compounds which boil over 100°C, while the VOST collects organic com-

pounds in the 30-100°C boiling range. EPA Methods 1 through 4 will be used to obtain gas flow information from the stack.

### 3.1.3 Determination of the Composition of Incineration Emissions

The results of the Area 1 tests will be used to design the procedure for collecting the emissions from the incineration of hazardous waste at sea. This will require use of either the single-point or traverse procedure, whichever is appropriate, for collection of high volumes of stack gas.

#### 3.1.3.1 Fuel Oil Control Test

When the incinerator vessel is at the incineration site, a one-day test will be conducted using fuel oil for comparison to the dockside fuel oil test if it is conducted. The results will be used to determine if being at sea has any effects on either the incinerator combustion efficiency or the sample collection efficiency.

#### 3.1.3.2 Emissions Sampling

Emissions samples will be collected with the MM5 or SASS train for subsequent trace chemical analysis. Ambient air will also be collected during the hazardous waste burn at sea as a background control using the same collection system as is used in the stack. Waste samples will also be collected for analysis. In the future (Area 3 studies), systems including seawater scrubbers will either be sampled upstream of the scrubbing device or require the development of adequate gaseous and scrubber water sampling procedures.

The recognized EPA methods for the collection of particulates in stack emissions through the use of traversing will be used only if the results of the previous tests demonstrate that one-point sampling will not provide a representative or even a worst case collection point.

EPA wishes to determine if the substances detected in the standard MM5 or SASS train samples (collected from inside the stack) are the same as those that actually enter the environment in the cooled off plume from the incinerator. During future tests, EPA will use a new sampling system which collects gas from the stack much like the MM5 and SASS trains, but cools and dilutes the gas before the particulates and organics are collected on the filter and resin. It is anticipated that the cooling of diluted gas before sample collection will more closely imitate the real world environment of the plume from a non-scrubbed stack.

This dilution sampling system has been used by EPA on industrial boilers but must be reconstructed of glass before it can be used in the acid environment of the ocean incineration plumes. This system will collect samples for organics analysis and may provide a better representation of the substances actually entering the environment from the incinerator.

3.1.3.3 Continuous Monitoring

During the entire research burn, several parameters will be continuously measured. The amount of oxygen, carbon monoxide, and carbon dioxide will be determined by continuous, rapid response monitors. The temperature of the incinerator wall at several points will be monitored. The measurement of these parameters is required by LDC regulations. The ratio of CO to $CO_2$ is defined as combustion efficiency (CE = $(CO_2 - CO)/CO_2 \times 100$). CE is a generally accepted guideline to the proper operation of an incinerator. In addition, a total hydrocarbon (THC) continuous monitor will be required. The use of a THC monitor will note if the organic portion of the stack emissions were to increase during an incineration burn indicating a decrease in optimum incineration operation. The monitoring of the oxygen provides assurance that the required air is present for proper oxidation of the organic compounds.

To date, incinerator experts from EPA and the rest of the hazardous waste technical community both here and in Europe have not found any reliable theoretical or empirical relationships among such performance parameters as destruction efficiency (DE), destruction removal efficiency (DRE), CE, $CO_2$, $O_2$, THC, or any mathematical ratio or combination thereof. From a theoretical sense, finding such relationships is a very difficult task due to the complexity of the high temperature flame processes which simultaneously occur within an incinerator. EPA's existing incineration data base is quite large; however, it is composed of performance data from dozens of different hardware designs, which adds yet another variable or dimension to complicate finding any of these relationships. The only possibilities for finding such relationships among DE, CE, etc., might be on an empirical basis, or as derived from extensive parametric (systematically varying all parameters during operation) on individual fixed designs of incinerators in a research laboratory. EPA is currently embarking on such studies on laboratory and pilot scale incinerators; however, the results of these studies are likely to take many years.

Meanwhile, EPA has gained from its broad incineration data base some reliable and useful engineering judgment rules or guidelines; for example, what levels of CO, $CO_2$, $O_2$, temperatures, and other design and operating parameters usually result in acceptable DE or DRE levels overall.

#### 3.1.3.4 Chemical Analysis Methods

The stack emission samples will be analyzed for compounds present by methods capable of measuring in the nanogram per sample range. In general, Gas Chromatography/Mass Spectroscopy (GC/MS) will be the analytical finish; however, other techniques will be used as necessary. All stack emission samples will be analyzed for all major compounds identified in the feedstock plus the most abundant compounds that can be detected. This will allow the identification of products of incomplete combustion and/or recombined compounds. Samples will be analyzed for total organohalogen (TOX) using a GC/Hall technique. If any unexpected compounds are found in the emission samples, the waste will be specifically re-analyzed for those compounds to determine if they are uncombusted compounds from the waste.

## 3.2 Exposure Considerations

### 3.2.1 Overview

In addition to knowing the identity and quantity of the emissions from ocean incineration, it is necessary to know where the emissions go after leaving the stack and at what concentrations they exist in the environment. This strategy includes the use of plume transport models to estimate where gaseous emissions will go and the use of ambient monitoring to validate the models. It is set up in a tiered approach where less sophisticated exposure estimates are used in worst-case scenarios first and, if necessary, sophisticated exposure estimates (models, etc.) are used later. This approach is designed to be used in a tiered risk assessment as described in section 3.3.4.

### 3.2.2 Site Selection and Environmental Monitoring

Before any incineration can take place in the ocean, a suitable site must be located which meets the requirements of the Marine Protection, Research, and Sanctuaries Act (MPRSA) and which will be appropriate for model validation studies.

### 3.2.2.1 Site Selection

Research burns must be conducted at sites believed to be environmentally acceptable, but need not be conducted in a location which has been officially designated by EPA as an ocean incineration site. The MPRSA allows research at non-designated sites, and the low volume of wastes to be incinerated indicates that the evaluation of an acceptable short-term site need not consider high-volume/long-term contamination to the degree needed to fully designate sites for operating permits.

This type of site may be useful for research into detailed plume modeling, environmental effects, and detection and quantification of trace substances in incinerator emissions from a source which is believed to operate efficiently. This type of site may not be appropriate for long-term use. Sites, as described in this document, will require additional evaluation before being considered for long-term use.

Sites used for incineration research must meet the general criteria requirements as defined in the ocean dumping regulations. Sites must be in areas of minimal interference with fishery or shellfishery areas and regions of heavy commercial or recreational activity. Sites must be in areas of low biological activity as exemplified by plankton density and the absence of sensitive biota, and should not have prevailing winds or currents toward sensitive areas or shore. In order to be useful for model validation, the site should be in an area of relatively consistent wind and predictable current velocities, or the models will not be capable of explaining environmental concentrations of the emissions.

In addition to the general criteria, 12 factors should be considered in site approval. These factors are the specific criteria described in EPA's ocean dumping regulations (40 CFR 228) with the addition of a twelfth factor suggesting that the occurrence of endangered and threatened species be considered. The twelve criteria are presented below.

(a) Geographical position, depth of water, bottom topography, and distance from coast or special marine resource areas. The site should not be near shore where the plume could potentially contact land prior to dispersal.

(b) Location in relation to breeding, spawning, nursery, feeding, or passage areas of living resources in adult or juvenile phases. Sites should not be located near these areas.

(c) Location in relation to beaches, marine sanctuaries, and other amenity areas. Sites should not be located in areas where winds or currents are likely to transport emission products toward these areas.

(d) Types and quantities of wastes proposed to be incinerated, and details of the proposed methods of incineration.

Types and quantities of waste need to be evaluated in order to determine the rates at which incineration can take place at a site without endangering local biota. The incinerator designs, including the use of sea water scrubbers, need to be evaluated in conjunction with the waste type in order to estimate how emissions will enter the environment (i.e., directly into the water as scrubber discharge, or to the atmosphere in hot gases). Because the site will be used for research, the total quantities of waste incinerated will be low.

(e) Feasibility of surveillance and monitoring.

(f) Seasonal circulation patterns, dispersal, horizontal transport, and vertical mixing characteristics of the area, including prevailing water current and wind direction and speed, air temperature, atmospheric stability, frequency of inversions and fog, precipitation amounts, and relative humidity.

These parameters of the site area must be known in order for research to be conducted at a time when air and water circulation patterns will not carry emissions into unsuitable areas, such as beaches, reefs, or fishing areas, and will assist in model validation.

(g) Existence and effects of current and previous discharges from incineration or other disposal activities in the area.

The existence of previous dumping activities at a site would be important in evaluating environmental data from baseline or trend assessment monitoring. The cumulative effect of ocean incineration and other discharges in the site must be considered in evaluating a site.

(h) Interference with shipping, fishing, recreation, mineral extraction, desalination, fish and shellfish culture, areas of special scientific importance, and other legitimate uses of the ocean.

(i) The existing water quality and ecology of the site as determined by available data or baseline surveys. Environmental characteristics of the marine ecosystem at the site should be described to identify sensitive organisms which may occur at the site during the test and the background levels of combustion emission related substances that are present at the site.

(j) Potential for the recruitment of nuisance species in the site.

(k) Existence at or in close proximity to the site of any significant natural or cultural features of historical importance.

(l) Occurrence of endangered or threatened species at or near the site. Seasonal migration patterns of endangered species should be described prior to site use. Seasonal migration may lead to specific seasonal use of the site so as not to interfere with endangered species.

3.2.2.2 Environmental Control Study

When a site has been selected and a research burn is about to begin, environmental control sampling should begin at the site. Environmental background data must be collected at the research burn site immediately prior to and during the research burn. This background data collection will be oriented toward determining background levels of organic substances in the area of the site during the research burn for comparison to levels determined during and after the burn. Other background data for sulfur hexafluoride ($SF_6$) or perfluorinated hydrocarbons (PFH) and HCl will also be collected for use in model validation studies. Indigenous organisms may also be collected and appropriate species selected for future laboratory bioassays. Sampling will begin a day or two before the incineration vessel arrives at the site to ensure EPA that the rest of the control data taken during the burn is in fact not contaminated by the incinerator.

Environmental baseline samples to be collected at the site will include the surface water, air, and neuston. These types of samples will be taken because any substances exiting the incinerator will likely be at their most concentrated levels in these media near the incinerator during the research burn. These baseline concentrations in the near field area are essential if the environment is to be sampled during a burn for detection of elevated levels of emission-related substances. These near field samples will undergo the same chemical analysis as that described for emission samples and will also be analyzed for background levels of HCl (air only) and $SF_6$ or PFH (air and surface water only).

3.2.2.3 Environmental Sampling During Research Burn

During a research burn, the same types of samples as described for controls will be collected in the plume area and analyzed after the emission samples are analyzed so that the specific substances observed in the emission samples can be searched for in the environmental samples.

HCl and $SF_6$ or PFH concentrations in the air will be vigorously tested during the burn to locate and describe the plume. $SF_6$ or PFH will be sought in surface water to determine areas of plume touchdown.

3.2.3 Model Evaluation and Exposure Assessment

Prior to the implementation of a research burn, various atmospheric and water transport models will be evaluated.

The reason for studying air quality plume dispersion models is that they will be used in the future at other sites to predict the location and extent of the incinerator emissions' sea surface impact zone and the amounts of material deposited in this zone based on stack emission rates. This information will also be used to determine where future air samples will be taken during operational burns. The study must include control data, modified overland plume dispersion models to accommodate overwater meteorology (air movements, stability, etc.) and model verification to demonstrate that these predictions are reasonable. The background data collection plan is designed to obtain data which will estimate background levels of organics, $SF_6$ or PFH tracer, and HCl. These data will be compared to the emission data collected during the research burns and used to estimate the extent and diffusion of the incineration plume. These comparisons will also be used to verify the use of the modified overland plume dispersion models for predicting the dispersion of plumes from incineration at sea.

### 3.2.3.1 Atmospheric Model Evaluation

Models exist for predicting the movement and impact of air masses, and the EPA has a series of air quality dispersion models referred to as UNAMAP that can be used. However, these models were designed for overland dispersion and not explicitly for overwater air quality modeling. In previous applications over water, poor results have been obtained mainly because the assumptions made in the models were based on wind speed and net radiation levels generally found over land and not generally found over water. Modification of the models and additional measurements at the site during the environmental testing will be used to overcome some of these deficiencies.

Two approaches are proposed for tracking the plume for model verification during the implementation of this strategy. First, the high concentration of HCl (which is produced during the combustion of chlorinated organic substances) released from the burning of PCB will provide an airborne tracer, the HCl. However, this cannot be used to determine the actual interaction of the plume with the sea surface since HCl is neutralized once it contacts seawater. The second approach will be to add a material such as perfluorinated hydrocarbons (PFH) or sulfur hexafluoride ($SF_6$) that can be tracked in the plume and in the water. Sulfur hexafluoride is one good candidate for use as a tracer, since it has been used as a plume tracer in many studies; analytical techniques, including continuous monitors capable of detecting as little as $10^{-12}$ parts $SF_6$ in air, are available. Several studies with $SF_6$ as the plume tracer have been carried out over the ocean. Tests have also shown that $SF_6$ is not destroyed by seawater and can be detected in low concentrations in seawater. $SF_6$ is not generally found in seawater; thus, a very low background and good analytical techniques will permit low detection limits. Tests of the validity of these tracers as surrogates of emissions will be required.

Since the PFH's are organic compounds, they should be the best surrogates for tracking the transport of the emission organics in the air and water. These compounds are also very stable in water and should not be present in the ocean. Detection limits are also very low for PFH's. The use of an organic tracer such as one of the PFH's as a surrogate for tracking the transport of the organic substances in the emissions is the more desirable approach. However, cost or technical problems may make this approach impossible, in which case $SF_6$ will be used as the organic emissions plume

tracer even though it is not organic. Generally, when tracers such as PFH and $SF_6$ are used, a second material or plume property such as plume visibility is used to help track the plume. In this study, HCl will be used as the supplementary tracer, and, as with PFH and $SF_6$ very good, highly sensitive detection methods are available for tracking the HCl.. Ammonia can also be added to the plume to make it visible.

Several releases of PFH or $SF_6$ are planned to cover a variety of meteorological conditions. The tracer will be released in the plume just above the stack at a point where the stack gases have cooled below the decomposition temperature of the tracers. Tracking by ships and planes is recommended. If the plume follows the predicted course, a limited use of planes will be needed. If the plume rises, extensive airplane sampling may be needed. Seawater samples and air samples will be taken in the site area during the baseline cruise for background data, and a wide range of samples will be taken during the burn in the areas of plume touchdown. These will include but not be limited to air, sea slicks, and surface water samples.

The needed meteorological measurements will be made from the incinerator ship and along the plume path. The standard wind speed, wind direction, temperature, and relative humidity measurements logged by the incinerator ship and sampling ships can be supplemented with pilot balloon soundings and airplane measurements for wind profiles and boundary-layer conditions.

When the plume has been identified using PFH or $SF_6$ and HCl, the environmental samples will be collected under the plume to be chemically analyzed for emissions-related substances for use in model verification.

The task of statistically identifying background levels of the potential organic substances in the air, water, and neuston of a pelagic site is quite different from defining $SF_6$ or PFH background levels. An approach for sampling and statistically describing the background levels of organic substances will be developed. The numbers, kinds, and sizes of the environmental samples will be an important consideration. The approach selected will be used for the samples taken before, during, and after the burns.

The on-site measurements of the tracer, HCl, and the incinerator-emitted organics in the plume and at the surface impact zone will be used to verify predicted values from the modified overland atmospheric dispersion models. Addi-

tional modeling and laboratory studies need to be conducted, however, to determine how emissions-related substances are incorporated into the surface microlayer and subsequently transported into the surface water and biota.

### 3.2.3.2 Aquatic Model Evaluation

Assuming a small level of incomplete combustion plus possible formation of organic compounds during the combustion process, release to the atmosphere of some amount of organic material is possible. The emissions during actual operations may also include small amounts of metals that were present in the original waste material. The most probable point of impact of incineration stack emissions, and scrubber water if applicable, will be the ocean surface and consequently the organisms directly or indirectly associated with this area of the marine ecosystem. Chemical characterization of emission exhaust will determine the types and levels of potential emissions including organics and HCl. The predictive modeling and tracer studies used in the research burn will determine the area and points of plume impact. Models will also be used to predict the levels and composition of emissions that ultimately reach the ocean surface and subsurface waters and associated organisms. Prevailing currents, wave action, and other hydrological disturbances will play a major role in final fate and exposure concentrations. In addition, biodegradation rates of emissions, potential for bioaccumulation, and residence time of HCl in surface microlayers are important components of an exposure assessment in the aquatic environment.

In Area 3 of this strategy, studies are planned to determine if, how much, and for how long emission components reside in the water surface microlayers. Laboratory ecosystems (microcosms) with simulated lipid surface microlayers will be sprayed with appropriate organic compounds similar to expected emissions as determined by previous trial burns. Periodic measurements will be made, using Nucleopore membranes, to determine:

1) the rate of organic compound uptake;

2) residence time in the microlayer; and

3) disruption of microlayer integrity by HCl.

Chemical constituents of the surface films can affect these rates and will be varied to determine their impact. Constituents such as protein, lipid, and carbohydrate content will be varied.

To determine exposure concentrations in marine surface microlayers, the microbiological fate of emissions will be investigated. These studies can be conducted in the laboratory with real microlayer materials and associated microflora or simulated microlayers as described above. Studies should be conducted in sterile and non-sterile systems and every effort made to account for mass balance of substances added to the system(s). Microbes associated with the surface film (i.e., microlayer) will be determined by chemical constituents of the film. Variation of these chemical constituents, as discussed above, will be correlated to changes in the microflora and assess their abilities to degrade the organic emissions.

Field samples (surface microlayers) may be taken during research burn events to determine concentrations of organic and acid emission accumulation and to verify data from laboratory ecosystem studies. Background samples will be taken prior to the burn to subtract levels of pollutants resident in the surface microlayers and associated organisms.

Various sampling techniques are available to retrieve environmental surface microlayers. These include screen techniques, a teflon disk technique, a Nucleopore or Millipore membrane technique, and a rollerdam technique. Each of these techniques have benefits for retrieving certain constituents or components of films. Most are limited in volume, thickness of film, or area which can be retrieved. One or more of these methods would need to be used in a statistically sound design in order to obtain valid information on film components prior to and during the research burn. At the present time, the statistical variability from sample to sample using any of these procedures is unknown and would need to be determined before a meaningful sampling program could be designed.

Because of the intensive decomposer-herbivore (detritivor) food chain in the microlayer, it is highly probably that organic chemicals from stack emissions, if not decomposed in the microlayer (biodegradation/photodecomposition), will be transferred to higher organisms via the food chain (i.e., dinoflagellates, ciliates, and fish). Heavy surface slicks on inland waterways and estuaries have been observed to contain an extensive food chain with small fish feeding directly on the slimy and filamentous organic layer. Therefore, if area 1 and 2 studies show that significant levels of organics are being emitted from the incineration stacks studies should be performed to determine if these substances accumulate in the surface microlayer of the ocean and if so,

what is the potential toxicity of these chemicals to representative marine organisms which may live in or feed on the microlayer. These organisms may feed during the night and then migrate to deeper water during the day, thus dispensing the emission constituents. The microlayer might therefore not accumulate emissions at all but serve as a distribution source.

Since surface microlayers contain a diverse community of bacteria, it is highly probable that small quantities of organic chemicals can be biodegraded to microbial biomass or harmless organic or inorganic products. The densities of the surface films, associated bacterial populations, and their catabolic capabilities will vary with the quantity of nutrients available, both organic and inorganic, as well as the type of substrates. For example, highly proteinous films will contain a higher proportion of peptide-utilizing bacteria than a film containing a high concentration of lipids.

Since surface films collect and concentrate hydrophobic chemicals across the ocean surface, these chemicals are exposed to a higher ultraviolet (UV) radiation than if they were dispersed in the water column and adsorbed to particulates. This enhanced UV exposure adds to the probability of photodecomposition of these compounds, particularly for photosensitive chemicals. Photodecomposition may or may not reduce the chemicals to harmless products;or render a normally non-biodegradable chemical more susceptible to microbial attack.

The ultimate fate of any incinerator emissions and therefore their exposure concentration to organisms of the marine ecosystem will be a function of biodegradation, photodecomposition, potential for bioaccumulation, and physical activities such as waves, currents, etc.

The microlayer and its associated organisms may be exposed to both organics and acid emissions from organochlorine combustion. While it is understood that relatively alkaline seawater has the capacity to neutralize significant quantities of acid (HCl), research may be done in Area 3 to determine the fate and potential impact of fairly large quantities of HCl on the important microflora associated with this microlayer. Laboratory studies could be conducted to determine the residence time of the acid precipitation in the surface microlayers. If the acid is rapidly neutralized by the alkaline seawater, no effect on the resident microbial populations would be expected. If, on the other hand, the acid precipitation significantly changes the pH in the surface microlayer more than transiently, coincident changes in microbial species composition and function could result.

Field verifications of predicted acid residence time in the surface water is needed. Surface water samples taken during burns will help to verify laboratory data and assist in monitoring potential depositions whether expected or unexpected.

The transport and exposure considerations addressed in this research strategy will therefore try to describe the transport and fate of any substances emitted from ocean incineration and estimate the levels of these substances that could exist in the environment based upon the results of stack emissions analyses. Best- and worst-case scenarios will be run through the models. If the worst-case scenario shows an extremely low probability of exceeding background ambient levels of emissions-related substances, the decision could be made that additional toxicity-related studies may not be necessary.

## 3.3 Biological Assessment Consideration

### 3.3.1 Overview

Information obtained from studies conducted to determine the types and quantities of substances emitted from ocean incinerators and the exposure concentrations of these substances in surface microlayers, subsurface waters, and air above background levels, will help determine if toxicological effects due to incineration stack emissions can be expected. If these substances accumulate in the marine environment and are not biologically degraded or photodecomposed, they may have the potential to cause adverse effects or bioaccumulate through the food chain. Laboratory studies will be conducted to determine the concentration of emissions that will produce significant changes in a suite of biological responses ranging from acute mortality to growth, reproduction, or ecosystem process interruption. If evidence does not exist which indicates that elevated levels of substances will appear in the environment (i.e., worst-case scenario), extensive laboratory studies of biological effects may not be needed. The effects testing proposed in this plan is therefore tiered with the least sophisticated and least complicated tests first, with more sophisticated test following--if necessary. This tiered approach will parallel the exposure-tiered approach and be used in the tiered Risk Assessment described in section 3.3.4.

### 3.3.2 Direct Biological Effects

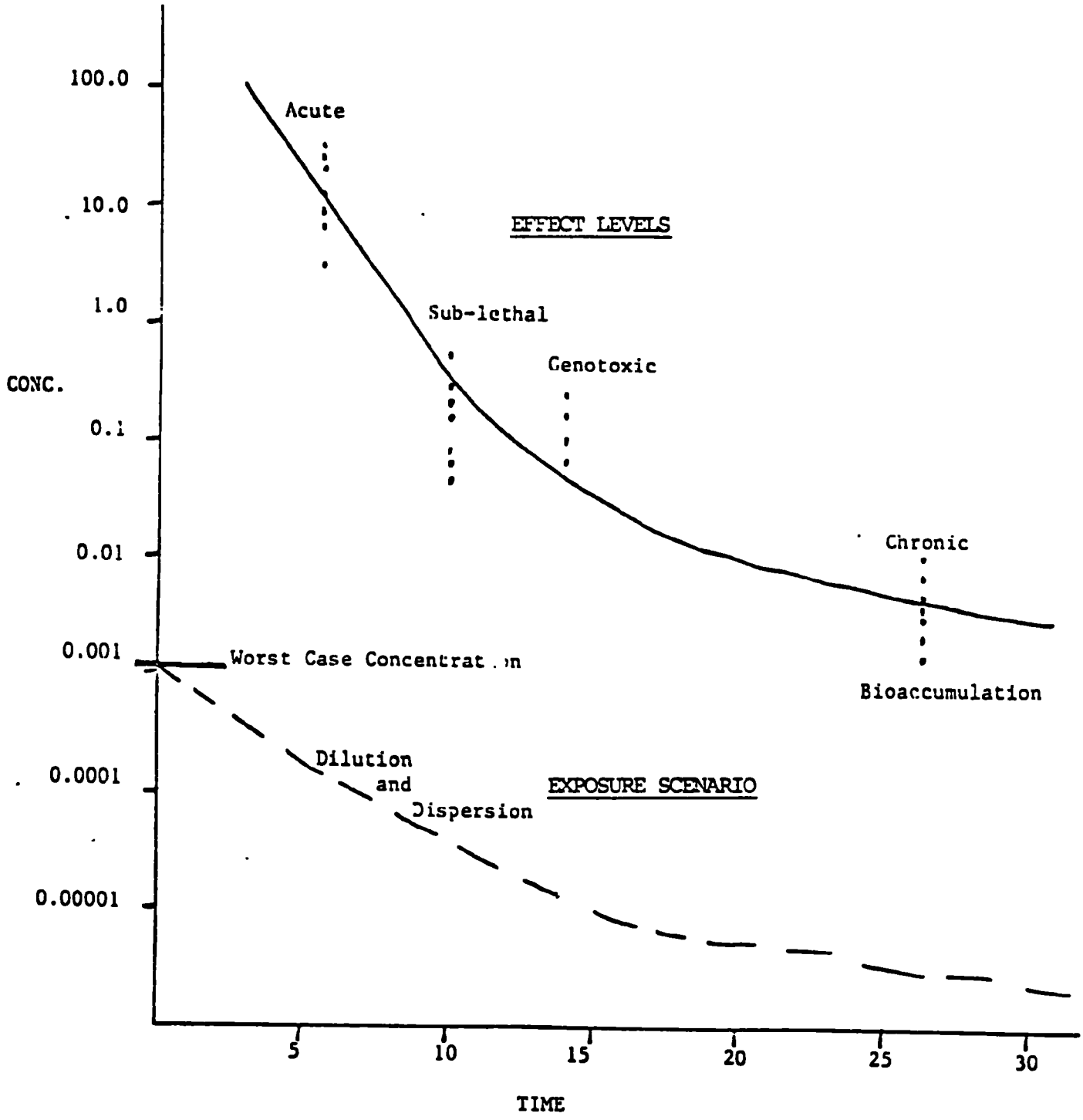
The objective of the aquatic toxicology part of this strategy is to determine from laboratory studies the concentration of emissions that produce significant changes in a suite of biological responses ranging from acute mortality to growth and reproduction. These biological responses to various concentrations of emission substances can then be compared to the concentrations estimated to occur in the environment, and decisions can be made regarding the acceptability of ocean incineration (see hypothetical example in Figure 1).

Before any biological testing can be initiated using emissions from burning hazardous wastes at sea, the testing methods themselves must be developed and proven effective. Preliminary studies will therefore be conducted where an operational, land-based combustion facility will be used as a source of emissions, and various emissions collection methods will be tested. These methods will include passing emission gas through a tank of seawater which will act directly as an adsorbent. This bubble-through method will require water, pH, and temperature adjustment before being used in bioassays on selected organisms.

This testing will also include a determination of the appropriate bioassay procedures, standard test organisms, and end points which should be used in at-sea studies.

After sampling methods and toxicity test procedures are developed, the approach is to collect emission products during an at-sea research burn and to use emissions to generate exposure response curves for the most sensitive life stages of standard test species using intercalibrated test protocols. A test of these procedures may be conducted at a land-based hazardous waste incinerator for toxicity range finding prior to a research burn at sea. Additional test species will subsequently be selected to include representatives of the indigenous neuston population and sensitive life stages of commercially important crustaceans, molluscs, and fishes. The chronic toxicity tests will follow the recommendations of the Water Quality Guidelines Committee (1984) as much as possible, and the specific toxicity test protocols for conducting the test will follow ASTM standard practices whenever applicable.

FIGURE 1




EFFECT CONCENTRATIONS AND WORST CASE EXPOSURE ESTIMATE (HYPOTHETICAL)

Because of the potential limitation of the test material, a hierarchical testing strategy will be employed in first attempts to define the relationship between acute and chronic responses for standard test species and then determine the range of acute toxicities for indigenous species. ' The mean of the acute: chronic ratios from the standard test species will then be applied to the acute toxicity values of the indigenous species to estimate the chronic values of the most sensitive species.

Specific test species cannot be recommended with certainty at this time. However, the strategy proposed in previous sections will logically suggest the selection of certain species types. For example, in order to optimize the predictive nature of the effects testing, species such as those for which we have standard protocols and extensive comparative toxicological data bases will be given priority. Next, we need to look at indigenous species to address the question of whether the standard species are representative of the sensitivity of the indigenous species. This will allow us to place some confidence limits on predictions made from standard test species. The precise approach to these types of tests will require further investigation.

The types of biological responses that should be measured range from survival to integrative responses such as growth and reproduction. For selected standard test species, methods have been developed for measuring the latter integrative responses from short-exposure durations and should be applied to this problem since the duration of the tests will be strongly influenced by the availability of the emission condensate.

Estimates of the potential for bioaccumulation of emission products will be conducted using predictive methodologies including the application of log-octanol water partition coefficients to those emission products that are identified in the emissions. Direct measures of bioaccumulation will be difficult due to the limited amount of emission product but will be attempted on those chronic studies where calculations indicate that the tissue residues could conceivably reach levels of analytical detection given the exposure concentrations, bioaccumulation factors, and available sample size.

Because of the nature of the original feedstock contaminant composition and the combustion processes, there is the possibility of genetic toxicants being present in the emissions. To test this hypothesis, a hierarchy of genotoxicity tests ranging from the Ames Test for mutagenicity, to tests for genetic damage (Sister Chromatid Exchange), to tissue culture tests designed to address the potential for tumor promotion are included in "Area 3" studies. However, the need to conduct these higher level tests will depend on initial data on the chemical characterization of the emissions and the availability of material.

### 3.3.3 Effects on the Surface Microlayer

Because surface microlayers can serve as food for higher organisms, the potential exists for food chain bioaccumulation of organic substances accumulated in the microlayer. If laboratory tests are indicated, studies should be conducted to determine the potential for bioaccumulation of these chemicals where appropriate.

EPA already possesses information showing that significant quantities of acid (HCl) will be emitted from combustion of organochlorine waste. If these acid emissions contact the ocean surface too rapidly and are not neutralized fast enough, they could adversely affect the organism structure or functions of the microlayer. Tests should be undertaken to determine the potential impact of acid emissions on surface film organism structure and function.

Since microorganisms accumulate in the surface microlayers (dinoflagellates, ciliates, and bacteria), acid precipitation from plume fallout could affect their life cycles. The potential damage to the ecosystem from such changes is only specula on. Certain microbes, however, can only function within narrow pH ranges, and speciation of certain metal ions necessary for growth and metabolic reaction are regulated by small pH changes.

Endpoints of concern other than death and bioaccumulation can be addressed in a laboratory situation using bioassays to determine potential impacts of incineration acid fallout. These bioassays include: ATP (total viable microorganisms predominantly algae), phospholipid (total bacterial content), and 14C-glucose metabolism (heterotrophic activity levels). Other biochemical characterizations of microbiological and macrobiological communities can be utilized to investigate changes in community structure and function.

Disruption of the community structure may or may not result in changes in the community function when changing the environmental pH. It has been suggested that acid rain deposition on terrestrial ecosystems can change the nitrogen recycling to some extent. Investigations of critical cycles in marine surface films can be addressed. However, initial studies will be needed to determine what function these films play in the current cycling in the open waters. It is believed that these films are vastly important to detrital and fecal degradation since the decomposer populations are 10 - 10,000 times higher in this area than in subsurface water.

### 3.3.4 Comparative Environmental Risk Assessment

Ecosystem impacts are typically inferred from tests on individual species from which forecasts are made to the population and community levels of biological organization. This can be accomplished by interfacing the source inputs (e.g., pollutant type and loading rate) to the biological effects through measurements of environmental exposure. Pollutant input rates are then used as source terms for transportation and fate models which are used to predict pollutant concentration isopleths on defined spatial and temporal scales. This form of output is directly compatible with biological effects measurements in the laboratory that are typically described as functions of pollutant concentration and exposure duration. The conduct of a risk assessment occurs when the probability of environmental impact is estimated from a comparison of the environmental contaminant exposure with contaminant concentrations producing biological effects.

One of the principal features of a risk assessment strategy is that the effects and exposure components are tiered. The ordering of the tiers implies increasing degrees of complexity, resolution, and predictive confidence. An additional assumption is that there are clearly defined criteria for decisions at each level of the hierarchy which then trigger the need for increased data acquisition at the higher, more complex tiers. A prediction of hazard is made by comparing the predicted environmental exposure concentration of the material (exposure assessment) and the concentration producing biological effects in the laboratory studies (effects assessment) at each tier. When properly synthesized, these data provide a confidence-bounded estimate of the probability (risk) of unacceptably altering the aquatic environment as the result of the disposal of the waste. If either the confidence of the prediction or the probability of risk is unacceptable, then additional levels of testing can be conducted. This strategy places the biological tests in a hierarchy of complexity which reflects a continuum from detection to assessment methods with increasing predictive confidence, and directly relates the contaminant concentrations causing effects to the predicted environmental concentrations determined at the same hierarchical level. This approach permits the development of a series of testable hypotheses that is amenable to both laboratory and field verification.