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AL-TR-1991-0101

ARMSTRONG LABORATORY

PRELIMINARY PUBLIC HEALTH, ENVIRONMENTAL RISK, AND DATA REQUIREMENTS ASSESSMENT FOR THE HERBICIDE ORANGE STORAGE SITE AT JOHNSTON ISLAND

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October 1991

Final Report for Period September 1990 - August 1991

Approved for public release; distribution is unlimited.

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235-5000

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This report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE October 1991

3. REPORT TYPE AND DATES COVERED Final September 1990 - August 1991

4. TITLE AND SUBTITLE Preliminary Public Health, Environmental Risk, and Data Requirements Assessment for the Herbicide Orange Storage Site at Johnston Island

5. FUNDING NUMBERS
C: F33615-87-D-4024/0015

6. AUTHOR(S) Geoffrey Huse, Jeffrey Driver, Scott Baker, Louis Corio, Sally Kamem, Alfred Pinkney, Gary Whitmyre, Michelle Silkowski, Thomas Piccin, Leslye Wakefield, Nica Mostaghim, and Sonja Young

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
RiskFocus
VERSAR Inc.
6850 Versar Center
Springfield, VA 22151

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Occupational and Environmental Health Directorate
Brooks Air Force Base, TX 78235-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL-TR-1991-0101

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report contains the results of a screening-level risk assessment conducted for the Air Force Armstrong Laboratory, Occupational and Environmental Health Directorate, concerning the Herbicide Orange storage site at Johnston Island. The risk assessment is part of a remedial investigation and feasibility study (RI/FS) process established by the U.S. EPA for characterizing the nature and extent of risks posed by hazardous waste sites and for developing and evaluating remedial options. This process is being conducted in the context of the U.S. Department of Defense Installation Restoration Program (IRP).

14. SUBJECT TERMS
IRP, Risk Assessment, Herbicide Orange, Agent Orange 2,7,8,8-TCDD, Dioxin, 2,4-D, 2,4,5-T, Johnston Island, Johnston Atoll, RI/FS

15. NUMBER OF PAGES 308

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

Foreword

This report was prepared under the management and supervision of VERSAR's **RiskFocus** Division located in the Washington, D.C. metropolitan area. **RiskFocus** provides comprehensive *stewardship* for product integrity and registration, worker safety, waste disposal, regulatory interpretation and compliance, and risk communication.

Authorship of this report is credited to Geoffrey Huse, Jeffrey Driver, Scott Baker, Louis Corio, Sally Kamem, Alfred Pinkney, Gary Whitmyre, Michelle Silkowski, Thomas Piccin, Leslye Wakefield, Nica Mostaghim and Sonja Young. Special thanks is given to Sylvia Johnson for word processing and other editorial support. Quality assurance is credited to Gary Whitmyre. Further information about this report may be obtained by writing directly to Robert Tardiff, Director, **RiskFocus** Division or by calling 703/642-6884.

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Ref No 61.5049.15.2

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Executive Summary

This report contains the results of a screening-level risk assessment conducted for the Air Force Occupational and Environmental Health Laboratory concerning the Herbicide Orange (HO) storage site at Johnston Island (JI). The risk assessment is part of the remedial investigation and feasibility study (RI/FS) process established by the U.S. EPA for characterizing the nature and extent of risks posed by hazardous waste sites and for developing and evaluating remedial options. This process is being conducted in the context of the U.S. Department of Defense (DoD) Installation Restoration Program (IRP).

After the Vietnam war, in April 1972, 1.37 million gallons of unused HO in 24,910 fifty-five gallon drums were transferred to JI and stored on a 4-acre site at the northwest corner of the Island. The HO stored on JI was successfully dedrummed and incinerated at sea in 1977. While stored on the Island, the sea air corroded some of the steel drums, resulting in HO leakage onto the ground and necessitating an active maintenance and redrumming operation at the storage site. It has been estimated that approximately 49,000 pounds of HO escaped into the environment annually during the period from 1972 to 1977. The HO stock was determined to contain two active ingredients (the n-butyl ester of 2,4-dichlorophenoxy acetic acid (2,4-D) and the n-butyl ester of 2,4,5-trichlorophenoxy acetic acid (2,4,5-T), as well as 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) as a byproduct contaminant of 2,4,5-T. Consequently, through leakage and spillage during maintenance, redrumming, dedrumming, and drum crushing operations, the site was contaminated over a period of six years with 2,4-D, 2,4,5-T, and TCDD. The site has remained essentially untouched since that time.

Objectives of the study. There is some concern that contaminants at the site may be moving offsite into all environmental media: the adjacent air compartment, seawater, sea sediments, and groundwater aquifer that may underlie the site. It follows that if the contaminants are in any or all of these media, humans associated with them and biota contained in them may have a potential for exposure to HO site-derived contaminants and an attendant health risk. Therefore, the site-specific objectives of this investigation are to determine, based on available evidence:

- The potential contaminants at the site;
- The levels of contaminants at the site;
- The potential levels of the contaminants in each offsite environmental compartment;
- The potential levels of exposure to humans and wildlife, and to humans from biomagnification in the food chain; and finally
- The risk of health injury from potential multimedia exposure.

A companion objective is to determine, within the scope of existing environmental regulations, whether the quantified risks fall within acceptable risk limits.

The HO site on JI is a unique environment with exceptionally uneven scientific data (particularly on the monitoring of environmental media) because data collection practices, in accordance with the needs prescribed for a baseline risk assessment, have not been orderly and systematic over the years since HO was stored there and contamination began. As a result, the risk assessment contained in this document includes reasonable conservative assumptions to bridge information gaps where such information is usually present to support the baseline assessment. A more complete baseline risk assessment, suitable for responsible decision-making on remedial alternatives and closure, can be constructed only after additional field data at the HO site are collected.

Chemicals at the site. Thirteen monitoring studies were undertaken during and after disposal of the HO to characterize the site, including sampling of marine biota, ocean sediments, air, and soil. Selected sampling of marine biota have revealed the presence of TCDD. Although sampling has not been systematic and the results are not definitive, 37%, 16%, and 12.5% of the marine biota taken at three sampling sites around the HO site contained measurable quantities of TCDD. Of 38 sediment samples taken between 1985 and 1988, only two have been positive (160 and 190 ppb) above the 50 or 100 ppb detection limit for TCDD. No monitoring has been conducted for 2,4-D and 2,4,5-T in marine sediments and biota.

Air monitoring has occurred in support of the Johnston Atoll Chemical Agent Disposal System (JACADS). Insignificant levels of particle-associated

TCDD were dispersing from the HO site during the sampling period, given that these samplers were downwind of at least the southern portion of the HO site's total surface area, in addition to being downwind of the soil decontamination experiments. However, because of the limited number of samples and the lack of data for the entire downwind area relative to the HO site (i.e., the western fenceline), no conclusions can be made regarding TCDD exposure potential via inhalation of contaminated, airborne particulate at the time the samples where taken in 1986, or particularly prior to 1986, when the site was being used for storage purposes.

The groundwater under the HO site has never been analyzed for HO or dioxin.

Three comprehensive soil characterization activities produced surface and subsurface soil data on 2,4-D, 2,4,5-T, and TCDD throughout the defined waste site and at selected areas around the waste site. These data formed the basis of the risk assessment. The most recent soil study (1984-86) revealed TCDD levels in surface soil ranging from nondetect (0.01 ppb) to 163 ppb, with an average concentration of 0.8 ppb. 2,4-D in surface soil ranges from 2.5 ppb to 281,330 ppb with an average of 49,986 ppb. 2,4,5-T in surface soil ranges from 53 ppb to 237,155 ppb, with an average of 48,914 ppb.

Approximately 25% of the site was sampled for subsurface TCDD in the 3-7 inch layer of subsurface soil. Values ranged from 0.02 ppb to 207 ppb, with an average reading of 15 ppb. Approximately 2% of the site was sampled for subsurface 2,4-D and 2,4,5-T. Values for 2,4-D ranged from 2.5 ppb to 55,070 ppb, with an average reading of 4138 ppb (all but two values were below 44 ppb). Values for 2,4,5-T ranged from 7 ppb to 82,210 ppb, with an average reading of 6210 ppb (two-thirds of the values were below 100 ppb).

Exposure scenarios. Exposure assessment for the HO site included determination of the exposure setting and the exposure pathways that are of particular relevance to the types of human populations present and their respective activity patterns and thus involved characterization of the potentially exposed populations, descriptions of the identified plausible exposure pathways, estimations of human exposure, and identification of uncertainties related to the exposure assessment methods used in this evaluation.

In addition to the current scenario, two future land use scenarios were considered: (1) remediation through excavation and incineration of contaminated soil; and (2) covering of the site with cement.[1] In both of these scenarios, certain activities such as construction vehicles on the site and excavating alter the patterns of particulate suspension and soil volatilization of contaminants from those in the current use scenario. These were incorporated into the calculation of emission factors and exposure estimation. Based on the activities associated with these scenarios and consideration of the currently available soil sampling data, the following potential future exposure pathways were considered for:

- *Future-Use Scenario 1 (Excavation)*: Inhalation of contaminated soil from vehicular traffic, loading and unloading operations during site excavation and treatment, and wind erosion of disturbed soil.

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[1] The latter scenario is not intended to be a substitute for prescriptive site capping, which is a more thorough and rigorous form of remediation.

- *Future-Use Scenario 2 (Cement Covering)*: Inhalation of contaminated soil from vehicular traffic and wind erosion of disturbed soil.

Exposure Quantification. Risk to the theoretical maximum exposed individual (MEI) is based on access to any point around the perimeter of the HO site (including the seawall) and selection of the maximum point of exposure around the perimeter. However, in actuality there are certain limitations to where the MEI can be situated because of the restrictions on access to the site. Therefore, risk to an *alternate*, more realistic MEI (a person who has "reasonable maximum exposure"), restricted to the portion of the site boundary that is fenceline and not the inaccessible portion of the site boundary that is seawall, was also calculated for comparison. As a result, risk was calculated for two receptors, the theoretical MEI (TMEI) and the alternate MEI (AMEI).

The Industrial Source Complex (ISC) model was used in a screening mode to conservatively estimate ambient air concentrations of the vapor-phase compounds. A total of 140 ground-level, non-buoyant, point sources were used to represent the area of compound emissions in the modeling. The main HO site was extended westward to the shoreline to include isolated TCDD "hotspots" and this identical area was used for estimating 2,4-D and 2,4,5-T emissions.

Emission rates and exposures were estimated for the current scenario and the two future-use scenarios, taking into account wind erosion, construction, excavation, and vehicular traffic. For both vapor-phase and particulate-bound TCDD, Lifetime Average Daily Dose (LADD) was calculated for the TMEI and AMEI. In similar fashion, Average Daily Dose (ADD) was calculated for 2,4-D, and 2,4,5-T. The results are presented in Table ES-1.

TABLE ES-1

Estimated lifetime average daily absorbed dose (LADD)
and average daily absorbed doses (ADD) expressed as mg/kg/day
for TCDD, 2,4-D, and 2,4,5-T resulting from
inhalation exposure to the TMEI and the AMEI.

CURRENT SCENARIO

Chemical	TMEI		AMEI	
	LADD	ADD	LADD	ADD
TCDD	5.6×10^{-11}	2.3×10^{-10}	5.6×10^{-11}	2.3×10^{-11}
2,4-D		4.1×10^{-6}		1.5×10^{-6}
2,4,5-T		4.5×10^{-6}		2.9×10^{-6}

FUTURE SCENARIO: EXCAVATION

TMEI		AMEI	
LADD	ADD	LADD	ADD
1.5×10^{-12}	1.6×10^{-10}	1.5×10^{-12}	1.6×10^{-10}
----	2.7×10^{-6}	----	1.2×10^{-6}
----	3.0×10^{-6}	----	1.9×10^{-6}

FUTURE SCENARIO: CEMENT COVER CONSTRUCTION

TMEI		AMEI	
LADD	ADD	LADD	ADD
3.5×10^{-13}	7.5×10^{-11}	3.5×10^{-13}	7.5×10^{-11}
----	1.3×10^{-6}	----	5.0×10^{-7}
----	1.5×10^{-6}	----	9.4×10^{-7}

Exposure to contaminated fish. There is TCDD fish contamination in certain areas. The contamination appears to be restricted to the area adjacent to the former HO storage site, which is off-limits to fishing. If contaminated fish migrate into the fishing areas near the former HO storage site, there is a potential for JI inhabitants to consume contaminated fish. For the fish that showed positive TCDD values, the migratory fish species had the lowest values. These values may be low because these fish may not spend all of their time in the contaminated area. It is not possible to quantify this potential exposure because the fishermen's catches have not been sampled. The potential for exposure may be low, but sampling of the fishermen's catches should be performed to confirm this. Sampling at the west wharf has revealed no contaminated fish. This may indicate a low probability of catching a contaminated fish.

Risk assessment. Critical toxicological dose-response data for TCDD, 2,4-D, and 2,4,5-T are presented in Tables ES-2 and ES-3. Application of the slope factors (for carcinogenic effects) and R_fD's (for noncarcinogenic effects) in these tables, representing the toxicity component, to the LADD's and ADD's, respresenting the exposure component, produces estimates of risk. Although all media were considered in the analysis, lack of or inadequate monitoring data on water and marine biota reduced multimedia considerations to air only. For this medium, both vapor phase and chemical-bound particulate were factored into the calculations.

For the *current scenario*, the cancer risk from exposure to TCDD is 3×10^{-5} for the TMEI and 3×10^{-5} for the AMEI. The hazard quotient (for noncarcinogenic risk) from exposure to TCDD is 0.76 for the TMEI and 0.76 for the AMEI. The hazard quotient from exposure to 2,4-D is 0.0014 for the TMEI

TABLE ES-2
Critical Carcinogenic Toxicity Values for Indicator Chemicals

Chemical Name	Slope Factor (SF) (mg/kg-day)$^{-1}$	Weight of Evidence Classification	Type of Cancer	SF Basis/ SF Source
Oral Route				
2,3,7,8-Tetrachlorodibenzo-p-Dioxin[a]	1.56×10^5	B1[a]	Lung, liver, hard palate, nasal turbinates	Food/ATSDR
2,4-Dichlorophenoxy acetic acid[b] (n-butyl ester)	No data	No data	No data	No data
2,4,5-Trichlorophenoxy acetic acid[b] (n-butyl ester)	No data	No data	No data	No data
2,4,5-Trichlorophenoxy acetic acid[b] (Iso-octyl ester)	No data	No data	No data	No data
Inhalation Rate	No data	No data	No data	No data

[a] When associated with phenoxy herbicides and/or chlorophenols, B2 when considered alone.

TABLE ES-3
Critical Noncarcinogenic Toxicity Values for Indicator Chemicals

Chemical Name	Chronic R_fD (mg/kg-day)	Confidence Level[a]	Critical Effect	R_fD Basis/ R_fD Source	Uncertainty and Modifying Factors[b]
Oral Route					
2,3,7,8-Tetrachlorodibenzo-p-Dioxin	1×10^{-9}	No data	<u>Primary:</u> Fetal survival <u>Secondary:</u> Renal	No data/ ATSDR	UF=100 for A, L MF=10
2,4-Dichlorophenoxy acetic acid (n-butyl ester)	1×10^{-2c}	Medium	<u>Primary:</u> Renal <u>Secondary:</u> Hematologic, hepatic	Food/ IRIS	UF=100 for H, A MF=1
2,4,5-Trichlorophenoxy acetic acid (n-butyl ester)	1×10^{-2d}	Medium	<u>Primary:</u> Neonatal survival <u>Secondary:</u> Increased urinary coproporphyrin	Food/ IRIS	IF=300 for H, A, D MF=1

Inhalation Route	No data	No data	No data	No data	No data

[a] Confidence level from IRIS, either high, medium, or low.

[b] Uncertainty adjustments: H=variation in human sensitivity; A=animal to human extrapolation; and D=deficiencies in toxicity data.

[c] R_fD value for acid, n-butyl ester value not available.

[d] R_fD value for acid, n-butyl ester and iso-octyl ester values not available.

and 0.00051 for the AMEI. The hazard quotient from exposure to 2,4,5-T is 0.0015 for the TMEI and 0.00095 for the AMEI.

For the *future-use scenario involving excavation (Scenario 1)*, the cancer risk from exposure to TCDD is 8 x 10^{-7} for the TMEI and 8 x 10^{-7} for the AMEI. The hazard quotient from exposure to TCDD is 0.52 for the TMEI and 0.52 for the AMEI. The hazard quotient from exposure to 2,4-D is 0.00090 for the TMEI and 0.00034 for the AMEI. The hazard quotient from exposure to 2,4,5-T is 0.0010 for the TMEI and 0.00063 for the AMEI.

For the *future-use scenario involving paving (Scenario 2)*, the cancer risk from exposure to TCDD is 2 x 10^{-7} for the TMEI and 2 x 10^{-7} for the AMEI. The hazard quotient from exposure to TCDD is 0.25 for the TMEI and 0.25 for the AMEI. The hazard quotient from exposure to 2,4-D is 0.00045 for the TMEI and 0.00017 for the AMEI. The hazard quotient from exposure to 2,4,5-T is 0.00049 for the TMEI and 0.00031 for the AMEI.

Ecological effects. Releases of HO have exposed fish and invertebrates and possibly birds to dioxin. Only a rough estimate of risk is possible given the limitations of the data. When possible, risks were assessed by comparing body burdens with levels associated with toxic effects.

The highest concentration of dioxin was reported in the crown squirrelfish. Squirrelfishes tend to remain close to the bottom and do not travel long distances. These behaviors may increase their exposure to localized sources of dioxin in sediments. Out of four samples, TCDD was detected in one sample at 352 ppt and in one sample at 472 ppt. These concentrations exceed the 260 ppt measured in rainbow trout muscle that was associated with decreased growth and fin lesions. The only other fish species with concentrations exceeding 100 ppt was the yellowfin goatfish. Three samples had concentrations of 11, 85, and 102 ppt. Goatfishes are bottom feeders, which may account for their enhanced body burdens.

Several invertebrate samples were detected at levels between 14 and 28 ppt. The only invertebrate sample detected at greater than 100 ppt was a "snails" sample measured at 120 ppt. No data linking tissue concentrations with effects in snails could be located.

In three samples of birds, there were no detectable concentrations of dioxin.

Data requirements. There has not been a systematic effort in collecting the needed monitoring data at the HO site. To date, the most definitive data-collection activity has been soil characterization. ***In order for a multimedia baseline risk assessment to be considered complete enough to determine whether there is sufficient risk to warrant remediation (including a decision on the best cleanup and closure method from among the range of alternatives), the US Air Force needs to carefully craft a sampling plan and engage in a coordinated sampling and analysis activity[2] to provide the necessary baseline data.*** This is necessary so that:

- The output from the sampling and analysis serves as effective input to the baseline risk assessment;

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[2] With input from a sampling statistician, marine biologist, and Fish and Wildlife personnel associated with the Island, and in coordination with any other work being done to support JACADS.

- No further analyses will have to be done; and
- The sampling data used to predict exposure and risk are convincing enough to EPA in its decision-making process about clean closure of the site.

The nature of the needed data is described below by medium.

Air - The risk assessment used estimated values for the particulate and vapor phase emissions from the site. Air sampling would characterize the particulates and vapors coming from the site. Particle size distribution will enable determination of the percentage of respirable dust. To determine the wind erosion around the site several Hi-Vol samplers, equipped with particulate traps, could be placed downwind around the fence line. At the southwestern fenceline the odor of 2,4-D was detectable during the site visit, indicating that there may be significant vapor emissions from the site. Organic vapor phase samplers capable of collecting dioxins, 2,4-D, and 2,4,5-T can be placed around the site to characterize ambient air concentrations. There are other potential sources of dioxin on JI, including JACADS, the burn pit, and the fire training area. Sampling would permit source apportionment of dioxin from each of these sites.

Soil - The characteristics of the soil can have an influence on the bioavailability of dioxins and the other chemicals. Soil moisture content, organic content, and particle size distribution are missing elements that are important for lowering the uncertainty in the soil exposure calculations. It was originally planned to vertically sample the TCDD hot spots, but sample results were not available in time to accomplish this, and, therefore, some hot spots were missed in the vertical soil sampling. These hot spots could now be sampled vertically for all three compounds, TCDD, 2,4-D, and 2,4,5-T. Only 15 plots were sampled for 2,4-D and 2,4,5-T, presenting a spacial distribution for these compounds inadequate for risk assessment. More plots could be sampled for these two compounds. One method that can be used to accomplish this is to revisit the 48 plots that were originally vertically sampled. These 48 plots could be sampled for all three chemicals of concern. This sample design would have two benefits: (1) better knowledge of the spacial distribution for 2,4-D and 2,4,5-T; and (2) knowledge of the fate of these chemicals over time.

<u>Sediment</u> - Positive sediment samples were found near the western shore, prior to construction of the seawall in that area. This area could be revisited to determine if the seawall is performing according to its intended function. More sediment samples are needed to better characterize the spacial pattern of contamination. A grid pattern similar to the soil sampling protocol would help to characterize the spacial contamination pattern. These samples should include areas close to the shoreline.

<u>Water</u> - No seawater sampling has been conducted off the former HO site. TCDD levels of 38 pg/l are toxic to fish. Toxic endpoints include severe adverse effects on survival, growth, and behavioral responses. With this potency, seawater sampling may be important. The groundwater under the former HO site has never been sampled and may be a vital link in any discovery of HO site-related fish contamination.

<u>Biota</u> - More sampling can to be performed at offshore sites adjacent to the HO site to determine if contaminated fish are in this area. No biological samples have been analyzed for 2,4-D or 2,4,5-T. It is not possible to assess the potential impact from fish ingestion for these two chemicals if this analysis is

not performed. Several adult fish species inhabiting the waters surrounding the Island are known to have large migratory movements. A study could be performed to ascertain if these migratory fish species are moving from the waters adjacent to the former HO site into fishing waters. Sampling and analysis of fishermen's catches can be easily used to determine if humans are consuming contaminated fish. This is the only study that would demonstrate if the fish being consumed are contaminated.

Ecological risk - Further field investigations may be needed to adequately characterize the ecological risks at JI. Any additional research should be coordinated with the work underway by Dr. John Labelle of the Woods Hole Oceanographic Institute in support of the JACADS monitoring program. Additional sampling programs could be designed so that statistical comparisons can be made between concentrations in the different areas. In such an investigation sediment sampling would be expanded to allow better characterization of the spatial pattern of contamination. Biota samples would be focussed on species whose behavior may lead to greater levels of contamination (e.g., bottom feeding resident species). Organisms that are important parts of marine food chains (e.g., small invertebrates such as marine worms) would be sampled. Based on the available data, the crown squirrelfish, yellowfin goatfish, snails, and crabs are good candidates for further sampling. Increased sampling of birds may be required to determine whether populations are at risk due to consumption of contaminated prey (e.g., fish and snails). Sampling could focus on one or two bird species that tend to be localized on the Island.

Although the contaminant studies should remain focussed on dioxin, it would be useful to examine several fish samples for 2,4-D. This compound has been measured at levels as high as 281 ppm in soil samples on the Island. Although it is not bioaccumulated to the same extent as dioxin, measurable residues have been reported in fish from lakes treated with the compound and toxicity data are available.

Preliminary Public Health, Environmental Risk, and Data Requirements Assessment for the Herbicide Orange Storage Site at Johnston Island

1.0 Introduction

This report contains the results of a screening-level risk assessment conducted for the Air Force Occupational and Environmental Health Laboratory concerning the Herbicide Orange (HO) storage site at Johnston Island (JI). This risk assessment is part of the remedial investigation and feasibility study (RI/FS) process established by the U.S. EPA for characterizing the nature and extent of risks posed by hazardous waste sites and for developing and evaluating remedial options. This process is being conducted in the context of the U.S. Department of Defense (DoD) Installation Restoration Program (IRP). The following section provides a conceptual overview of the risk assessment for the HO storage site, site specific objectives of this investigation, a description of background information concerning the site, and defines the risk assessment's scope and study design.

1.1 Overview

During the Vietnam war, HO was widely used as a broad-scale defoliant. Large quantities of technical grade material were shipped to Vietnam. After the war, in April 1972, 1.37 million gallons of unused HO were transferred to JI from the stockpile in Vietnam for temporary storage. This was the result of the suspension of certain uses of 2,4,5-trichlorophenoxy acetic acid, a component of HO, by the Secretary of Health, Education and Welfare, and the Secretary of the Interior on April 15, 1970, following reports that HO may be teratogenic. The 24,910 fifty-five gallon drums of HO were stored on a 4-acre site at the northwest corner of JI (Figure 1.3). Further toxicity studies were conducted, and in September 1971 the Secretary of Defense directed the Joint Chiefs of Staff to dispose of all stocks of Herbicide Orange (HO). The HO stored on JI was successfully dedrummed and incinerated at sea in 1977. While stored on the Island, the sea air corroded some of the steel drums, resulting in HO leakage onto the ground and necessitating an active maintenance and redrumming operation at the storage site. Patrols of the storage area revealed approximately 20 to 70 leaking drums per week. It has been estimated that approximately 49,000 pounds of HO escaped into the environment annually during the period from 1972 to 1977 (Thomas et al., 1978). The HO stock was determined to contain two active ingredients (the n-butyl ester of 2,4-dichlorophenoxy acetic acid (2,4-D) and the n-butyl ester of 2,4,5-trichlorophenoxy acetic acid (2,4,5-T)), as well as 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) as a byproduct contaminant of 2,4,5-T (Holmes and Narver, 1989). Consequently, through leakage and spillage during maintenance, redrumming, dedrumming, and drum crushing operations, the site was contaminated over a period of six years with 2,4-D, 2,4,5-T, and TCDD. The site has remained essentially untouched since that time. Significant activities that have occurred include a trial burn of contaminated soil (Helsel et al., 1987), construction of a seawall for those portions of the site adjacent to the ocean (as referenced in Channell and Stoddart, 1984), and extensive soil sampling in 1984.

There is some concern that contaminants at the site may be moving offsite into all environmental media: the adjacent air compartment, seawater, sea sediments, and groundwater aquifer that may underlie the site. It follows that if the contaminants are in any or all of these media, humans associated with them and biota contained in them may have a potential for exposure to HO site-derived contaminants and an attendant health risk. Therefore, the site-specific objectives of this investigation are to determine, based on available evidence:

- The potential contaminants at the site;
- The levels of contaminants at the site;
- The potential levels of the contaminants in each offsite environmental compartment;
- The potential levels of exposure to humans and wildlife, and to humans from biomagnification in the food chain; and finally
- The risk of health injury from potential multimedia exposure.

A companion objective is to determine, within the scope of existing environmental regulations, whether the quantified risks fall within acceptable risk limits. As such, this is *not* an Applicable or Relevant and Appropriate Requirement (ARAR) analysis, which is based on remediation alternatives, associated cleanup levels, and their compliance with relevant and applicable regulations. An ARARs analysis follows later in the RI/FS process.

1.2 Site Background

Johnston Atoll (JA) is a group of isolated coral islands located in the central Pacific Ocean lying approximately 717 nautical miles southwest of Honolulu Hawaii (Figure 1.1). Four small islands, Johnston Island, Sand Island, North (Akau), and East (Hikina) Island, comprise the egg-shaped atoll (Figure 1.2). JI the largest of the islands, 625 acres, has been enlarged over the years with dredged calcareous sand and coral rubble. The Island is approximately two miles long and one-half mile wide. JI is very flat with its highest elevation at seven feet. The Island has a 9000 foot runway down its middle. Details of the construction of JI can be found in Holmes and Narver (1989).

JI is an unincorporated territory of the United States. It was originally created as a bird refuge by Executive Order 4467 on June 29, 1926, and on July 25, 1940 was designated a National Wildlife Refuge. Historically, the Island has been under the control of various federal agencies. The Island is currently under the control of the Defense Nuclear Agency (DNA). A detailed outline of the agencies that have controlled the Atoll can be found in Table 1.1.

Figure 1.2 illustrates the location of JI to the other islands on the Atoll. Sand Island is the major brooding grounds for the birds. A detailed history and description of the atoll can be found in the following references: U.S. Air Force (1974), Thomas et al. (1978), Crockett et al. (1986), and Holmes and Narver (1989).

The Island is currently used for two major purposes. First, in the late 50's and early 60's it was used to launch missiles for atmospheric testing of nuclear

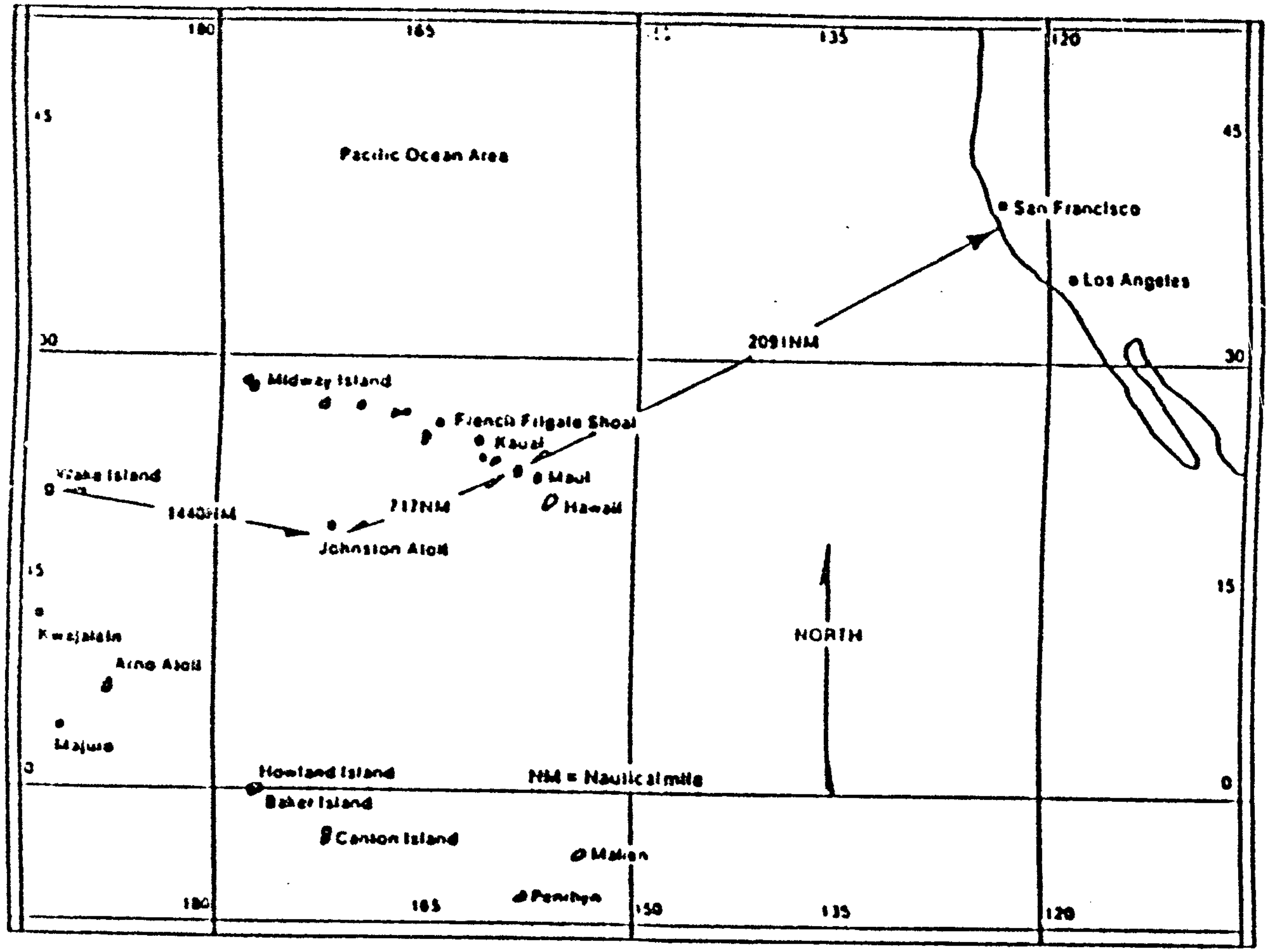
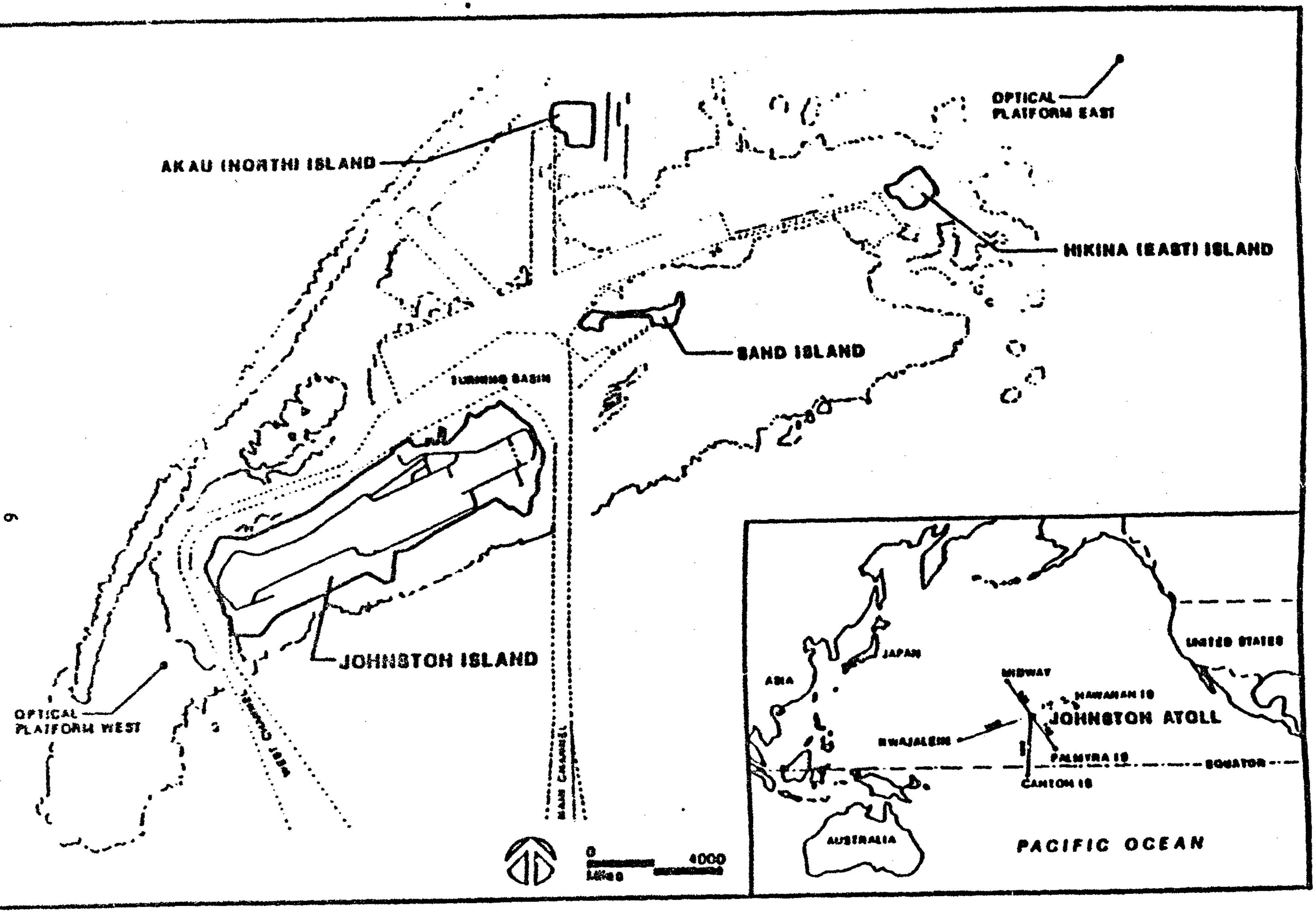


FIGURE 1.1 LOCATION OF JOHNSTON ISLAND
From Crockett AB 1986



JOHNSTON ATOLL LOCATION MAP
FIGURE 1.2
From Holmes & Narver 1989

TABLE 1.1 Ownership and Control of Johnston Atoll

Period	Jurisdiction	Operational Control	Purpose of Document	Authority	Event/Use
1926	Dept. of Agriculture	Agriculture	Plant and sea life surveys	*Executive Order 4467	Bird refuge (Executive Order June 29, 1926)
1934	Dept. of the Navy (USN)	USN	Pacific Defense	*Executive Order 6935	
1940	Dept. of the Navy (USN)	USN	Redesignation	Presidential Proclamation No. 2416	Johnston Island National Wildlife Refuge (July 25, 1940)
1941	Dept. of the Navy (USN)	USN	Established Naval Defense Sea Area for military sea and air operations	*Executive Order 8682	Became Johnston Island Naval Air Station
1947	Dept. of the Navy (USN)	USN	---	Secretary of the Navy	Became a Naval Air Facility
1948 July 1	Dept. of the Navy (USN)	USAF	Transfer of operational control to USAF	Agreement	Pacific Air Command (MATS, ARS, AACS, AWS Dets) (SecNAV ordered transfer to USAF)
1949 June 1	Dept. of the Navy (USN)	USAF	---	---	Pacific Air Command inactivated; Pacific Division MATS took over
1951-52	Dept. of the Navy (USN)	USAF	---	---	Korean airlift support
1957 Jan. 25	Dept. of the Navy (USN)	USAF	---	---	USAF granted Treasury Department five-year use for USCG LORAN
1957 Sept. 13	Dept. of the Navy (USN)	USAF	---	---	USAF granted Department of Commerce five-year use for U.S. Weather Bureau
1958 April 22	Dept. of the Navy (USN)	CJTF-7	---	Agreement	Atomic tests in Pacific area under Commander Joint Task Force-7 (CJTF-7) until August 19, 1958; then roll-up

TABLE 1.1 Ownership and Control of Johnston Atoll (continued)

Period	Jurisdiction	Operational Control	Purpose of Document	Authority	Event/Use
1959 June 30	Dept. of the Navy (USN)	USAF	—	--	**Secretary of the Treasury asked Secretary of Defense for Sand Island as LORAN Station, to be under operational control of Commander-in-Chief, Pacific**
1962 Jan. 17	Dept. of the Navy (USN)	CTJF-8/AEC	—	Agreement	**USAF signed Operations Agreement for 1962 nuclear tests**
1962 Jan. 18	Dept. of the Navy (USN)	CTJF-8/AEC	—	Agreement	**Commander-in-Chief, Pacific, signed agreement with Commander, Joint Task Force Eight (CJTF-8)**
1963 June 11	Dept. of the Navy (USN)	CTJF-8/AEC	—	--	**Joint Chiefs of Staff reaffirmed operational control of Joint Task Force Eight**
1970 July 1	Dept. of the Navy (USN)	USAF	**Transfer of operational control to USAF**	--	**JTF-8 inactivated. Deputy Secretary of Defense Memorandum to Secretary of Air Force**
1973 July 1	Dept. of the Navy (USN)	DNA (FCDNA)	**Transfer of operational control to DNA**	Agreement	**Department of the Air Force signed agreement with DNA**
1976	Dept. of the Navy (USN)	DNA	--	Agreement	**Safeguard "C" revised, JA placed in caretaker status**
1976	Dept. of the Navy (USN)	DNA	Responsibilities and jurisdiction guideline	Memorandum of Understanding DOD/DOI	**Allow the Departments to perform their functions in a manner that is mutually compatible and agreeable**

*Executive Orders are still in effect and have not been amended or rescinded as to affect "ownership."

Source: Johnston Atoll Chemical Agent Disposal System (JACADS) Final Environmental Impact Statement, November, 1983.

From: Holmes and Narver, 1989.

weapons. In 1963 the Limited Test Ban Treaty banned atmospheric nuclear testing. The facilities at JI are still maintained for this purpose in case this type of testing is deemed necessary for national defense. These facilities are currently held in a caretaker status. During 1962, three missile aborts caused transuranic contamination on parts of the Island, the section labelled LE-1 on Figure 1.3. The second purpose of operations at the Island has been to destroy chemical weapons at the Johnston Atoll Chemical Agent Disposal System (JACADS) facilities, which is a state-of-the-art incineration operation. The JACADS facilities are located in the "Red Hat" area of the Island.

Figure 1.3 illustrates the location of the HO site relative to the other facilities on the Island. A detailed map of the HO site is provided in Figure 1.4. The dedrumming area was used to redrum HO that was leaking from the corroded drums during their storage, and later during the HO removal process to transfer the HO from the drums to the trucks for transport to the wharf area and loading onto the incineration ship. A drum crusher was used in 1977 during the removal operation. The dedrumming and drum crushing areas are of particular interest in this investigation because they are potential sources of contamination. The purpose of a concrete pad in the northwest corner of the HO site has not been determined. A transformer, Hi-Vol air sampling station, beacon building, and a berm are adjacent to the site immediately downwind. The Hi-Vol sampler is associated with the JACADS operation. A fire training area and burn pit are located further downwind.

Thirteen separate media sampling and analysis studies have been conducted on JI. These are summarized in Table 1.2. The first study was conducted during the disposal of HO in 1977. The sites of sampling in various environmental media are presented in Figures 1.5 through 1.9. This study was

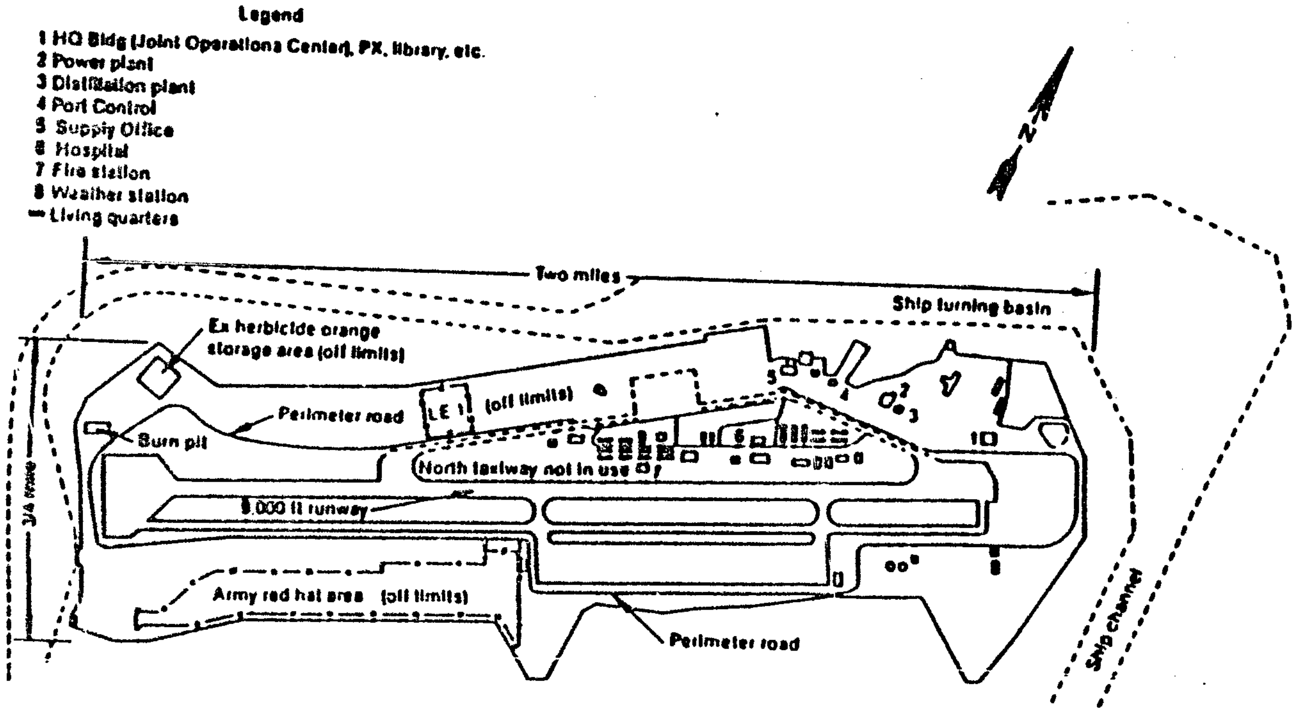


FIGURE 1.3 MAP OF JOHNSTON ISLAND
From Crockett AB 1986

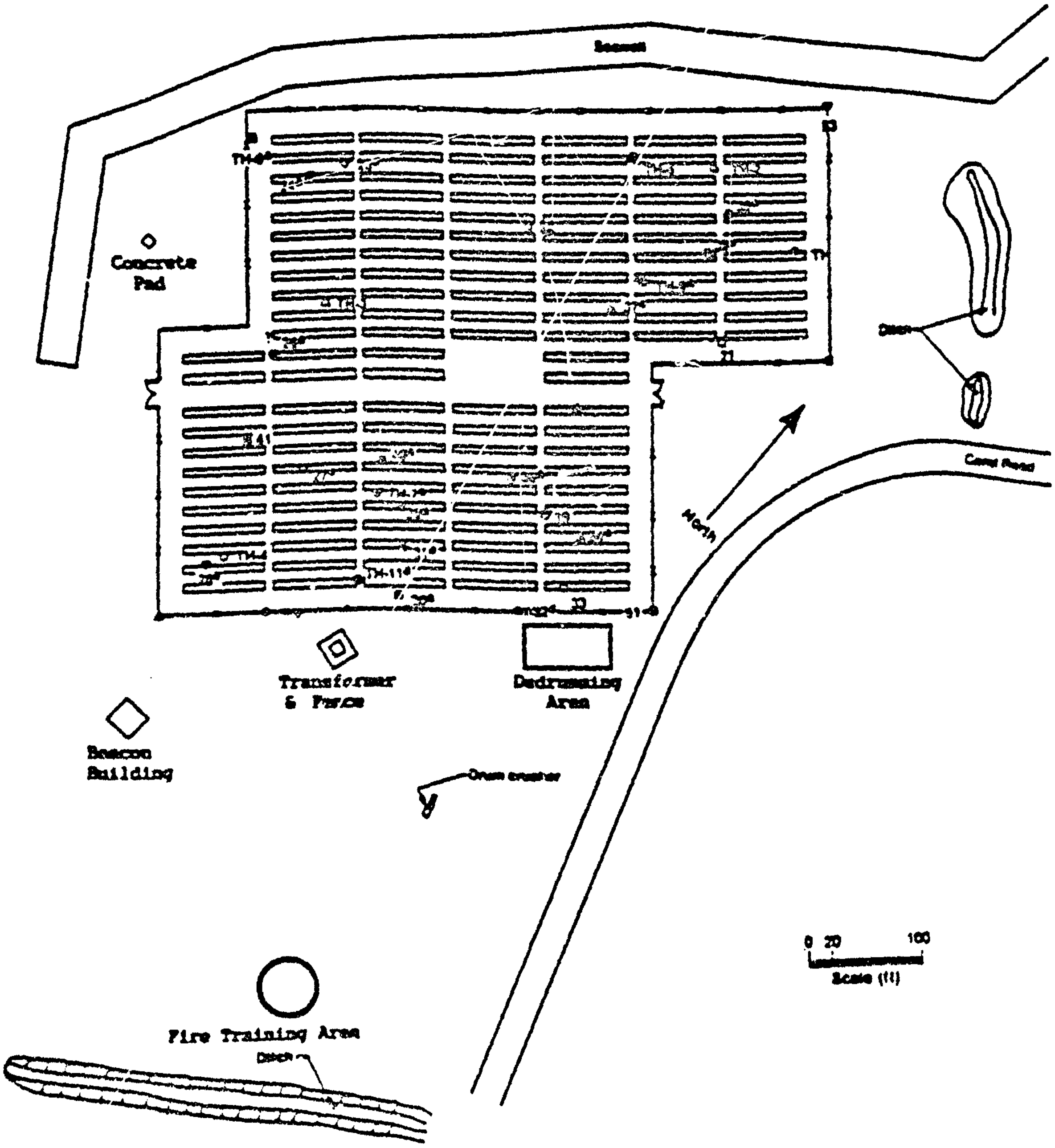


FIGURE 1.4 HERBICIDE ORANGE STORAGE AREA
From Crockett AB 1986

TABLE 1.2 Sampling Studies of Johnston Island

Study	Period of Performance	Soils	Ocean Sediments	Water	Air	Biota	Reference Document(s)
Associated with the Dedrumming Operation							
1. HO Monitoring during disposal of HO by OEHL	May 1977 - September 1978		X	X	X	X	Thomas, T.J., D.P. Brown, J. Harrington, T. Stanford, L. Taft, B.W. Vigon, September 1978, *Land-Based Environmental Monitoring at Johnston Island: Disposal of Herbicide Orange, May 1977 - September 1978*, OEHL TR-78-87, OEHL, AFOEHL, Brooks Air Force Base (AFB), Texas.
Associated with the Period Subsequent to the Disposal Operation							
2. Initial HO Monitoring Program by OEHL and ESL	August 1977 - September 1984	X	X				Channell, R.E., and T.L. Stoddart, April 1984, *Herbicide Orange Monitoring Program: Interim Report, January 1980-December 1982*, ESL-TR-83-56, ESL, AFESC, Tyndall AFB, Florida.
3. Supplementary Dioxin Biomonitoring Program	1984					X	Rhodes, 2 Lt., Albert N., January 2, 1985, *Johnston Island Fish Samples*, Letter to USAF OEHL/EC.
4. Supplementary Dioxin Biomonitoring Program	1985		X			X	Markland, Col. Darryl T., January 3, 1986, *Dioxin Monitoring at Johnston Island*, Consultative Letter, 85-192 EQ 805 MBC, to HQ USAF/SGES (Lt.Col. Capell).

TABLE 1.2 Sampling Studies of Johnston Island (continued)

Study	Period of Performance	Soils	Ocean Sediments	Water	Air	Biota	Reference Document(s)
5. Comprehensive Soil Characterization Study	April 1984-April 1986	X					Crockett, A.B., A. Propp, and T. Kimes, EG&G/Idaho, Inc., Idaho Falls, Idaho, October 1986, *Soil Characterization Study of Former Herbicide Storage Site at Johnston Island: April 1984-April 1986*, Final Report, ESL-TR-86-18, ESL, AFESC, Tyndall AFB, Florida.
6. JI Survey Sampling and Analysis Project in Support of the Johnston Atoll Chemical Agents Disposal System (JACADS)	September 1985	X			X[1]		Casanova, J.N., January 1986, *JI Survey Sampling and Analysis Project*, EG&G/Idaho, Inc., Idaho Falls, Idaho.
7. Supplementary Dioxin Biomonitoring Program	1986		X			X	Markland, Col. Darryl T., March 18, 1987, *Dioxin Monitoring Analytical Results, Johnston Island*, Consultative Letter, 87-031-EQ-805-CEF, to HQ USAF/SGPA.
8. Supplementary Dioxin Biomonitoring Program	May 1987		X			X	Forsell, Doug, May 11, 1987, *Second Quarter Samples Collected from Johnston Island for Dioxin Testing*, Letter to Chief Ecology Functions (Maj. Thomas Doane).

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[1] Dust and sweepings sampling.

TABLE 1.2 Sampling Studies of Johnston Island (continued)

Study	Period of Performance	Soils	Ocean Sediments	Water	Air	Biota	Reference Document(s)
9. Supplementary Dioxin Biomonitoring Program	October 1987		X			X	Forsell, Doug, October 4, 1987, *October Samples Collected from Johnston Island for Dioxin Testing*, Letter to Ecology Function (Maj. Elliott Ng), USAF OEHL.
10. Supplementary Dioxin Biomonitoring Program	January 1988		X			X	Forsell, Doug, January 16, 1988, *January Samples Collected from Johnston Island for Dioxin Testing*, Letter to Chief Hazardous Waste Function (Maj. Elliott Ng), USAF OEHL.
11. Supplementary Dioxin Biomonitoring Program	August 1988		X				Forsell, Doug, August 26, 198, *August samples from Johnston Island for Dioxin Testing*, Letter to Chief Hazardous Waste Function (Maj. Elliott Ng), USAF OEHL.
12. Supplementary Dioxin Biomonitoring Program	December 1988		X			X	Forsell, Doug, December 17, 1988, *December Samples Collected from Johnston Island for Dioxin Testing*, Letter to Chief Hazardous Waste Function (Maj. Elliott Ng), USAF OEHL.
13. Supplementary Dioxin Biomonitoring Program	December 1989					X	Mertens, Sharon K., December 7, 1989, *Analytical Results for December 1989 Regarding Contract F 33615-84-D-4402/0012/Analytical Work*, Letter to HSD/YAQI (Mr. Rodriquez).

Adapted from Holmes & Narver, 1989.

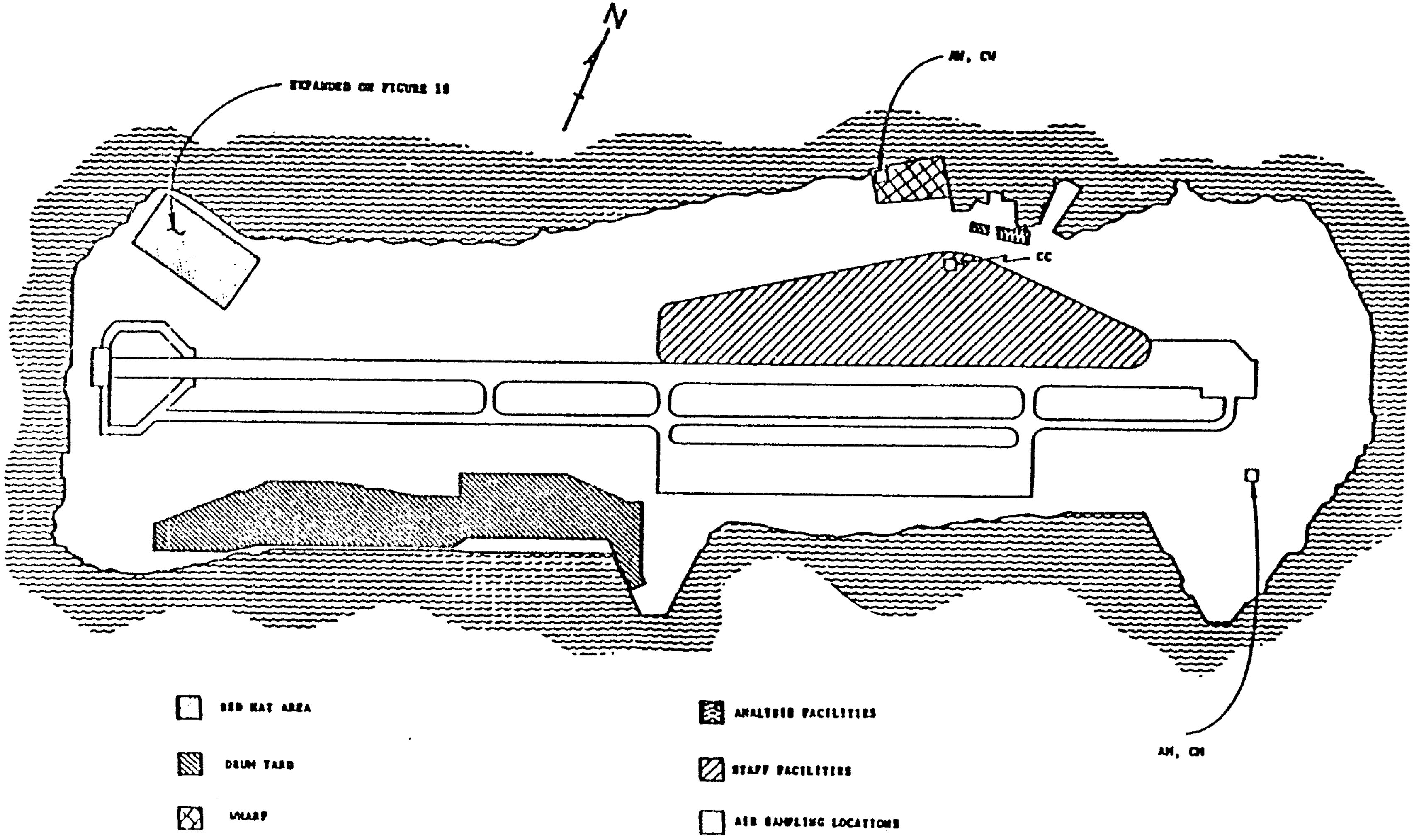

FIGURE 1.5 AIR SAMPLING SITES
From Thomas 1978

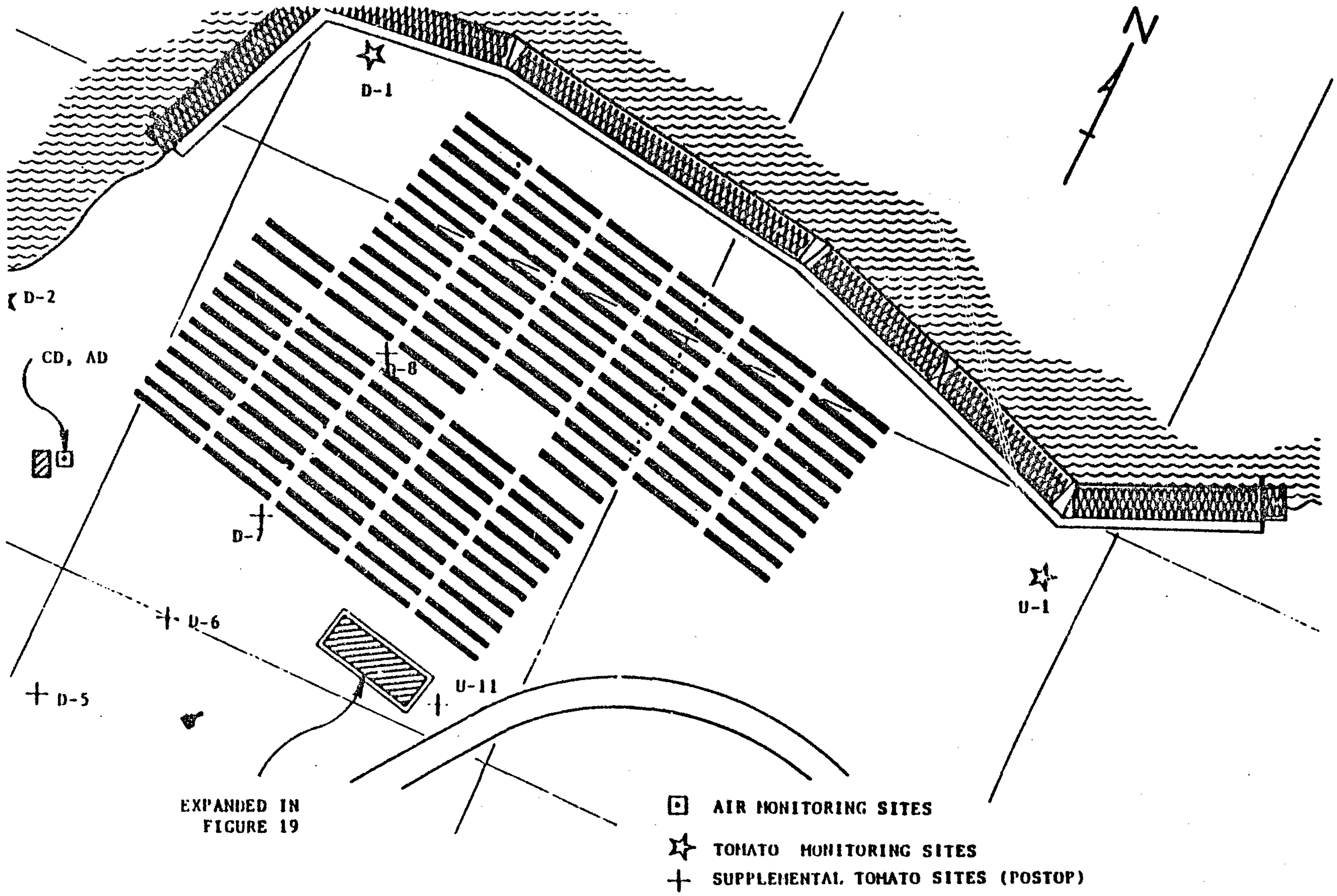

FIGURE 1.6 AIR MONITORING SITES, DRUMYARD
From Thomas 1978

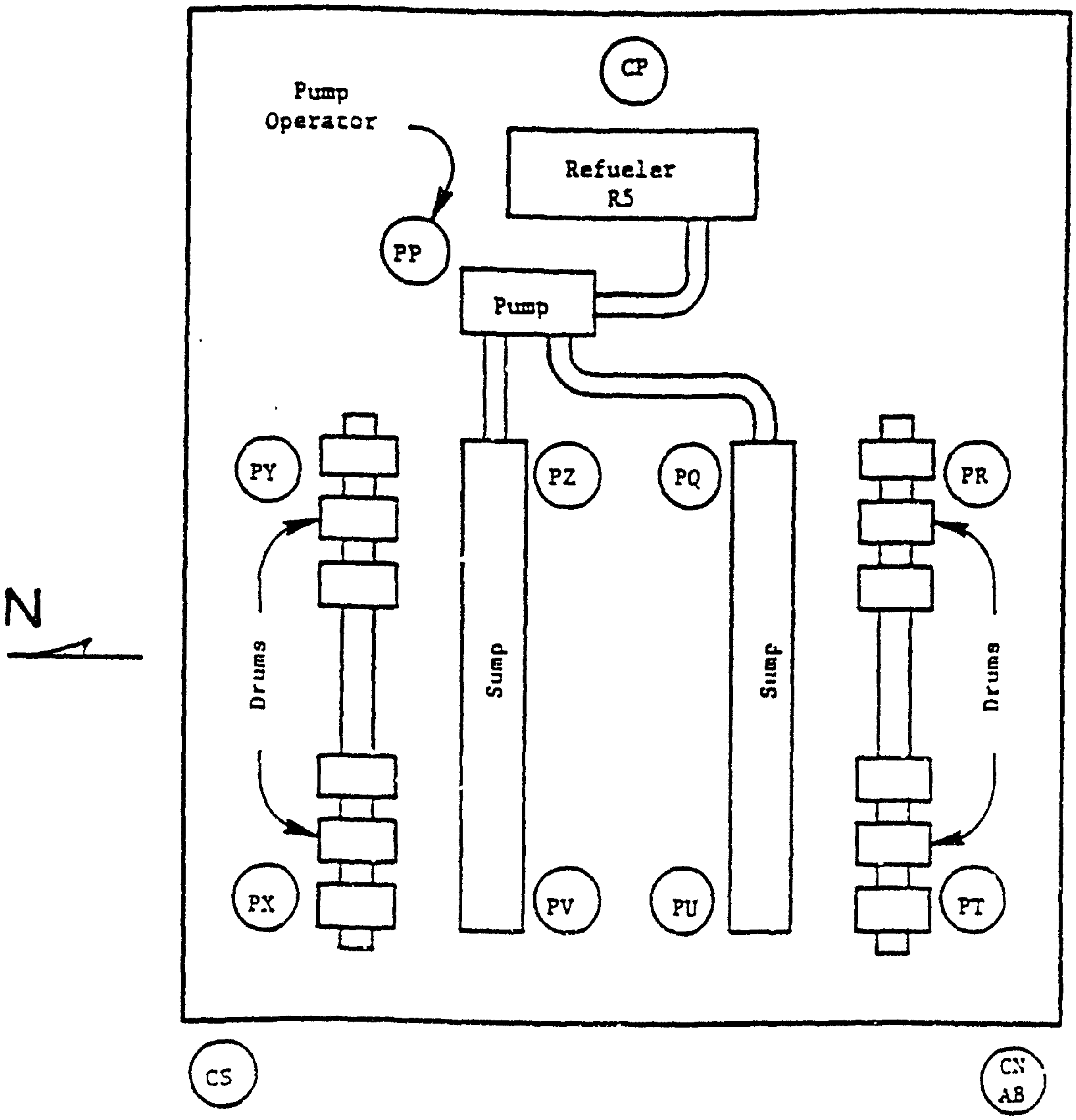

FIGURE 1.7 SAMPLING SITES AT DEDRUM FACILITY
From Thomas 1978

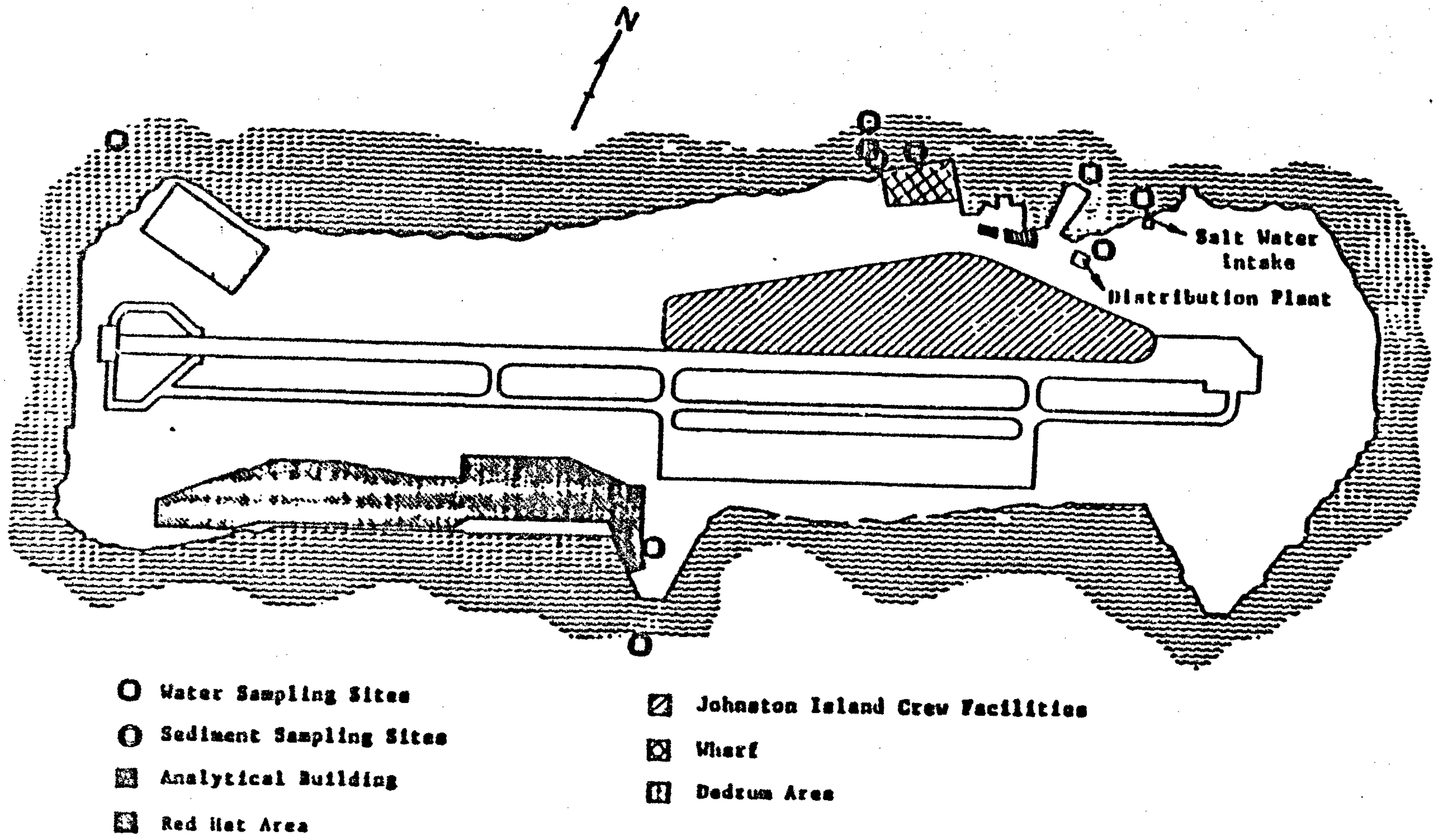

FIGURE 1.8 WATER AND SEDIMENT SITES
From Thomas 1978

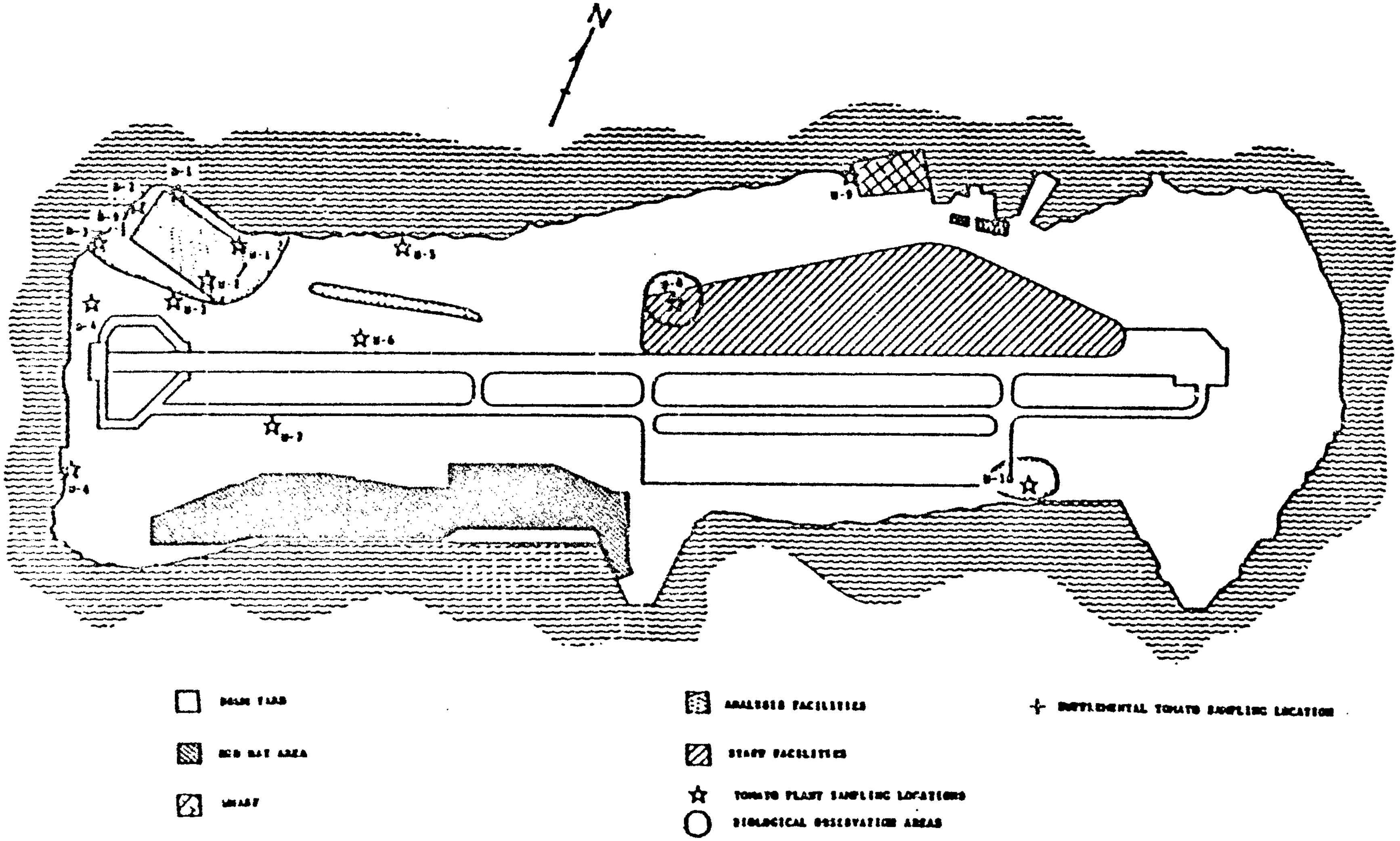

FIGURE 1.9 BIOTA MONITORING SITES
From Thomas 1978

used to assess the possible environmental impacts resulting from the disposal of HO. The ground water under the HO site has never been analyzed for HO or dioxin. The second through thirteenth studies continued to measure the impacts to the environment from the HO storage site after disposal was completed. Studies 3, 4, and 7 through 13 are part of a continuing effort to monitor biological effects from the former HO storage site. These studies include invertebrates, fish, and sediments around the former HO site and the west wharf, where sport fishing is conducted by Island inhabitants. The fifth study was conducted to obtain a comprehensive soil profile of the former HO storage site and the immediate surrounding area. The sixth study was initiated in support of the JACADS operation. It included TCDD soil measurements.

1.3 Scope of the Risk Assessment

This analysis follows the conventional structure of a risk assessment as laid out in documents of the EPA (1988c, 1989c). Its basic features include a health hazard assessment, exposure assessment, dose-response determination, and a risk characterization. The results of the risk characterization are then used to determine if existing concentrations on the site present a level of risk to human health and the environment that is acceptable or unacceptable and, if deemed to be unacceptable, the degree to which remediation is necessary to lower risks to an acceptable level.

This is a multimedia assessment that includes air, soil, water, and the food chain. The HO site has some unique features that make some of the multimedia components of the risk assessment straightforward and others complex. Among the straightforward components, the meteorological features of the Island and the surrounding area are the strongest, being well characterized, predictable, and relatively nonvariable. There is a finite human population that has a potential for exposure from all media and whose exposure is controllable should it be necessary. Access to the site can be limited or expanded to any degree desired, and there are a limited number of optional future uses for the site which limit the need for more elaborate analyses. On the complex side, possible offsite contamination means that the HO site is uncontained and extended into the surrounding environment. The site may be contiguous with the sea and marine environment via ground water and provides some element of runoff into the open water. The dynamics of the ocean as an environmental compartment are too difficult to characterize for predicting potential zones of contamination; nevertheless dynamic transfer from one environmental compartment to another (e.g., emission factors from soil into air, partitioning of TCDD into sediments and seawater) must be quantified. The soil composition (variable coral) is unusual and its characteristics poorly defined. Fate and transport phenomena must be accounted for to predict contaminant form and concentration in secondary media. As a mixture, chemical-chemical interactions, particularly associated with possible additive, potentiative, or synergistic effects of the mixture's toxicity must be considered. TCDD is a potent carcinogen and even though there is considerable evidence of carcinogenic and noncarcinogenic toxicity on 2,4-D and 2,4,5-T, there are no published benchmark toxicity values (UCR, RfD) that quantitatively represent their dose-response characteristics. There is a potential confounding effect posed by other sources and their contaminants on the Island (i.e., JACADS and the launch area). Lastly, as will be described in detail later, data on the site and surrounding area are quite limited.

This analysis should be considered as a *preliminary* baseline risk assessment. In a *full* baseline risk assessment that forms an integral part of the RI/FS process, prescribed procedures are followed as specified in key documents of the EPA, such as the *Human Health Evaluation Manual* (EPA, 1989c) and the *Superfund Exposure Assessment Manual* (EPA, 1988c). To the extent possible, these prescribed procedures were utilized. However, the HO site on JI is a unique environment with exceptionally uneven scientific data (particularly on the monitoring of environmental media) because data collection practices, in accordance with the needs prescribed for a baseline risk assessment, have not been orderly and systematic over the years since HO was stored there and contamination began. As a result, the risk assessment contained in this document includes reasonable conservative assumptions to bridge information gaps where such information is usually present to support the baseline assessment. Accordingly, *this risk assessment should be viewed only as a screening-level evaluation*, to:

- Provide a plausible preliminary estimate of risk;
- Identify the areas where information is needed to provide more quantitative estimates of risk with less associated uncertainty for decision-making by risk managers; and
- Provide a basis for determining what future data development ought to be undertaken to:
    - Decide if remediation is necessary and, if so, to what level of cleanup;
    - Enable adequate analyses of remedial options (including an assessment of residual risk associated with implementation of each viable remedial option and future use scenario); and
    - Aide in the sensible selection of the most appropriate option.

A more complete baseline risk assessment, suitable for responsible decision-making on remedial alternatives and closure, can be constructed only after additional field data at the HO site are collected. The default assumptions used in this screening-level risk assessment and the data needed to develop a more definitive risk assessment for the site are clearly laid out in discrete sections of this report.

1.4 Organization of the Report

This report generally follows the organizational structure recommended by the EPA (1989c) and is progressive in laying out the sequential components along the path to determination of human health risk. The site features relevant to this analysis, scope, and rationale are presented in Section 1.0. Data collection and evaluation practices, and identification of chemicals of concern are addressed in Section 2.0. A complete exposure assessment, including pathway analysis and exposure quantification for different scenarios is presented in Section 3.0. A toxicity assessment is presented in Section 4.0. Characterization of risks for current and future land-use conditions are presented in Section 5.0. An ecological assessment is presented in Section 6.0. Data needs for the various preceding components of the analysis are presented in Section 7.0. A summary of the report is presented in Section 8.0.

2.0 Identification of Chemicals of Potential Concern

Identification of chemicals of potential concern is based on consideration of the types of chemicals known or expected to be present at the site, the toxicity and physicochemical properties of these chemicals, and potential human exposure pathways. Evaluation of the potential human exposure pathways which are relevant to a given site includes consideration of the types of environmental media of concern, geographical/physical areas of concern, potential routes of contaminant transport through the environment (e.g., inter-media transfer, food chain), and the human populations present and their activity patterns. This section provides information regarding site-specific data collection and evaluation considerations and identifies chemicals of concern based on human exposure pathways of potential relevance to the HO storage site.

2.1 Site-Specific Data Collection

Monitoring data that have been collected since 1977 are presented in Table 1.2. Study number 1 was conducted during ocean incineration of HO. Study number 2 was the first investigation conducted after the disposal operation. Data from Study numbers 3 through 13 (except number 6) were utilized for this risk assessment because they comprise the most recent data available. The water samples taken in Study number 1 were from drinking water supplies on the east side of JI. These samples showed no detectable levels of TCDD. No water samples have been taken since that study. Particulates and vapor phase organics were not sampled. Air sampling for Study number 6 was taken for two criteria pollutants: SOx and NOx. For this risk assessment, limited data are available for residues in soil, fish, birds, and sediment.

Crockett et al. (1986) performed an extensive soil study of the HO site from 1984 to 1986. Approximately 900 soil samples were analyzed for TCDD, 2,4-D, and 2,4,5-T. The sample grid (Figure 2.1) contained 445 plots, each 400 ft^2. Each plot was sampled five times to produce one composite sample for analysis. Replicate samples were taken from 18 plots. Vertical chemical profiles were taken for TCDD to a depth of 1 ft in 33 plots, and for TCDD, 2,4-D, and 2,4,5-T to a depth of 5.5 ft in 15 plots. For 1-foot profiles, samples were taken at depths of 0, 0.1, 0.4, and 0.8 ft. for 5.5-ft profiles, samples were taken at depths of 0, 0.1, 0.4, 0.8, 2.0, 3.0, 4.0, and 5.0 ft.

Surface samples for 2,4-D and 2,4,5-T were taken in 15 vertical sampling plots. The authors originally intended to perform vertical sampling in the plots where high levels of TCDD were detected. However, sample processing time was insufficient to permit this. The vertical sampling plots were chosen by three criteria: brown staining of the soil surface, random selection, and results from previous soil studies. Some of the plots with the highest TCDD surface concentrations were not identified before completion of vertical sampling; therefore vertical sampling of these plots were not performed. Greater detail of the sampling protocol can be found in Crockett et al. (1986).

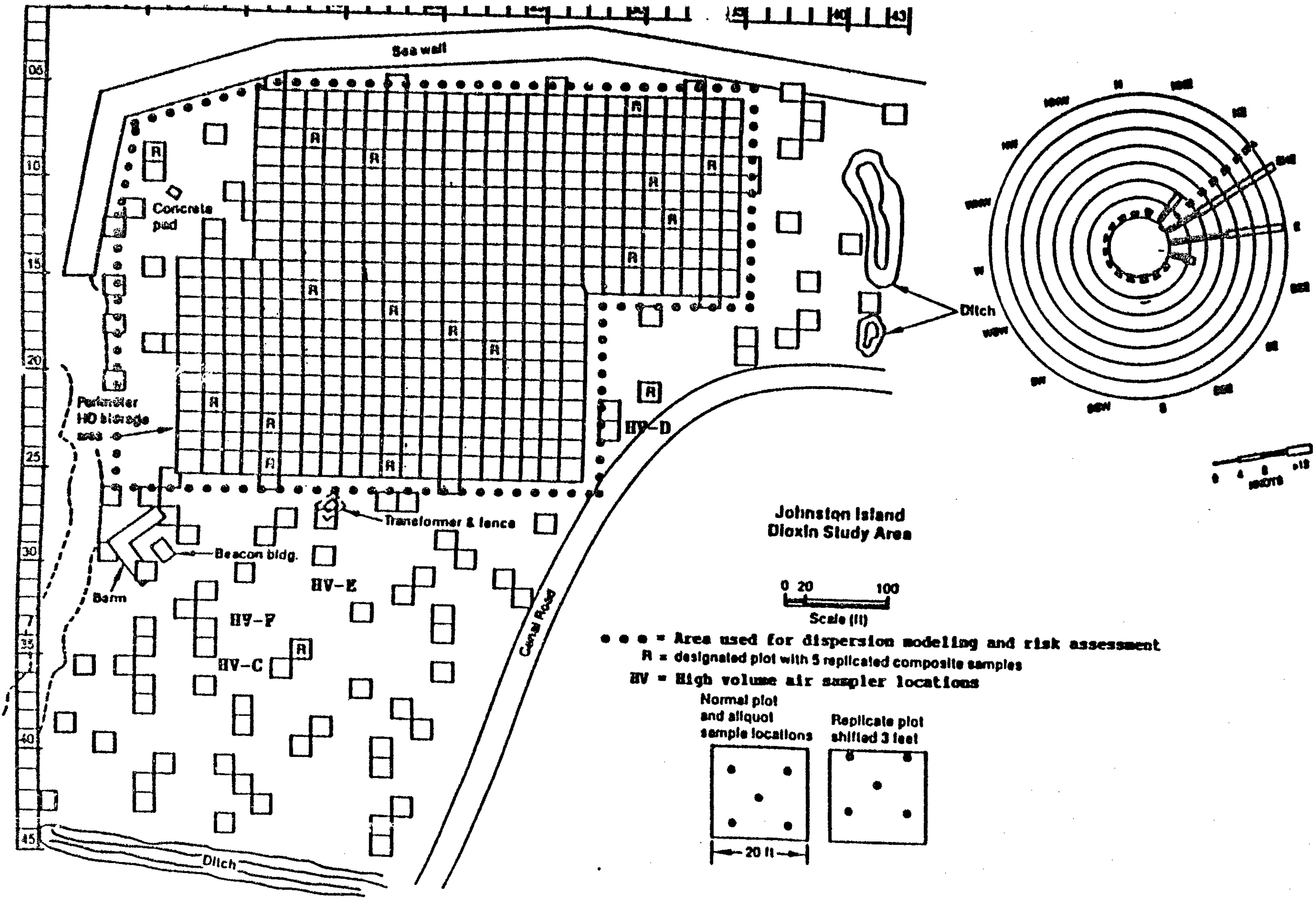

FIGURE 2.1 STUDY AREA GRID WITH REPLICATE SHIFT PATTERN

Results of the *surface* soil analysis are presented in Figures 2.2 to 2.4. The X,Y coordinates in all figures correspond the to X,Y coordinates in Figure 2.1. The 2,4-D and 2,4,5-T values were taken from the 0-3 inch vertical depth sample.

Results of the *subsurface* soil analysis are presented in Figures 2.5 to 2.7. The value for each plot is the median concentration from all vertical samples taken within that plot. Results reported to be invalid by the authors of the study were not considered in the calculation of the median value. The highest concentration of all three chemicals analyzed were found in the 3 to 7 inch layer of soil: 510 ppb for TCDD, 365,202 ppb for 2,4-D, and 682,247 ppb for 2,4,5-T. The authors suggested that remediation to a vertical depth of 30 inches would result in TCDD levels below 1 ppb in all plots but one (at 1.3 ppb). The highest concentration of 2,4-D below 30 inches was 140 ppb and of 2,4,5-T was 450 ppb. The plots south and east of the fenceline were considered to be outside the HO site for purposes of this risk assessment. This is because the plots are small and isolated, there are no data available on concentrations for adjacent areas, and the concentrations are relatively low and therefore not expected to contribute significantly to offsite risk were access to them limited. In a few of these isolated plots, the concentrations are likely to be representative of what is expected to have been leaky drums on similar plots of the HO site.

In this risk assessment, marine biota, sediment, and avian samples were used from data that have been collected since 1984. These samples were analyzed only for TCDD. Samples of marine biota were obtained from six sites (Figure 2.8), according to the protocol described in Forsell (1987). Sites 1 through 3 are located in the water adjacent to the former HO site. Site 4 is located on the east side of JI and serves as a control. Site 5 is located at the west wharf, and Site 6 is located at the coral reef off the northwest corner of JI. Site seven is located on the former HO area. Some of the samples were not identified by site number. The marine biota samples were collected as grab samples by divers using a spear. Prior to September 1987,

Figure 2.2 2,3,7,8-Tetrachlorodibenzo-p-dioxin Surface Soil Concentration (ppb)

	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
06									ND	8.7	ND	ND	0.1	0.1	0.1	0.1	31	ND	ND	0.1	1.3	ND	7.0	ND	ND	1	0.4	ND	ND	ND	ND	ND
07									0.3	ND	1.5	2.0	1.4	17	13	24	27	5.0	6.8	0.1	2.5	45	0.8	20	19	18	1.4	13	6.4	57	0.8	ND
08						0.6			136	163	91	20	6.7	0.8	1.1	0.3	0.1	9.5	ND	0.1	ND	0.2	3.1	0.2	ND	0.2	1.9	41	0.2	0.2	32	39
09			9.6						26	50	46	21	7.7	0.5	9.4	ND	0.2	ND	ND	ND	0.1	19	0.5	ND	ND	9.8	0.5	0.8	2.6	25	1.7	0.1
10			77						0.9	26	59	25	7.2	1	1	0.3	0.1	0.4	1.3	0.2	0.3	ND	1.4	ND	ND	18	1.6	1.1	20	8.5	0.4	0.2
11							0.2		0.2	5.0	18	1.8	ND	0.1	12	41	0.5	12	M	M	1.9	1.2	31	0.4	34	0.3	5.2	1.7	0.9	18	6.6	0.3
12		36						0.2	0.7	0.3	2.2	ND	ND	ND	ND	ND	ND	5.6	2.7	1.3	0.4	18	53	0.6	7.1	29	1.5	0.1	4.2	22	43	ND
13	23					0.6			0.1	ND	ND	ND	0.3	ND	0.1	ND	0.1	29	ND	0.7	1.0	ND	ND	0.2	43	3.9	32	ND	0.1	0.3	0.1	0.3
14						1.0			0.2	0.8	0.4	1.4	21	1.8	0.2	ND	ND	ND	0.2	2.2	0.6	18	0.2	ND	0.5	1.7	1.0	3.1	5.1	1.6	0.2	1.8
15			2.8		1.1	12	13	59	0.5	0.4	4.0	15	27	ND	0.6	15	10	0.2	0.3	43	9.7	24	ND	1.4	55	27	3.5	3.1	24	9.0	0.2	ND
16	1.1				1.1	1.2	0.5	0.3	35	19	4.7	0.3	0.1	ND	0.4	0.1	0.9	ND	2.7	0.9	1.1	ND	0.1	0.6								
17					27	26	10	9.7	0.1	0.3	0.4	0.5	11	14	16	0.2	4.9	0.4	17	0.8	2.9	1.7	0.9	ND								
18	9.0				0.5	21	ND	0.5	0.3	0.4	ND	0.4	M	0.2	61	ND	ND	17	1.8	18	ND	17	28	ND								
19			0.7	0.2	0.9	148	4.0	ND	59	2.8	1.2	0.8	0.7	ND	3.5	5.2	0.3	0.1	2.1	0.1	0.1	0.1	ND	ND								
20					0.2	1.5	13	0.4	0.1	0.2	0.4	0.4	0.9	0.1	7.1	0.6	ND	ND	ND	0.1	0.1	1.5	0.2	ND								
21	1.9				0.6	6.7	46	53	ND	41	23	27	ND	ND	1.3	22	0.4	61	0.6	0.2	0.6	ND	ND	ND								
22					ND	0.2	0.5	2.7	0.9	21	1.6	12	ND	0.1	14	0.4	ND	22	24	42	11	132	11	0.9								
23					0.1	0.1	0.3	0.1	5.5	3.7	0.4	0.7	0.1	0.1	0.2	ND	ND	1.3	1.0	0.7	0.1	0.3	ND	ND								
24					2.4	1	9.0	10	0.3	0.1	0.1	5.4	0.2	0.1	25	10	51	1.5	1.8	0.1	0.1	0.1	0.1	1								
25					37	ND	ND	ND	0.1	2.3	38	13	43	18	20	0.3	4.8	9.0	2.1	0.8	42	42	7.2	0.5								

I = Invalid Result
M = Missing Sample
ND = Not Detected

Figure 2.3 2,4-Dichlorophenoxy Acetic Acid Surface Soil Concentration (ppb)

	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
06										231235																						
07																									350							
08											17729																					
09																																
10																																
11																											189					
12																																
13																									62							
14							2.5																161									
15																																
16																																
17																																
18		66647																														
19						395							281330																			
20																																
21														80506																		
22																						872										
23																																
4													53																			
5														274																		

Figure 2.4 2,4,5-Trichlorophenoxy Acetic Acid Concentration (ppb)

	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
06										237155																						
07																									1040							
08											53291																					
09																																
10																																
11																											518					
12																																
13																									101							
14							221																387									
15																																
16																																
17																																
18		152492																														
19						1087							180363																			
20																																
21														56528																		
22																						872										
23																																
4													53																			
5														686																		

Figure 2.5 2,3,7,8-Tetrachlorodibenzo-p-dioxin Subsurface Soil Concentration (ppb)

	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
06										8.7																						
07																								0.15	2.6		8.1					
08											1.6		3.6								.08				.05							
09																																
10										80.9								.19					.36									
11																											.02					
12																																
13													44.7												.09							
14							.04		.23														.03									
5											41.7								2.3		4.12	.03						1.19				
6																		.03				.56										
7									.06							.09																
8		.02																	9.55		.38	.36										
9						.25					.85		1.75																			
0						.33															207											
1										109				.6							163											
2																						.08										
1																	.04															
-					1.75								.1					4.7					9.55									
														.05						.45												

Figure 2.6 2,4-Dichlorophenoxy Acetic Acid Subsurface Soil Concentration (ppb)

	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
06										53078																						
07																									2.5							
08											723																					
09																																
10																																
11																											23.5					
12																																
13																									2.5							
14							28.8																34									
15																																
16																																
17																																
18		7																				41										
19						2.5							6058																			
20																																
21														44																		
22																						2.5										
23																																
24													25.8																			
25														2.5																		

Figure 2.7 2,4,5-Trichlorophenoxy Acetic Acid Subsurface Soil Concentration (ppb)

	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
06										82210																						
07																									103							
08											1181																					
09																																
10																																
11																											32					
12																																
13																									13							
14							97																17									
15																																
16																																
17																																
18		7																				93										
19						93							8974																			
20																																
21														51																		
22																						19										
23																																
24													263																			
25														9																		

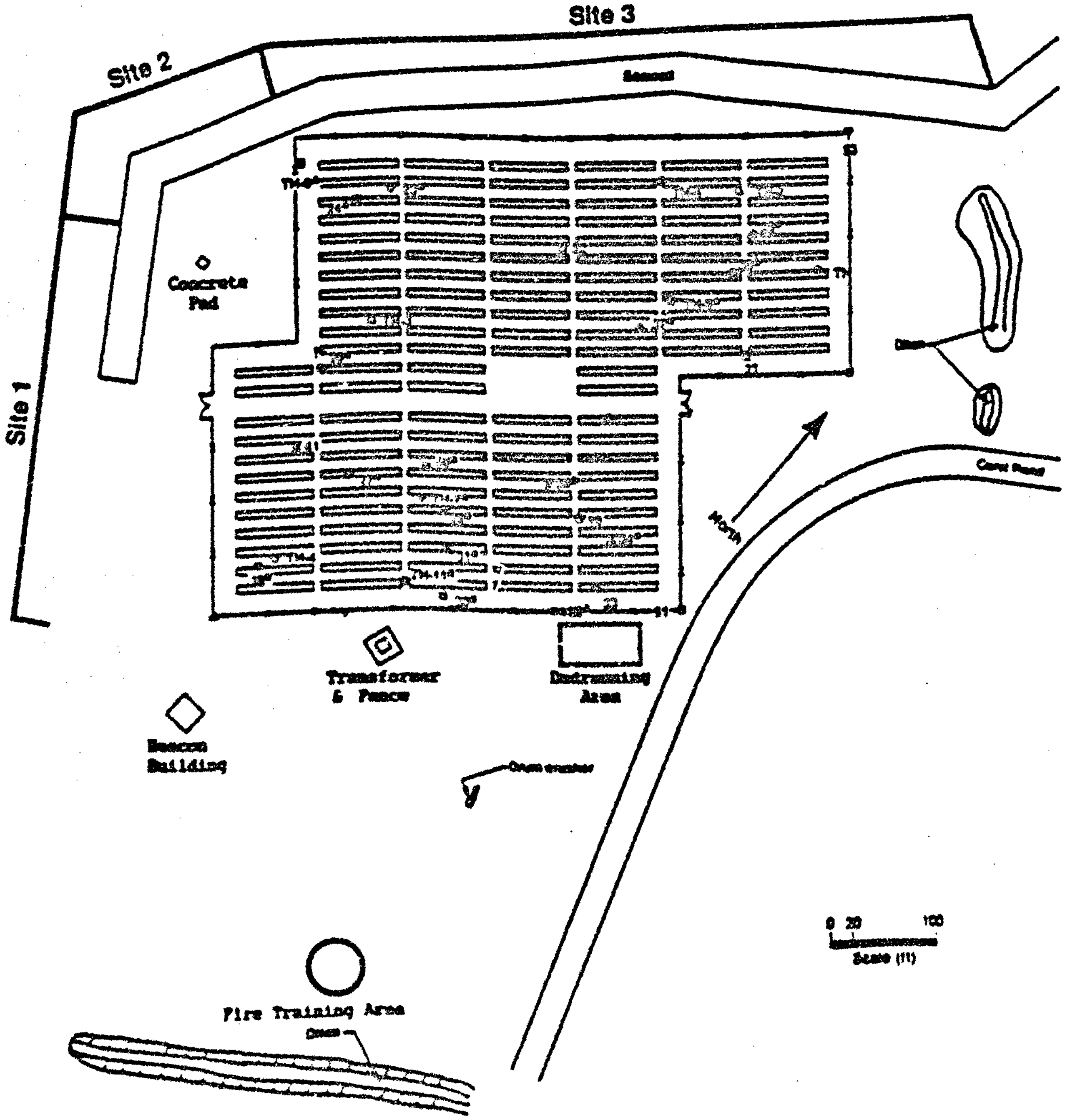

FIGURE 2.8 MARINE BIOTA SAMPLING SITES
Adapted from Crockett AB 1986

monitoring consisted of collecting one fish, one invertebrate, and one sediment sample from Sites 1 through 4. After September 1987, the monitoring program progressed to a more systematic collection procedure. Site 4, the control site, was deemed to be unnecessary because of the low frequency of positive values from Sites 1 to 3. From Sites 1 to 3, two fish from each of the following species or species groups were collected and combined:

- Bullethead parrotfish (*Scarus sordidus*) or spectacled parrotfish (*Scarus perspicillatus*);
- Convict tang (*Acanthurus triostegus*) or goldring surgeon fish (*Ctenochaetus strigosus*); and
- Goatfish (*Pseudupenus* sp. or *Mulloides* sp.).

An additional three to four fish samples from Sites 1 to 3 were collected. These fish had different feeding habits than the algal or bottom feeders listed above. The additional samples included:

- Coral feeders such as chevron butterfly (*Megaprotodon trifascialis*); predators such as eels, octopus, or jacks (*Caranx* sp.); and
- Nocturnal feeders such as shoulderfish (*Myripristis* sp.), squirrelfish (*Sargocentron* sp. or *Neonephin* sp.), or trigger fish (*Rhinecanthus* sp. or *Melichthys* sp.).

Two to three samples of invertebrates were collected and combined. These included crabs, snails, cucumbers, gastropods, or worms. Two to four fish were collected from the west wharf. These species were to be representative of the species caught by sport fishermen on JI. One or two sediment samples from Sites 1 to 3 were also taken. It should be noted that no fish caught in wharf fishing have been analyzed.

Results of the marine biota and avian analyses are presented in Table 2.1. All avian samples were taken from Site 7. The number of marine biota and avian samples from each site are presented below and the percentages with positive residue values:

Site	Number	Positive values (%)
1	62	37
2	32	16
3	8	12.5
4	6	0
5	47	0
6	23	0
7	3	0

Eighteen samples had no site numbers. Sites 1 to 3, the areas adjacent to the HO site, generated 28.4% positive samples. From all sites combined, 16% of the samples were positive. Fourteen samples, or 7% overall, had values above 25 ppt, FDA's limit for levels in edible fish.

Results of the sediment analysis are presented in Table 2.2. Thirty-eight samples were taken; two were positive. Many samples are missing site numbers. Previously, Channell and Stoddard (1984) took three sediment samples prior to construction of the seawall on the west side of the Island. These samples averaged 57 ppt of TCDD. The authors felt that sediment contamination was due to soil runoff from the site.

Table 2.1
Johnston Island Fish Data

Sample Species	Sample Tissue	Sample Date	Site Taken	Dioxin Level PPT	Detection Limit PPT
Achilles Tang	Muscle	Sep-89	1	ND	10
Achillies Tang	Muscle	Dec-88	1	ND	10
Blackspot Sergeant	Muscle	Dec-88	1	41	10
Blackspot Sergeant	Muscle	Sep-89	1	26	10
Bluelined Surgeonfish	Muscle	Jan-88	1	ND	10
Bluelined Surgeonfish	Muscle	Dec-88	1	14	10
Bluelined Surgeonfish	Muscle	Sep-89	1	ND	10
Brick Soldierfish		Jan-88	1	ND	10
Bullethead Parrotfish	Muscle	May-87	1	ND	10
Bullethead Parrotfish	Muscle	Oct-87	1	ND	10
Coelenterate		Oct-87	1	ND	10
Cone	Muscle	May-87	1	ND	10
Cone	Muscle	Oct-87	1	18	10
Cone	Muscle	Dec-88	1	14	10
Cone Shells	Muscle	Sep-89	1	15	10
Convict Tang		May-87	1	12	10
Convict Tang	Muscle	Oct-87	1	ND	10
Convict Tang	Muscle	Dec-88	1	19	10
Convict Tang	Muscle	Sep-89	1	ND	15
Crab		Sep-84	1	ND	9
Crabs		Feb-84	1	20	
Crown Squirrelfish	Muscle	Dec-88	1	352	10
Crown Squirrelfish	Muscle	Sep-89	1	ND	10
Crown Squirrelfish	Muscle	Sep-89	1	ND	10
Dolabella	Muscle	Sep-89	1	ND	21
Doublebar Goatfish		Oct-87	1	ND	10
Eel		Sep-84	1	ND	21
Eel	Muscle	Sep-89	1	ND	10
Fish		Nov-85	1	8.9	10
Fish		Nov-85	1	13	10
Fish		Sep-86	1	ND	10
Goldring Surgeonfish	Muscle	Oct-87	1	15	10
Goldring Surgeonfish	Muscle	Sep-89	1	ND	14
Hermit Crab	Muscle	Dec-88	1	ND	10
Hermit Crabs	Muscle	Oct-87	1	ND	10
Hermit Crabs	Muscle	Sep-89	1	ND	10
Live Coral		Sep-84	1	ND	13
Manybar Goatfish	Muscle	Sep-89	1	ND	10
Moana Kali	Muscle	Sep-84	1	ND	73
Moana Kali	Liver	Sep-84	1	ND	10
Morey eel		Feb-84	1	64	
Morey eel		Feb-84	1	30	
Octipus	Muscle	Dec-88	1	28	10

Table 2.1 (cont.)
Johnston Island Fish Data

Sample Species	Sample Tissue	Sample Date	Site Taken	Dioxin Level PPT	Detection Limit PPT
Octopus	Muscle	Sep-89	1	ND	10
Orange Spine Unicornfish	Muscle	Sep-89	1	ND	10
Orangemouth Lizardfish	Muscle	Dec-88	1	21	10
Sea Cucumber		Nov-85	1	ND	10
Sea Cucumber		Sep-86	1	ND	10
Sea Cucumber	Muscle	Dec-88	1	ND	10
Sea Cucumber	Muscle	Sep-89	1	ND	10
Slipper Lobster	Muscle	Sep-89	1	ND	10
Snail		Sep-84	1	ND	24
Snails	Muscle	Oct-87	1	ND	10
Snails	Muscle	Dec-88	1	ND	10
Stocky Hawkfish	Muscle	Sep-89	1	ND	10
Tahitian & Spotfin Squirrelfish	Muscle	Jan-88	1	ND	10
Tahitian Squirrelfish	Liver	Oct-87	1	27	10
Threadfin Butterflyfish		Oct-87	1	12	10
Yellowfin Goatfish	Muscle	Dec-88	1	102	10
Yellowfin Goatfish	Muscle	Sep-89	1	11	10
Yellowfin Goatfish	Muscle	Sep-89	1	85	10
Yellowstripe & Yellowfin Goatfish	Muscle	Jan-88	1	49	10
Achilles Tang	Muscle	Sep-89	2	ND	10
Bluelined Surgeonfish	Muscle	Sep-89	2	ND	10
Bullethead Parrotfish	Muscle	May-87	2	ND	10
Cheveron Butterflyfish	Muscle	Dec-88	2	ND	10
Cone		May-87	2	ND	10
Cone		Jan-88	2	ND	10
Convict Tang	Muscle	Jan-88	2	ND	10
Convict Tang	Muscle	Dec-88	2	ND	10
Convict Tang	Muscle	Sep-89	2	ND	10
Crown Squirrelfish	Muscle	Dec-88	2	472	10
Dolabella	Muscle	Dec-88	2	ND	10
Fish		Nov-85	2	ND	10
Fish		Nov-85	2	ND	10
Fish		Sep-86	2	40	10
Goldring Surgeonfish	Muscle	Jan-88	2	ND	10
Goldring Surgeonfish	Muscle	Sep-89	2	ND	10
Hermit Crab		Jan-88	2	ND	10
Manybar Goatfish	Muscle	Sep-89	2	23	10
Moana	Whole Fish	Sep-84	2	ND	10
Octopus		Sep-84	2	ND	19
Orange Mouth Lizardfish	Muscle	Sep-89	2	ND	10
Red Snapper	Muscle	Sep-84	2	ND	10
Red Snapper	Liver	Sep-84	2	ND	14
Red Snapper	Fat	Sep-84	2	ND	25

Table 2.1 (cont.)
Johnston Island Fish Data

Sample Species	Sample Tissue	Sample Date	Site Taken	Dioxin Level PPT	Detection Limit PPT
Sea Cucumber		Jan-88	2	ND	10
Sea Cucumber	Muscle	Sep-89	2	ND	11
Snails		Feb-84	2	120	
Spectacled Parrotfish		May-87	2	ND	10
Threadfin Butterflyfish	Muscle	Dec-88	2	ND	10
Trigger Fish	Muscle	Sep-84	2	ND	10
Trigger Fish	Liver	Sep-84	2	18	
Yellowfin Goatfish	Muscle	Dec-88	2	ND	10
Fish		Nov-85	3	4.6	10
Fish		Sep-86	3	ND	10
Menipachi	Whole Fish	Sep-84	3	ND	5
Moana	Whole Fish	Sep-84	3	ND	4
Moana Papa	Muscle	Sep-84	3	ND	10
Moana Papa	Liver	Sep-84	3	ND	35
Sea Cucumber		May-87	3	ND	10
Snapper		May-87	3	ND	10
Cone		May-87	4	ND	10
Crab		Sep-84	4	ND	5
Fish		Nov-85	4	ND	10
Fish		Sep-86	4	ND	10
Fish	Liver	Sep-86	4	ND	18
Snail		Sep-84	4	ND	3
Achilles Tang	Muscle	Sep-89	5	ND	10
Ahole Hole	Whole Fish	Sep-84	5	ND	2
Ahole Hole	Whole Fish	Sep-84	5	ND	1
Ahole Hole	Whole Fish	Sep-84	5	ND	31
Ahole Hole	Whole Fish	Sep-84	5	ND	18
Ahole Hole	Whole Fish	Sep-84	5	ND	27
Blackspot Sergeant		Jan-88	5	ND	10
Blackspot Sergeant	Muscle	Dec-88	5	ND	10
Bluelined Surgeonfish	Muscle	Sep-89	5	ND	10
Convict Tang		Oct-87	5	ND	10
Convict Tang	Muscle	Dec-88	5	ND	10
Convict Tang	Muscle	Sep-89	5	ND	10
Dracula	Whole Fish	Sep-84	5	ND	3
Dracula	Whole Fish	Sep-84	5	ND	7
Dracula	Muscle	Sep-84	5	ND	7
Eel	Muscle	Dec-88	5	ND	10
Goldring Tang	Muscle	Dec-88	5	ND	10
Halalu	Whole Fish	Sep-84	5	ND	2
Lowfin Chub		May-87	5	ND	10
Lowfin Chub	Muscle	Dec-88	5	ND	10
Mackerel Scad		Oct-87	5	ND	10

Table 2.1 (cont.)
Johnston Island Fish Data

Sample Species	Sample Tissue	Sample Date	Site Taken	Dioxin Level PPT	Detection Limit PPT
Manybar Goatfish	Muscle	Sep-89	5	ND	10
Manyray Flatfish	Muscle	Dec-88	5	ND	10
Moana	Whole Fish	Sep-84	5	ND	4
Moana	Whole Fish	Sep-84	5	ND	2
Moana Kali	Muscle	Sep-84	5	ND	10
Moana Papa	Muscle	Sep-84	5	ND	300
Moana Papa	Liver	Sep-84	5	ND	10
Octopus		Sep-84	5	ND	7
Palani	Muscle	Sep-84	5	ND	10
Palani	Liver	Sep-84	5	ND	15
Palani	Whole Fish	Sep-84	5	ND	1
Papio	Muscle	Sep-84	5	ND	1
Papio	Liver	Sep-84	5	ND	1
Papio	Fat	Sep-84	5	ND	8
Papio	Muscle	Sep-84	5	ND	3
Papio	Liver	Sep-84	5	ND	6
Papio	Fat	Sep-84	5	ND	48
Parrot Fish	Muscle	Sep-84	5	ND	1
Parrot Fish	Liver	Sep-84	5	ND	22
Parrot Fish	Fat	Sep-84	5	ND	604
Parrot Fish	Muscle	Sep-84	5	ND	3
Parrot Fish	Liver	Sep-84	5	ND	3
Red Weke	Whole Fish	Sep-84	5	ND	53
Sheephead	Whole Fish	Sep-84	5	ND	1
Stocky Hawkfish	Muscle	Sep-89	5	ND	10
Yellowfin Goatfish		Oct-87	5	ND	10
Ahole Hole	Whole Fish	Sep-84	6	ND	8
Blue Ulua	Muscle	Sep-84	6	ND	1
Blue Ulua	Liver	Sep-84	6	ND	3
Blue Ulua	Fat	Sep-84	6	ND	18
Hinalaya	Whole Fish	Sep-84	6	ND	15
Hinalaya	Muscle	Sep-84	6	ND	12
Hinalaya	Liver	Sep-84	6	ND	46
Moana	Whole Fish	Sep-84	6	ND	1
Moana Papa	Muscle	Sep-84	6	ND	22
Moana Papa	Liver	Sep-84	6	ND	343
O'Paka Paka	Muscle	Sep-84	6	ND	1
O'Paka Paka	Liver	Sep-84	6	ND	7
O'Paka Paka	Muscle	Sep-84	6	ND	1
O'Paka Paka	Liver	Sep-84	6	ND	1
Palani	Muscle	Sep-84	6	ND	1
Palani	Liver	Sep-84	6	ND	3
Papio	Muscle	Sep-84	6	ND	1

Table 2.1 (cont.)
Johnston Island Fish Data

Sample Species	Sample Tissue	Sample Data	Site Taken	Dioxin Level PPT	Detection Limit PPT
Papio	Liver	Sep-84	6	ND	7
Papio	Fat	Sep-84	6	ND	6
Trigger Fish	Whole Fish	Sep-84	6	ND	1
Trigger Fish	Whole Fish	Sep-84	6	ND	3
Trigger Fish	Muscle	Sep-84	6	ND	1
Trigger Fish	Liver	Sep-84	6	ND	6
Pacific Golden Plover	Immature Male	May-87	7	ND	10
Ruddy Turnstone	Adult Male	May-87	7	ND	10
Turnstone & Plover	Liver	May-87	7	ND	10
Biota		Jun-86		ND	10
Biota		Jun-86		ND	10
Biota		Jun-86		ND	10
Fish		Nov-85		11	10
Fish		Nov-85		ND	10
Fish		Nov-85		ND	10
Fish		Nov-85		ND	10
Fish		Dec-86		ND	10
Fish		Dec-86		14	10
Fish	Liver	Dec-86		150	10
Fish		Dec-86		ND	10
Fish		Dec-86		ND	10
Liver		Nov-85		ND	10
Liver		Jun-86		ND	10
Liver		Jun-86		ND	10
Sea Cucumber		Nov-85		ND	10
Sea Cucumber		Nov-85		ND	10
Shell Fish		Dec-86		ND	10

Table 2.2
Johnston Island Sediment Data

Sample Date	Site Taken	Dioxin Level PPT	Detection Limit PPT
Nov-85	1	ND	50
Sep-86	1	ND	100
May-87	1	ND	100
Oct-87	1	160	100
Jan-88	1	ND	100
Jan-88	1	ND	100
Jan-88	1	ND	100
Aug-88	1	ND	100
Aug-88	1	ND	100
Aug-88	1	ND	100
Dec-88	1	ND	100
Dec-88	1	ND	100
Dec-88	1	ND	100
Nov-85	2	ND	50
Sep-86	2	ND	100
May-87	2	ND	100
Oct-87	2	ND	100
Jan-88	2	ND	100
Aug-88	2	190	100
Dec-88	2	ND	100
Nov-85	3	ND	50
Sep-86	3	ND	100
May-87	3	ND	100
Jan-88	3	ND	100
Nov-85	4	ND	50
Sep-86	4	ND	100
Nov-85		ND	50
Nov-85		ND	50
Nov-85		ND	50
Nov-85		ND	50
Jun-86		ND	100
Jun-86		ND	100
Jun-86		ND	100
Jun-86		ND	100
Dec-86		ND	100
Dec-86		ND	100
Dec-86		ND	100
Dec-86		ND	100

Helsel et al. (1987) collected a variety of liquid, solid, and gas samples as part of a series of monitoring tests for evaluating thermal desorption and ultraviolet photolysis of contaminated soil. To determine if any downwind exposure occurred as a function of distance, four high-volume air particulate samplers were positioned based on the prevailing easterly trade wind direction.

The specific locations for the downwind samplers were determined by using a simple Gaussian plume dispersion model. The model estimated the distance downwind from the test area where the ground level particulate impact could be anticipated. The dispersion model used the exhaust stack of the test process as the emission point. The stack was situated approximately 15 feet above the ground surface. An average wind velocity of 11 miles per hour blowing parallel to the island's runway (i.e., 60 degrees) was used. Pasquill-Gifford Stability Class A (unstable) conditions were assumed for measuring contaminant migration during the daylight testing activities, and Stability Class D (neutral) conditions were assumed for measuring nighttime testing activities. The layout of the high-volume air particulate samplers, in relation to the Agent Orange site are shown in Figure 2.1. The sampler located nearest the east side of the site, referred to as HV-D, served as an upwind control; whereas, the remaining three samplers, HV-E, HV-F, and HV-C, were placed 80, 160, and 240 feet downwind, respectively. Sampler HV-E was used to monitor offsite migration at the predicted maximum impact location, HV-F acted as a monitor of offsite migration of contaminated particulate due to natural processes, and HV-C was used to monitor contaminated particulate migrating off the island.

The ambient air filter samples (11 samples total) were analyzed for the amount of particle-associated TCDD collected on each filter. TCDD was not detected on any of the samples analyzed. A summary of the TCDD concentrations in the ambient air filter samples is presented in Table 2.3. The detection limits presented as ng of TCDD and as air concentrations (pg/m^3). The results of this study suggest that

TABLE 2.3

Summary of 2,3,7,8-TCDD Concentrations in
Ambient Air Filter Samples

Run	Migration Path Monitored[a]	Sampler	Sample Number	Quantity (ng)	Average Concentration (pg/m^3)
1	**Equipment Setup and Testing**				
	Upwind control	HV-D	R1-12A	<1.4[b]	<0.52[b]
	Offsite	HV-E	R1-12B	<2.4	<0.88
	Offsite control	HV-F	R1-12C	<1.4	<0.55
	Off island	HV-C	R1-12D	<1.1	<0.44
2	**Operation of TD/UV Photolysis System**				
	Upwind control	HV-D	R2-12A	<0.96	<0.24
	Offsite	HV-F	R2-12C	<1.1	<0.27
	Offsite control	HV-E	R2-12B	<1.5	<0.36
	Off island	JV=C	R2-12D	<0.67	<0.17
3	**Decontamination and Demobilization**				
	Upwind control	HV-D	R3-12A	<0.75	<0.25
	Offsite	HV-F	R3-12C	<0.94	<0.33
	Offsite control	no sample	---	---	---
	Off island	HV-C	R3-12D	<1.3	<0.30

[a] See Figure 2.1 for layout of air samples.
[b] Not detected. Detection limit value shown.

Source: Helsel et al., 1986.

virtually no exposure to TCDD occurred as a result of the soil decontamination experiments conducted by Helsel et al. (1987). Further, these data suggest that insignificant levels of particle-associated TCDD were dispersing from the site during the sampling period, given that these samplers were downwind of at least the southern portion of the site's total surface area, in addition to being downwind of the soil decontamination experiments. However, because of the limited number of samples and the lack of data for the entire downwind area relative to the site (i.e., the western fenceline), no conclusions can be made regarding TCDD exposure potential via inhalation of contaminated, airborne particulate at the time the samples where taken in 1986, or particularly prior to 1986, when the site was being used for storage purposes.

2.2 Data Quality Assurance

The study design and sample collection procedure for the soil study (Crockett et al., 1986) appear to be adequate. The study design was approved by EPA. However, the apparent problems that occurred during sample analysis may have been corrected, but their resolution not reported. On this basis, the quality of the soil data in this report cannot be accurately judged. Quality assurance concerns are discussed below.

The analytical procedure used in this study was adapted from an existing EPA method for dioxin analysis where the detection limit was 0.1 ppb for surface samples. The sample digestion procedure was modified and the detection limit was lowered to 0.01 ppb. There is no indication that a method validation study was performed to verify that this modified procedure worked adequately with this coral matrix and lower detection limit. [However matrix spikes at 1.0 ppb analyzed concurrently with the soil samples indicated good recoveries; accordingly, the analytical method appears to have been adequate for the coral matrix.] According to the EPA method for TCDD analysis, sample extraction must be completed within 7 days after sample collection, and the resulting sample extract must be analyzed within 40 days thereafter. Only one laboratory, U.S. Testing Laboratories, analyzed all samples collected in this study, approximately 900 samples. With such a large influx of samples to one laboratory along with shipping problems, it is possible that the holding times may not have been met. This report did not indicate if a storage stability study was conducted to ensure the stability of samples until analysis could be performed.

Matrix spike standards and surrogate spikes were used at the 1.0 ppb level to test the accuracy of the analytical procedure. More than one spike concentration should have been used to test the accuracy of the procedure over a range of the expected soil concentrations. Spikes of 0.1 and 10 0 ppb should also have been used because these concentrations reflect the range found in many of the soil samples. A spike of 1.0 ppb is 100 times the reported detection limit, therefore the method was not rigorously tested near the detection limit. The report indicated that the average percent recoveries and the standard deviations from the matrix spike analyses were well within the guidelines of the protocol. The analytical guidelines describing data acceptability, (e.g., recovery and standard deviation ranges), were not provided with this report such that criteria used to evaluate the data is unclear. The report also indicated that five recoveries were considered outliers. Reasons for the outliers were explained only for two of the recoveries. The method used to determine why the other three values were outliers was not explained.

An independent QA/QC laboratory was utilized to perform various QA functions. The QA/QC laboratory submitted summaries of its findings in various reports, but these reports were not appended to the soil study report. The report indicated that there were several discrepancies between the performing and QA/QC laboratories. The average relative percent difference (RPD) for split sample analysis between the two labs was reported as 51% with a standard deviation of 76%. This is a large difference between the two labs. The report stated that most of the outliers had RPD's of 200%, and they represented sample pairs where one sample value was not detected and the other value was low. An RPD of greater than 200% was also reported for split sample analysis within the performing laboratory for the same stated reasons. This indicates that the analytical method used may not have been as rugged near the detection limit as originally intended. Other discrepancies between the two labs included differences in results from field performance audit samples and performance evaluation standards. As stated above, these discrepancies may have been resolved, but this report did not discuss if they were or how.

The report stated that two field blanks, considered as outliers, were not rerun because the level of contamination at 0.2 ppb was not considered significant. A review of Figure 7 in the report shows that approximately 46% of the samples had values at 0.5 ppb or lower. The report did not indicate how many samples were collected with these positive blank samples, nor did it indicate if the positive sample blank values were subtracted from the positive soil samples. If the positive sample blanks were not subtracted from the positive soil values, then some of the reported positive soil samples could be false positive values.

The sample collection protocol for fish, sediments, and birds was made more systematic in October of 1987, but it still appears to be lacking in some aspects. The protocol does not specify that different stages in the fish life cycle be sampled. This information would be helpful to determine to what degree the adult fish are bioaccumulating the contaminants. Not all trophic levels of the marine biota have been sampled, (e.g., filter feeders). No systematic protocol has been established for sediment sampling. Many of the reports did not specify the exact location where the sediment samples were taken. Channell and Stoddart (1984) noted three positive sediment sample near the shore on the west side of the site. This area should be resampled to determine if the seawall is preventing further contamination of the lagoon. Only three birds have been sampled; more birds should be sampled to assess the possible impact of the site on the nesting birds. There are no data for 2,4-D or

2,4,5-T in fish, sediment, or birds, and there are no data for TCDD, 2,4-D, or 2,4,5-T in sea water and in groundwater under the site.

Data validation for the fish, sediment, and avian analyses can not be performed for several reasons. First, the exact EPA method used to analyze these samples was never mentioned in the reports. Second, there are no data from the performing laboratory on their QA/QC procedures, or results of their QA/QC analyses. Percent recovery data were given, but comprehensive data validation cannot be made on this one piece of QA/QC data. Third, since the samples must have been shipped a great distance, there is no information on whether a storage stability study had been performed.

2.3 Summary of Chemicals of Potential Concern

Herbicide Orange (HO) was used in two different formulations (U.S. Air Force, 1974). Orange was composed of a 50:50 mixture of n-butyl 2,4-dichlorophenoxyacetic acid and n-butyl 2,4,5-trichlorophenoxyacetic acid. Orange II was composed of a 50:50 mixture of n-butyl 2,4-dichlorophenoxyacetic acid and isooctyl 2,4,5-trichlorophenoxyacetic acid. The ratio of these two lots on JI was not known. The arithmetic mean TCDD concentration on JI was determined to be 1.909 mg/kg (U.S. Air Force, 1974). The sample analysis did not differentiate between the two 2,4,5,-T compounds. The only dioxin isomer tested in all of the samples was 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). Other isomers of dioxin could have been present in the HO, and therefore could also be contaminants at the HO site. Both phenoxy herbicides and TCDD have been detected at the site, and TCDD has been detected in biological samples. Therefore, these three chemicals are of potential concern, along with any other possible isomer of dioxin as of yet unanalyzed.

3.0 Exposure Assessment

The following section describes the procedures used for conducting the exposure assessment for the HO site. The objective of the exposure assessment is to estimate the type and magnitude of current exposure and, to the extent possible, future exposures to the chemicals of potential concern at JI. The exposure assessment methods used in this evaluation are those described in various documents developed by the U.S. Environmental Protection Agency (EPA) and include Cowherd *et al.* 1985, EPA 1988b, EPA 1988c, EPA 1989a, EPA 1989b, and EPA 1989c. The methods used in the exposure assessment for the HO site at JI include consideration of the exposure setting and the exposure pathways which are of particular relevance to the types of human populations present and their respective activity patterns. This section presents the following:

(1) Characterization of the physical setting of the HO site and the resulting potentially exposed populations;
(2) Descriptions of the identified plausible exposure pathways;
(3) Estimations of human exposure; and

(4) Identification and discussion of uncertainties related to the exposure assessment methods used in this evaluation.

3.1 Characterization of the Exposure Setting

The potential for exposure is dependent on the physical setting of the HO site, including the climate, vegetation, soil type, and hydrology, as well as the features of the potentially exposed population, dependent on population characteristics and land use.

3.1.1 Physical Setting

The physical setting of JI has been extensively characterized and reported (U.S. Air Force, 1974; Thomas et. al., 1978). The features are briefly synopsized below.

The climate is marine and tropical with little variation in temperature, wind speed, and wind direction over its entire surface due, in part, to the small land area, uniform terrain, and low elevation. The mean temperature is 79°F ranging from 62°F to 89°F. The mean annual rainfall is 26 inches; the lowest annual rainfall recorded was 13 inches and highest 42 inches. The annual mean relative humidity is 75%.

Wind characteristics are important for the dispersion modeling component of exposure via the air medium. The mean annual windspeed is 15 mph with little variation throughout the year due to dominating surface trade winds. Monthly means are 14 mph to 16 mph. Winds are from the northeast and east 85% of the time, at least 62% of the time in every month. Occasionally from December through March, the winds are light and variable or westerly.

Mean monthly sky cover, sunrise to sunset, averages 6 on a scale of 0 to 10 with little variation.

To a large extent, the type and density of vegetation is determined by the amount of rainfall. To a lesser extent at the HO site, it is influenced by residual levels of 2,4-D and 2,4,5-T. Vegetation consists of a few grasses, herbs, and dwarf shrubs. Most are not indigenous and have been introduced to JI by humans. Terrestrial animal life is equally limited in variety. These are described in Section 6.0.

Soil is the most critical physical component of the Island with respect to risks posed by the HO site because it is the medium within which the chemical contaminants of concern are contained. Environmental fate and transport, which characterizes the movement of the contaminants from the soil medium, is largely dependent on the soil type and its ability to release or retain them. The surface of JI is mainly coral sand with a mixture of fine coral fragments. The area of the HO site is not part of the original Island but, through dredging and reconstruction, was built up artificially with alternating layers of coral and sand of various consistency and porosity. Beach rock on the Island is formed by sand and coral gravel loosely cemented together by calcium carbonate. The HO site has been left relatively undisturbed since the dedrumming operation (a trial soil burn and comprehensive soil sampling program are the only major activities to have occurred for relatively brief time periods). As a consequence, most of the loose fines on the surface have been blown away, leaving the surface covered with a combination of cobble-sized or compacted coral fragments. The soil has not been well characterized for its physical features (composition, density, porosity, pH, organic content). During the most recent chemical characterization study (Crockett et al., 1986), moisture content was determined to be approximately 9.57% and 9.0% by air and oven drying, respectively.

There is no surface water on the HO site due to the coarse texture and extreme permeability of the coral sand and rubble within the first few feet of the regolith. Groundwater on the Island lies in general at a depth of 1.2 to 2.4 meters (4 to 8 feet). The aquifer under the HO site, if it exists, has neither been characterized nor its chemical composition determined. A thin lens of brackish water (dissolved solids greater than 1,000 mg/L) that is rust colored and has an odor of hydrogen sulfide underlies the original Island. Characteristics of the groundwater are important for determining the fate and transport of contaminants at the site.

3.1.2 Current and Future Land Use Conditions

The site is currently not in use, is dormant, and has access limited by a surrounding fence. Potential avenues of human exposure include volatilization of the contaminants into the air, suspension of particle-laden contaminants into the air, and consumption of edible marine life that have become contaminated in the waters adjacent to the site.

Two future scenarios that would alter exposure potential from that presented by current land conditions and which form the basis of the quantitative estimations of risk in this analysis are: (1) remediation through excavation and incineration[2] of contaminated soil; and (2) covering of the site with cement. The latter scenario is not intended to be a substitute for prescriptive site capping, which is a more thorough and rigorous form of remediation. In both of these scenarios, certain activities such as construction vehicles on the site and excavating alter the patterns of particulate suspension and soil volatilization of contaminants from those in the current use scenario. These are explained in Section 3.3 as they are incorporated into the calculation of emission factors and exposure estimation.

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[2] Although incineration is a plausible remediation alternative, potential exposures resulting from incinerator emissions during thermal desorption and combustion of TCDD, 2,4-D, and 2,4,5-T in soil were not included in this evaluation.

3.1.3 Potentially Exposed Populations

The permanent and semi-permanent Island population is a mixture of military personnel whose stay on JI generally ranges from one to three years and civilians employed by a DoD service contractor who remain on JI for longer periods. Some individuals have been on JI for over 15 years and at least two who are still on JI were involved in the HO dedrumming operation. Any occupational and recreational activities of these individuals at certain distances downwind of the HO site create a potential for exposure to contaminants at the site. These activities are a matter of specific job functions and responsibilities of individuals as well as lifestyle on the Island.

The circumstances that create a potential for human exposure are related *not* to activities at the site itself (it is assumed that individuals working on the actual site would be wearing appropriately protective gear and clothing), but rather to activities beyond the boundary of the HO site (Figure 2.1).

For exposure through the air medium, these activities include but are not necessarily limited to any occupational operations associated with the seawall, the electrical transformer, the Hi-Vol sampler, the beacon building in the immediate area, the fire training area, the rip-rap area used as a boat-launch site, and the burn pit at an intermediate distance. The time that an individual is located in these areas conducting operations related to facilities for any one episode and the frequency with which these areas are visited is variable. As important components in the calculation of potential human exposure, it was necessary to assume reasonable values for time and frequency within the range of 0 to 24 hours per day, 0 to 7 days per week. Typical values used for atmospheric dispersion estimates are one hour, eight hours, and annual averages concentrations (e.g., mg/m^3), which are usually based on continuous exposure. Without the benefit of actual time-activity data and considering the structures around the site, their functions, and the need to choose exposure parameters that are conservative but nevertheless reasonable, a value of 1 hour per day, five days per week was assumed to be appropriate for the time and frequency that an individual would be located in proximity to the site. This represents a reasonable approximation, although actual values may be greater or lesser.

Sport fishing presents a potential for exposure through the food chain, since fish sampling data indicate a potential for TCDD exposure though consumption of contaminated fish. Sport fishing is an important recreational activity on Johnston Atoll (JA). Approximately 350 boxes of frozen fish are exported each year for home leave (Irons et al., 1990). Many fishermen give some of their catch to nonfishermen for consumption on the island, and for export during home leave. Fishing is conducted from the shorelines around the islands and from boats. Both line fishing and spear fishing are allowed on JA. Line fishing is conducted both at night and during the daytime. The only area that is off limits to fishing is the area adjacent to the former HO site out to the shipping channel. Residents are aware of this restriction and it is not violated. Fishing is allowed on the other side of the channel out to the reef (Zone 5 in Figure 3.1). Irons et al. (1990) has conducted an extensive fish catch survey to characterize the fish population on JA, a portion of which is attached in Appendix A of this report.

3.2 Identification of Exposure Pathways

The identification of exposure pathways involves consideration of the environmental fate and transport of a chemical in media where its presence has been detected and if possible, quantified, as well as human activities which may present opportunities for exposure to occur. An exposure pathway generally consists of four elements:

(1) A source and mechanism of chemical release;

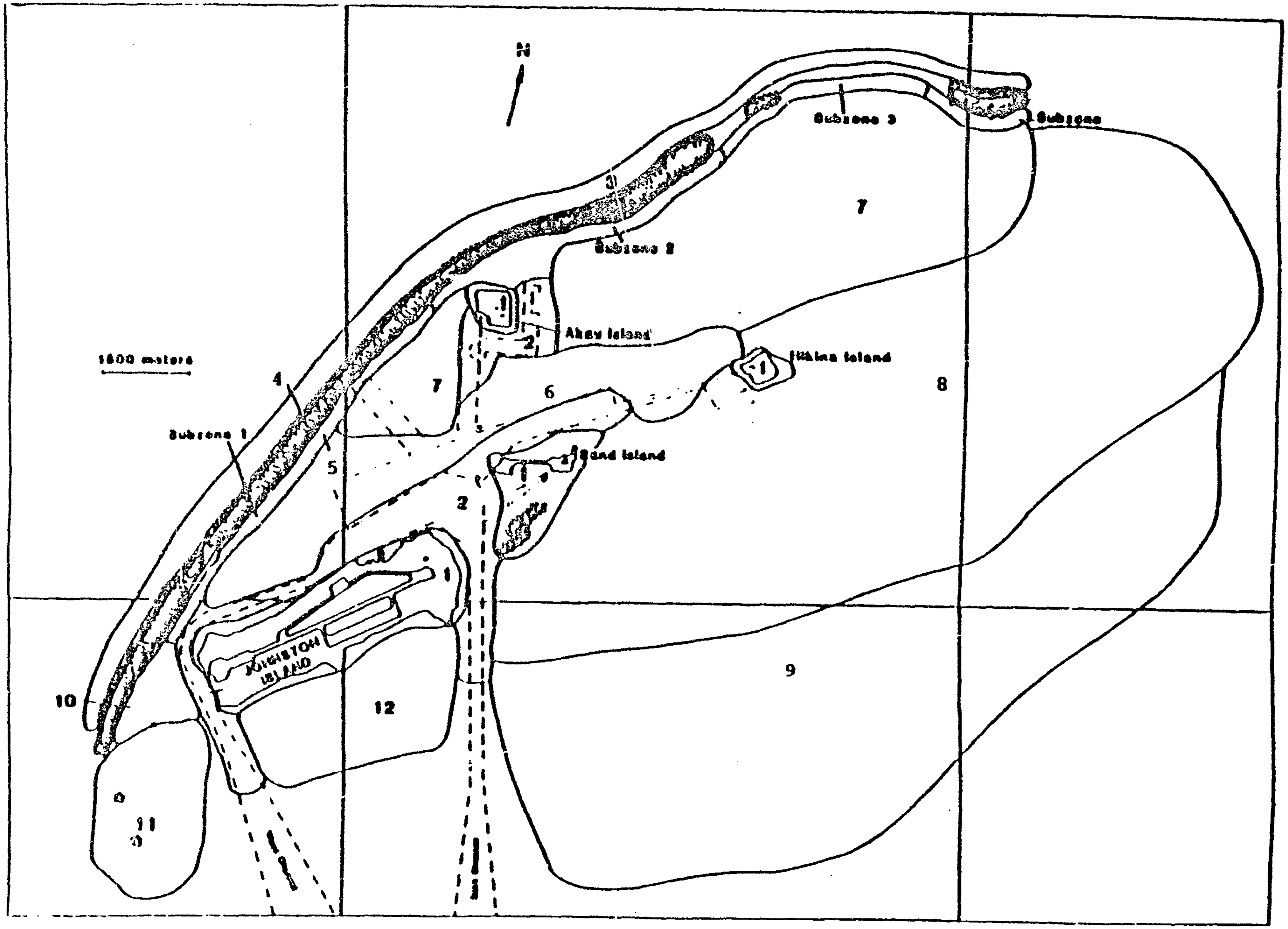


FIGURE 3.1 "ECOTYPE" ZONES (AREAS WITHIN LINE BOUNDARIES) AT JOHNSTON ATOLL From Irons 1990

(2) A retention or transport medium;

(3) A "point" of potential human contact with the chemical or contaminated medium; and

(4) An exposure route (e.g., inhalation, ingestion, or dermal contact) by which the chemical may be absorbed into the body.

The following sections (3.2.1 through 3.2.3) present the plausible exposure pathways for persons at JI which form the basis for quantification of exposure in Section 3.3.

3.2.1 Identification of Sources and Receiving Environmental Media

As described in Section 1.2, the primary source of environmental release of HO at JI (i.e., corroded steel drums containing HO) was removed in 1977. However, contaminated soil has subsequently served as a source for environmental release of the active ingredients of HO (i.e., 2,4-D, 2,4,5-T) and the contaminant TCDD. As described in Section 2.0, the environmental media which has been sampled and analyzed is the soil directly beneath the HO storage site. In addition, ocean sediment and limited fish species, which are native to the reef surrounding the island, were caught and subjected to tissue analyses. The soil samples were analyzed for TCDD, 2,4-D, and 2,4,5-T, whereas the fish tissue and sediment samples were analyzed for TCDD only. Based on an evaluation of the sampling data provided to RiskFocus (see Section 2.0), the receiving media for the contamination is the soil at the site and apparently, through an unknown mechanism, the aquatic biota near the site. Air and groundwater sampling has not yet been performed and thus, cannot be evaluated as to their potential significance as receiving media (see Section 7.0).

Potential significant mechanisms of release for TCDD, 2,4,-D and 2,4,5-T from the soil at the HO site include volatilization and emission as soil-associated airborne particles (EPA, 1988b). Emission of the compounds adsorbed to airborne particulate matter is particularly important to consider if the surface of the soil at the HO storage site is disturbed (e.g., during excavation) which creates dust emissions from activities such as vehicular traffic and of vehicular loading and unloading of contaminated soil and which allows wind erosion to occur unless dust control measures are taken (EPA, 1988b). Wind erosion of the undisturbed soil at the HO site is assumed not to be significant for several reasons:

- JI experiences continuous air movement (see Section 3.1) across the island's surface. Thus, any fine particles available for erosion would have eroded soon after activity ceased on the site in 1977, leaving it relatively undisturbed with the exception of the most recent soil sampling effort (Channell and Stoddart, 1984);

- Based on direct observation during a site visit in 1990, the particle size distribution of the surface soil at the site was found to include large coral rocks which would tend to prevent wind erosion; and

- Vegetation covers approximately 20% of the surface area of the HO site, further preventing significant wind erosion.

- Helsel et al. (1987) conducted a study in 1986 which included sampling airborne particles and subsequent analysis of TCDD levels; this study suggested that particle-associated TCDD was not dispersing from the undisturbed site.

Other release processes (EPA, 1989a) that may be important are apparent from the fish tissue data. These data suggest that one or both of the following release processes may also be important:

- Leaching of TCDD (and possibly 2,4,D and 2,4,5-T) from the soil via surface and ground water migration into the ocean; and

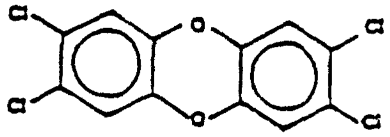
- Migration of contaminated soil particles into the ocean due to water drainage.

The rate and extent of bioconcentration of these compounds in the local reef ecosystem cannot be assessed with the available data. Similarly, without air sampling data (e.g., vapor phase and particulate matter) the extent to which the compounds may be directly volatilizing or emitted as contaminated dust from the site is unknown. The next section (3.2.2) presents further rationale for the exposure pathways of potential concern based on physicochemical characteristics, and the environmental fate and transport of these compounds.

3.2.2 Evaluation of Environmental Fate and Transport

3.2.2.1 Environmental Fate and Transport of Dioxin

Polychlorinated dibenzo-p-dioxins are tricyclic aromatic compounds consisting of two benzene rings connected through oxygen atoms and containing a varying number of chlorine atoms at different positions on the benzene rings. There are 75 possible isomers of polychlorinated dibenzo-p-dioxins (EPA, 1979). Most of the environmental fate and transport data on this class of compounds are on the 2,3,7,8 isomer. Its structure is shown below.



2,3,7,8-Tetrachlorodibenzo-p-dioxin

TABLE 3.1
Physical/Chemical Properties of Constituents of Herbicide Orange Found at Johnston Island
Herbicide Orange Storage Area
Johnston Island, Johnston Atoll

Chemical Name	Molecular Weight	Specific gravity	Water solubility (mg/L)	Vapor pressure (mm Hg)	Henry's Law Constant (atm-m^3/mol)	Log (K_{oc})	Log (K_{ow})
2,3,7,8-Tetrachloro-dibenzo-p-Dioxin[a]	321.97	1.827	1.93×10^{-5}	1.52×10^{-9}	8.1×10^{-5}	6.0-7.39	6.15-7.28
2,4-Dichlorophenoxy acetic acid[b] (n-butyl ester)	277.15	No data	2.47	4.62×10^{-6}	6.8×10^{-7}	4.0	4.60
2,4,5-Trichlorophenoxy acetic acid[b] (n-butyl ester)	311.59	1.316-1.340[d]	0.268	5.08×10^{-7}	7.77×10^{-7}	5.0	5.34
2,4,5-Trichlorophenoxy acetic acid[b] (Iso-octyl ester)	367.7	1.2-1.22[d]	NA[c]	6.12×10^{-9}	NA[c]	NA[c]	7.33

[a] Values from ATSDR, June 1989.
[b] All values except specific gravity estimated by GEMS.
[c] Not available (no estimation method available).
[d] From Department of the Air Force, 1974.

TCDD is formed as a byproduct under the conditions of synthesis of polychlorinated phenols and products formed from them, including the herbicide 2,4,5-T. The amount of TCDD occurring in 2,4,5-T appears to vary with each batch and with each manufacturer (EPA, 1979). Table 3.1 lists the key physical properties of 2,3,7,8-TCDD. The ultimate environmental fate of 2,3,7,8-TCDD appears to be strong adsorption to soils and sediments and bioaccumulation in biota.

(1) *Soil*. Once 2,3,7,8-TCDD moves into soils, it is strongly sorbed and only limited migration through the soil is expected to occur [(as suggested by its low water solubility (200 ppt)] and high log K_{OC}) unless organic solvents are present that are able to elute the compound from the soil particles (EPA, 1990). Transport of 2,3,7,8-TCDD through or from contaminated soil occurs to a limited extent through:

- Slow movement of the compound through the soil column as a result of leaching;
- Overland transport of contaminated soil particles as runoff;
- Wind erosion; and
- Diffusion of 2,3,7,8-TCDD vapor through the soil pore spaces and ultimately to the atmosphere (EPA, 1988b).

The latter process, however, is expected to be slow due to the high affinity of the compound for soil particles and the low vapor pressure of 2,3,7,8-TCDD (on the order of 10^{-9} to 10^{-11} mm Hg at 25°C) (EPA, 1990). As a result, the half-life of volatilization from soil is measured in weeks for surface soil and in years for 2,3,7,8-TCDD occurring below 5 cm of soil (EPA, 1990).

Chemical degradation of 2,3,7,8-TCDD via hydrolysis or oxidation in soil is unlikely to be an important fate process in light of the very low rate constants for these reactions in aqueous media (EPA, 1988b). Laboratory studies indicate that after deposition of 2,3,7,8-TCDD onto surfaces, there is initially a high loss due to photodegradation in the presence of hydrogen donors, and possibly volatilization (EPA, 1990). However, there is little evidence to support the suggestion that photolysis plays a significant role in the fate of 2,3,7,8-TCDD in soils, especially when the compound occurs in horizons below the soil surface (EPA, 1988b). Some loss due to the biodegradation by microorganisms in the soil may occur, but the extent of loss through this mechanism is highly dependent on the type and concentration of organisms present in the soil; under most circumstances; biodegradation is not expected to make a significant contribution to the fate of 2,3,7,8-TCDD (EPA, 1988b).

(2) *Water*. The major fate of 2,3,7,8-TCDD in aquatic ecosystems is related to adsorption and loss to sediments and suspended particulate matter, due to the low water solubility and high K_{OC} of this compound. Half-lives in water due to photolysis, as estimated from quantum yield data, are from roughly 1 to 4.6 days; however measured half-lives of 2,3,7,8-TCDD in water due to photolysis exceed 28 days (EPA, 1990). 2,3,7,8-TCDD is probably stable to oxidation in aquatic environments, based on limited data (EPA, 1990). There is no available evidence that 2,3,7,8-TCDD would be degraded to any extent by hydrolysis in water (EPA, 1990). The estimated Henry's Law constant of 1.6×10^{-5} atm-m^3/mol suggests that 2,3,7,8-TCDD may volatilize from water and enter the atmosphere.

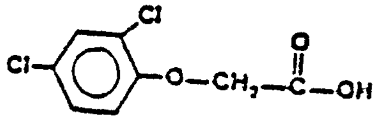
(3) *Sediments*. 2,3,7,8-TCDD is transferred to sediments via leaching from contaminated soil, runoff of contaminated soil particles, and precipitation of resuspended contaminated soil particles and vapor (adsorbed to particles or in rainfall) from the atmosphere into bodies of water. As with soil, microbial degradation is expected to be slow and, hence, not an important fate mechanism for this compound.

(4) *Air.* The air over a contaminated site will contain limited amounts of 2,3,7,8-TCDD as a result of slow volatilization from the soil and resuspension of contaminated soil particles from the site. Laboratory studies indicate that indirect photolysis occurs through reaction of atmospheric hydroxyl radicals with 2,3,7,8-TCDD, indicating a half life of airborne gaseous 2,3,7,8-TCDD in sunlight of 5 to 24 days (EPA, 1990). Methods for estimating photolysis half life are inconsistent with measurements in the laboratory, producing values of 1 to 200 hours as the half-life (EPA, 1990).

(5) *Biota.* 2,3,7,8-TCDD has been shown to be bioavailable to fish and other aquatic organisms primarily from sediments (EPA, 1988b). In fact, of the possible substituted dioxin isomers in the tetra- through octachlorinated homologous series, the 2,3,7,8 isomer has the highest bioaccumulation in fish (EPA, 1988b). The extent of actual bioaccumulation will depend on the species, lipid content, ratio of surface area to weight, food intake rate, density of suspended particulate matter, the time each species spends in given contaminated areas, and the concentrations of the compound in the contaminated sediments (EPA, 1988b). Marine biota may bioaccumulate 2,3,7,8-TCDD from intake of sediments, from intake of contaminated food, and via absorption from external surfaces (although the latter is probably a minor route). While no data exist to determine whether a correlation exists between the bioconcentration factor (BCF) and concentration in the water for marine species, studies with warm- and coldwater freshwater species indicate that the lower the water concentration, the higher is the BCF observed (EPA, 1990). Estimated BCFs for 2,3,7,8-TCDD based on measured versus estimated Log K_{OW} values range from 3,000 to 68,000 and from 7,000 to 900,000, respectively (EPA, 1984). Adequate measured data to characterize the actual range of BCFs for marine species for 2,3,7,8-TCDD are not available. Measured data for freshwater fish include a whole-body BCF of 2,000 for channel catfish (after 28 days) and a steady-state BCF of 5,450 to 9,270 in rainbow trout (EPA, 1984). Section 6.0 of this report contains additional information on the uptake of TCDD in biota.

3.2.2.2 Environmental Fate and Transport of 2,4-D

The chemical structure of 2,4-D is shown below.

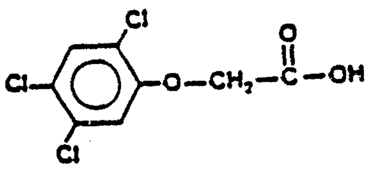


2,4-D

There is only limited fate information available on 2,4-D; however, its environmental fate and transport properties can at least be inferred in part from the physicochemical properties listed in Table 3.1. The log K_{OC} value of 4 ($K_{OC} = 10{,}000$) indicates that 2,4-D will absorb strongly to soil, but 100 or more times less tenaciously than 2,3,7,8-TCDD. Due primarily to the higher water solubility of 2,4-D relative to that of 2,3,7,8-TCDD, 2,4-D will volatilize even less than 2,3,7,8-TCDD from contaminated waters, as suggested by the difference in Henry's law constant. Because of its lower log K_{OW}, 2,4-D is expected to bioaccumulate in fish to a much lesser extent than 2,3,7,8-TCDD. Because the magnitude of its vapor pressure is 3 orders greater than that of TCDD, 2,4-D is expected to volatilize to a greater extent from contaminated soil. 2,4-D is biodegraded by soil microorganisms, and there is reportedly no accumulation of 2,4-D in soil as a result of normal agricultural use (IARC, 1977). Based on experience in Southeast Asia, less than or equal to 0.02 percent of the amount originally applied remained in the soil after 6 to 7 years (IARC, 1977). 2,4-D is reported to have a half-life of considerably less than 28 days in sediments from freshwater ponds (IARC, 1977).

3.2.2.3 Environmental Fate and Transport of 2,4,5-T

The chemical structure of 2,4,5-T is shown below.



2,4,5-T

There is only limited fate information available on 2,4,5-T; however, its environmental fate and transport properties can at least be inferred in part from the physicochemical properties listed in Table 3.1. The fate properties of 2,4,5-T closely resemble those of 2,4-D. Thus:

- Strong adsorption to soil is expected, but not as high a binding strength as with 2,3,7,8-TCDD;
- Less volatilization from water and greater volatilization from soil are expected relative to 2,3,7,8-TCDD; and
- Less bioaccumulation is fish and other marine life is expected relative to TCDD.

2,4,5-T is reported to be biodegraded more slowly than 2,4-D by soil microorganisms; however, it is also reported that no accumulation of 2,4,5-T in soil occurs as a result of annual agricultural applications (IARC, 1977). Based on experience in Southeast Asia, less than or equal to 0.3 percent of the original applied amount remained in the soil 3 to 5 years after application (IARC, 1977).

3.2.3 Identification of Exposure Points and Routes

Based on the current exposure setting at the HO site, the physicochemical properties of TCDD, 2,4-D, and 2,4,5-T, their fate and transport, and the currently available environmental sampling data for soil and fish tissue, the following exposure pathways were considered in evaluating potential current exposures:

Current Scenario:

(1) Inhalation of vapor-phase TCDD, 2,4-D, and 2,4,5-T by persons working near the existing site (see Section 3.1.4); and

(2) Ingestion of contaminated fish.

Similarly, two proposed future-use scenarios for the HO site were considered based on options for future use known to have been considered by the U.S. Air Force (Jeffers, 1984):

(1) Excavation of the contaminated soil and concurrent treatment by incineration; or

(2) Construction of a cement layer on top of the entire HO site for use as a storage depot.

Thus, based on the activities associated with these scenarios and consideration of the currently available soil sampling data, the following potential future exposure pathways were considered for:

Future-Use Scenario:

- *Scenario 1 (Excavation)*: Inhalation of contaminated soil from vehicular traffic, loading and unloading operations during site excavation and treatment, and wind erosion of disturbed soil.
- *Scenario 2 (Cement Covering)*: Inhalation of contaminated soil from vehicular traffic and wind erosion of disturbed soil.

For both of the future-use scenarios, direct exposure to workers engaged in the remediation activities was not considered likely. It was assumed that these individuals would be adequately protected by personal protective equipment (e.g., clothing, gloves, respirators) used site remediation/modification involved in the two future-use scenarios. Thus, the exposure points (receptor sites) being evaluated include inadvertent exposure to individuals working near the site (see Section 3.1.4).

3.3 Quantification of Exposure

3.3.1. Estimation of Reasonable Maximum Exposure

The theoretical most exposed individual (MEI) is assumed to represent the risk receptor. This is consistent with procedures recommended by the EPA (1989c). In this assessment, risk to the MEI is based on access to any point around the perimeter of the HO site (including the seawall) and selection of the maximum point of exposure around the perimeter. However, in actuality there are certain limitations to where the MEI can be situated because of the real limitations on access to the site. Therefore, risk to an alternate, more realistic MEI (a person who has "reasonable maximum exposure"), restricted to the fenceline and not the seawall, is also calculated for comparison. As a result, risk is calculated for two receptors, the theoretical MEI (TMEI) and the alternate MEI (AMEI).

3.3.2 Inhalation of Vapors

As discussed in Section 3.2.2, volatilization is an important mechanism by which TCDD is depleted from the soil (EPA, 1988b). Further, based on EPA's analyses, the fate of TCDD in soil is so slow by water leaching that other transport mechanisms, such as volatilization and erosion, are much more important. However, in view of the very low vapor pressure of TCDD, volatilization itself may be an extremely slow process depending upon variables such as diurnal temperature changes on the surface of the soil, as well as concurrent processes such as photolysis of the compound at the surface, and microbial degradation (EPA, 1988b). Given the similar physicochemical properties of 2,4-D and 2,4,5-T, vapor-phase emission is also considered to be an important release mechanism for these compounds.

To assess potential inhalation exposure from vapor-phase TCDD, 2,4-D, and 2,4,5-T originating from contaminated soil at the HO site, a screening-level air modeling analysis was conducted to estimate one-hour, eight-hour, and annual average concentrations of these compounds at the fenceline of HO site beginning after removal of the drums containing HO. These predicted air concentrations were then used to estimate inhalation exposure to individuals working near the site (proximate to the fenceline).

The EPA-approved Industrial Source Complex (ISC) model (EPA, 1987) was used in a screening mode to conservatively estimate ambient air concentrations of the vapor-phase compounds. Model runs were made for wind directions every 10 degrees around the compass (36 runs total), starting from north (0 degrees). A wind speed of 1.0 m/s and an extremely stable atmosphere (Pasquill stability category 6) were assumed in the modeling.

A total of 140 ground-level, non-buoyant, point sources were used to represent the area of compound emissions in the modeling. The main HO site was extended