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June 23, 2011

VIA EMAIL AND HAND DELIVERY

Frank Melbourn
Water Resources Control Engineer
San Diego Regional Water Quality Control Board
9174 Sky Park Court, Suite 100
San Diego, CA 92123

Re: **In the Matter of: Tentative Cleanup and Abatement Order No. R9-2011-0001 Submissions by BAE Systems San Diego Ship Repair, Inc. to the Administrative Record**

Dear Mr. Melbourn:

Pursuant to the Third Amended Order of Proceedings in this matter, BAE Systems San Diego Ship Repair, Inc. is enclosing copies of the below list of documents as supplements to the Administrative Record in the above-referenced proceedings.

1. Environmental Protection Agency, Locating and Estimating Air Emissions From Sources of Polychlorinated Biphenyls, May 1987
2. Nisbet, Ian C.T. et al., Rates and Routes of Transport of PCBs in the Environment in Environmental Health Perspectives, April 1972
3. Environmental Protection Agency, Polychlorinated Biphenyl Inspection Manual, August 2004
4. Environmental Protection Agency, An Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States for Years 1987, 1995, and 2000, November 2006
5. EnecoTech Southwest, Inc., Final Report for Phase II Environmental Investigation Services, PCB Investigation, April 29, 1997
6. W. David Phillips, The Use of a Fire-Resistant Lubricant: Europe Looks to the Future in Turbine Lubrication in the 21st Century, 2001

7. A.C. M. Wilson, Fire-Resistant Fluids for General Hydraulic and Steam Turbine Systems, February 1967
8. Dowell Vertan 675 Chemical Cleaning Instructions and Schedule for Boilers 5 and 6
9. SDG&E Daily PCB Inspection Reports
10. SDG&E Internal Correspondence PCB Cleanup, May 14, 1981
11. SDG&E Letter to Fire Marshall, November 27, 1985
12. EPA Region 9 Toxics and Waste Management Division Inspection Report, April 27, 1987
13. List of Substation Equipment, November 3, 2004
14. EPA Superfund, Explanation of Significant Differences: Westinghouse Electric Corp., February 14, 1997
15. Woodward-Clyde Consultants, Underground Tank Assessment SDG&E Silver Gate Station, November 18, 1986
16. Letter from Walter Zitlau to M. Hjalmarson, May 1, 1950
17. SDG&E Power Plant Wastewater Treatment Facilities Project Design Guide, March 26, 1976
18. RBF Consulting, Phase I Environmental Site Assessment, March 2005
19. TN & Associates, Silver Gate Power Plant Basement Trench System Sediment Sampling, December 21, 2006
20. Proposed Dredging & Jetty on San Diego Bay, Application by SDG&E, April 20, 1942
21. Solid Waste Management Unit Information Data for Transformers and Circuit Breakers at Silver Gate power plant
22. Crosby & Overton, Site Assessment and Hydrocarbon Mitigation at the Silver Gate Power Plant, November 10, 1987
23. SDG&E Onsite Hydrology/Drainage Study, March 14, 2006
24. City of San Diego Map of Sampson Street Storm Drain from Belt Street to Harbor Street, February 27, 1985
25. City of San Diego Map of Portion of Sampson Street, June 22, 1988

26. Letter from SDG&E to the City of San Diego, October 25, 2005

27. Letter from SDG&E to the City of San Diego, December 1, 2005

28. Letters from SDG&E to the City of San Diego, January 10, 2006 and March 16, 2006

29. Schorer, M. Pollutant and organic matter content in sediment particle size fractions. Freshwater Contamination. IAHS Pub. no. 243, 1997

30. Estes, T.J. PAH and PCB distribution in sediment fractions and sorptive phases, 2005

31. Brannon, J.M., W.M. Davis, V. McFarland, and C. Hayes, Organic matter quality and partitioning of polychlorinated biphenyls, 1997

32. Delle Site, A., Factors affecting sorption of organic compounds in natural sorbent/water systems and sorption coefficients for selected pollutants; a review. J. Phys. Chem. Ref. Data 30:187-439, 2001

33. Chiarenzelli et al., Volatile Loss of PCB Aroclors from Subaqueous Sand in Environmental Science Technology, 1997

34. Van Dort et al., Reductive Ortho and Meta Dechlorination of a Polychlorinated Biphenyl Cogener by Anaerobic Microorganisms in Applied Environmental Microbiology, 1991

35. T.S. Hurme and J.A. Puhakka, Characterization and Fate of Polychlorinated Biphenyl Contaminants in Kernaalanjarvi Sediments in Boreal Environmental Resources, 1999

Very truly yours,

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EPA-450/4-84-007n
May 1987

Locating And Estimating Air Emissions From Sources Of Polychlorinated Biphenyls (PCB)

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office Of Air And Radiation
Office Of Air Quality Planning And Standards
Research Triangle Park, North Carolina 27711

EPA-450/4-84-007n

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FIGURES

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SECTION 1

PURPOSE OF DOCUMENT

EPA, States and local air pollution control agencies are becoming increasingly aware of the presence of substances in the ambient air that may be toxic at certain concentrations. This awareness, in turn, has led to attempts to identify source/receptor relationships for these substances and to develop control programs to regulate emissions. Unfortunately, very little information is available on the ambient air concentrations of many of these substances or on the sources that may be discharging them to the atmosphere.

To assist groups interested in inventorying air emissions of various potentially toxic substances, EPA is preparing a series of documents such as this that compiles available information on sources and emissions of these substances. This document specifically deals with polychlorinated biphenyls (PCBs). Its intended audience includes Federal, State and local air pollution personnel and others who are interested in locating potential emitters of PCBs and making preliminary estimates of air emissions therefrom.

Because of the limited amounts of data available on PCB emissions, and since the configuration of many sources will not be the same as those described herein, this document is best used as a primer to inform air pollution personnel about 1) the types of sources that may emit PCBs, 2) source variations and release points that may be expected within these sources, and 3) available emissions information indicating the potential for PCBs to be released into the air from each source.

The reader is strongly cautioned that using the emissions information contained in this document will not yield an exact assessment of emissions from any particular source. Since insufficient data are available to develop statistical estimates of the accuracy of these emission factors, no estimate can be made of the error that would result when these factors are used to calculate emissions from any given source. It is possible, in some extreme cases, that orders-of-magnitude differences could result between actual and calculated emissions, depending on differences in source configurations, control equipment and operating practices. Thus, in situations where an accurate assessment of PCB emissions is necessary, source-specific information should be obtained to confirm the existence of particular emitting operations, the types and effectiveness of control measures, and the impact of operating practices. A source test and/or material balance should be considered as the best means to determine air emissions directly from an operation.

This document presents information on rules governing the use and disposal of PCBs. The information contained herein represents the regulatory status of PCBs as of the compilation date of the document (February 1986). Because of the dynamics involved in regulating PCBs, rules are frequently revised. Therefore, the reader should consult references such as the Code of Federal Regulations to determine the current regulatory status.

SECTION 2

OVERVIEW OF DOCUMENT CONTENTS

As noted in Section 1, the purpose of this document is to assist Federal, State and local air pollution agencies and others who are interested in locating potential air emitters of polychlorinated biphenyls (PCBs) and making gross estimates of air emissions therefrom. Because of the limited background data available, the information summarized in this document does not and should not be assumed to represent the source configuration or emissions associated with any particular source.

This section provides an overview of the contents of this document. It briefly outlines the nature, extent and format of the material presented in the remaining sections of this report.

Section 3 of this document provides a brief summary of the physical and chemical characteristics of PCBs, their commonly occurring forms and an historical overview of their production and uses. With minor exceptions, PCBs are no longer produced in the United States (domestic production ceased in 1977) and have been used only in closed systems (e.g., transformers, capacitors) since 1971. A chemical use tree summarizes the quantities of PCBs consumed in various end use categories in the United States. This background section may be useful to someone who needs to develop a general perspective on the nature and uses of PCBs.

Section 4 of this document focuses on major industrial source categories that may discharge PCB air emissions. This section discusses disposal methods and sources of accidental releases of PCBs. For each major source category described in Section 4, available emissions information -- including emission factor estimates -- is presented that shows the potential for PCBs emissions.

The final section of this document summarizes available procedures for source sampling and analysis of PCBs. Details are not prescribed nor is any EPA endorsement given to any of these sampling and analytical procedures. At this time, EPA generally has not evaluated these methods. Consequently, this document merely provides an overview of applicable source sampling procedures, citing references for those interested in conducting source tests.

This document does not contain any discussion of health or other environmental effects of PCBs, nor does it include any discussion of ambient air levels or ambient air monitoring techniques.

Comments on the contents or usefulness of this document are welcomed, as is any information on process descriptions, operating practices, control measures and emissions information that would enable EPA to improve its contents. All comments should be sent to:

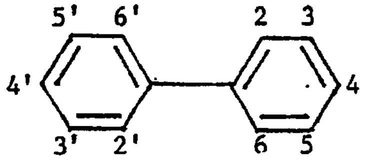
Chief, Noncriteria Emissions Section (MD-14)
Air Management Technology Branch
U.S. Environmental Protection Agency
Research Triangle Park, N.C. 27711

SECTION 3

BACKGROUND

NATURE OF POLLUTANT

The term "polychlorinated biphenyls (PCBs)" refers to a class of organic chemicals produced by the chlorination of biphenyl. Ten classes of PCBs may be formed (these include monochlorobiphenyl, although it is not technically polychlorinated), depending on the specific number of chlorine substitutions on the biphenyl molecule. These compounds, in increasing order of chlorine substitution, are monochlorobiphenyl, dichlorobiphenyl, trichlorobiphenyl, and so on. Several isomers of each PCB molecule are possible (for a total of 209), but not all are likely to be formed during the manufacturing processes. The biphenyl structure with possible substitution sites is shown below:[1]



PCB molecules and their molecular weights are presented in Table 1. Table 2 presents properties of selected isomers.

In general, higher PCB chlorine content corresponds to greater resistance to chemical degradation. PCB isomers, which range from liquids to high melting crystalline solids, exhibit low solubility in water, low vapor pressure, low flammability, high heat capacity, moderate heat of vaporization, and low electrical conductivity. These properties, as well as favorable dielectric constants and suitable viscosity-temperature relationships, make them extremely advantageous for use as dielectric and heat transfer fluids.[6]

TABLE 1. COMPOSITION OF POLYCHLORINATED BIPHENYLS[2]

Compound	Empirical formula	Molecular weight[a]	Weight percent chlorine[a]	Number of isomers
Monochlorobiphenyl	$C_{12}H_9Cl$	188	18.6	3
Dichlorobiphenyl	$C_{12}H_8Cl_2$	222	31.5	12
Trichlorobiphenyl	$C_{12}H_7Cl_3$	256	41.0	24
Tetrachlorobiphenyl	$C_{12}H_6Cl_4$	290	48.3	42
Pentachlorobiphenyl	$C_{12}H_5Cl_5$	324	54.0	46
Hexachlorobiphenyl	$C_{12}H_4Cl_6$	358	58.7	42
Heptachlorobiphenyl	$C_{12}H_3Cl_7$	392	62.5	24
Octochlorobiphenyl	$C_{12}H_2Cl_8$	426	65.7	12
Nanochlorobiphenyl	$C_{12}HCl_9$	460	68.5	3
Decachlorobiphenyl	$C_{12}Cl_{10}$	494	79.9	1

[a] Based on Cl^{35}.

TABLE 2. MELTING POINTS AND SOLUBILITIES OF SOME PCB ISOMERS

Compound	CAS number[3]	Melting point[4] (°C)	Solubility in water[5] (mg/l)
Monochlorobiphenyls			
2-	2150-60-7	34	5.90
3-	--	--	3.50
4-	2051-62-9	77.7	1.19
Dichlorobiphenyls			
2,4-	--	--	1.40
2,2'-	13029-08-8	60.5	1.50
2,3'-	25569-80-6	--	--
2,4'-	34883-43-7	44.5-56	1.88
4,4'-	2050-68-2	149-150	0.08
Trichlorobiphenyls			
2,4,4'-	7012-37-5	57-58	0.085
2,2',3-	38444-78-9	28.1-28.8	--
2,2',5-	37680-65-2	43-44	--
2,4',5-	16606-02-3	67	--
2',3,4-	38444-86-9	65-66	0.078
Tetrachlorobiphenyls			
2,3,4,4'-	33025-41-1	142	--
2,2',3,3'-	--	--	0.034
2,2',3,5'-	41464-39-5	49-50	0.170
2,2',4,4'-	--	--	0.068
2,2',4,5'-	41464-40-8	66-68.5	--
2,2',5,5'-	35693-99-3	87-89	0.046
2,3',4,4'-	32598-10-0	127-127.5	0.058
2,3',4',5-	32598-11-1	104-105	0.041
3,3',4,4'-	32598-13-3	182-184	0.175
Pentachlorobiphenyls			
2,3,3',4,4'-	--	117-118.5	--
2,3,3',4',6-	38380-03-9	--	--
2,2',3,4,5'-	--	111.5-113	0.022
2,2',3,3',6-	52663-60-2	--	--
2,2',3,5',6-	38379-99-6	98.5-100	--
2,2',4,5,5'-	37680-73-2	76.5-77.5	0.031
2,2',4,4',5-	38380-01-7	--	--
2,2',3',4,5-	41464-51-1	81-82	--
2,3',4,4',5-	31508-00-6	112-113	--

(continued)

TABLE 2. (continued)

Compound	CAS number[3]	Melting point[4] (°C)	Solubility in water[5] (mg/l)
Hexachlorobiphenyls			
2,2',3,4,4',5-	35694-06-5	77-78	--
2,2',3,4,4',5'-	35065-28-2	114-114.5	--
2,2',3,3',4,6-	38380-05-1	--	--
2,2',3,3',6,6-	38411-22-2	--	--
2,2',4,4',5,5'-	35065-27-1	103-104	0.088
2,2',3',4,5,6'-	38380-04-0	--	--
Heptachlorobiphenyls			
2,2',3,4',5,5'-	35065-29-3	109-110	--
2,2',3,3'4,5,6'-	38441-25-5	130.5-130.7	--
2,2',3,3',4,4',5-	35065-30-6	134.5-135.5	--
Octochlorobiphenyl			
2,2',3,3',4,4',5,5'-	--	--	0.007
Decachlorobiphenyl	--	--	0.015

Individual PCB isomers have been prepared in the laboratory by various synthetic routes.[7] However, for commercial purposes, PCBs are used and sold as a mixture of isomers. Large-scale U.S. production of PCBs was stopped voluntarily in October 1977 because of the tendency of PCBs to accumulate and persist in the environment and because of their toxic effects.[7] The principal U.S. producer of PCBs was Monsanto Industrial Chemicals Company which made the products under the registered trademark of Aroclor. As presented in Table 3, several Aroclor products were marketed prior to 1977 with various compositions. After 1977, manufacture of PCBs in the U.S. was restricted to situations requiring special authorization or exemptions by EPA. Manufacture of PCBs currently consists of low level incidental generation associated with the production of other compounds and the manufacture of small quantities of pure PCBs for research and development.[82]

All Aroclor products are designated by a four digit number, usually beginning with the prefix 12 to represent the biphenyl starting material, and a second set of digits to represent the approximate chlorine percentage. For example, Aroclor 1242 is a chlorinated biphenyl containing approximately 42 percent chlorine. Aroclors beginning with the prefixes 25 and 44 are blends of PCBs and chlorinated terphenyls while the prefix 54 represents a chlorinated terphenyl mixture with no biphenyl. Aroclor 1016 contains 41 percent chlorine by weight but the penta-, hexa-, and heptachlorobiphenyl content has been significantly reduced.[8]

Commercial mixtures of PCBs have been produced by companies in countries other than the U.S. and have been sold under various tradenames with various systems for product identification. These companies' tradenames are discussed in the subsection titled "Overview of Production and Uses."

The commercial mixtures of PCBs have properties quite different from the individual isomers, particularly in crystallinity and liquid range. PCBs are generally chemically inert and react with other materials only under high temperatures or extreme conditions. They are insoluble in water, glycerol, and glycols but are soluble in most of the common organic solvents. PCBs are highly resistant to oxidation. They are permanently thermoplastic in the higher chlorination levels and are considered extremely useful in energy

TABLE 3. PERCENT COMPOSITION OF SELECTED AROCLORS[2]

Chlorobiphenyl	Aroclor Type					
	1221	1242	1248	1254	1260	1016
$C_{12}H_{10}$	11	<0.1		<0.1		<0.1
$C_{12}H_9Cl$	51	1		<0.1		1
$C_{12}H_8Cl_2$	32	16	2	0.5		20
$C_{12}H_7Cl_3$	4	49	18	1		57
$C_{12}H_6Cl_4$	2	25	40	21		21
$C_{12}H_5Cl_5$	0.5	8	36	48	12	1
$C_{12}H_4Cl_6$		1	4	23	38	<0.1
$C_{12}H_3Cl_7$		<0.1	—	6	41	
$C_{12}H_2Cl_3$					8	
$C_{12}HCl_9$					1	
$C_{12}Cl_{10}$						

transfer applications. However, under elevated temperatures, the chlorine can react with metal to cause corrosion.[7] Chemical and physical properties of selected Aroclors are presented in Tables 4 and 5.

PCBs are not reactive chemically under normal environmental conditions. However, their use in quenching of heated metals, as heat-transfer media, and in transformer oil, may lead to the formation of degradation products such as dibenzofurans, polychloroquaterphenyls, polychloroquaterphenyl ethers, polychloroterphenyls, and oxygen-containing polymerics.[10]

Photodegradation of PCBs produces a variety of products via such pathways as chlorine replacement by hydrogen or hydroxyl groups, rearrangement, or condensation. Replacement of chlorine by hydroxyl groups at the ortho positions allows oxygen to bind in a similar position on the other ring, resulting in the formation of chlorodibenzofurans. Both heat and light can accelerate this process. However, while some experiments have indicated chlorodibenzofurans as a product of the process, other tests have resulted in no chlorodibenzofurans being detected. Because of the mixed results, no assessment of the accumulation of chlorodibenzofurans due to photodegradation of PCBs can be made.[10]

Biodegradation of PCBs has been reported to depend on the degree of chlorination. Although lower chlorinated biphenyls are readily transformed by bacteria, biodegradation of the pentachlorophenyls may be extremely slow, and that of hexa- and higher chlorinated biphenyls is practically negligible.[11]

PCBs are remarkable among organic industrial chemicals for their low solubility in water, their high octanol/water partition coefficients, accumulation coefficients, and their resistance to in-vivo degradation. As a result, they exhibit extraordinarily high values for bioaccumulation in animal tissues, especially in fish and other aquatic organisms. Bioaccumulation in fish may take place either through ingestion of contaminated food organisms or by direct absorption through the skin.[12]

OVERVIEW OF PRODUCTION AND USES

PCBs were first formulated in 1881 and were manufactured on a commercial scale in the United States as early as 1929.[13] Monsanto was the principal manufacturer in the United States until 1977 when they voluntarily ended

TABLE 4. CHEMICAL AND PHYSICAL PROPERTIES OF AROCLORS 1016 THROUGH 1260 [8,9]

Aroclor	1016	1221	1232	1242	1248	1254	1260
CAS registry no.	12674-11-2	11104-28-2	11141-16-5	53469-21-9	12672-29-6	11097-69-1	11096-82-5
Appearance	Clear, mobile oil	Clear, mobile oil	Clear, mobile oil	Clear, mobile oil	Clear, mobile oil	Light-yellow viscous liquid	Light-yellow soft, sticky resin
Weight % chlorine	41	20.5-21.5	31.4-32.5	42	48	54	60
Approx. mol. wt.	257.5	188.64	223.1	257.5	291.9	326.5	360.7
Stability	inert	inert	inert	inert	inert	inert	inert
Color, maximum	40 APHA	100 APHA	100 APHA	100 APHA	100 APHA	100 APHA	150 APHA
Acidity, mg KOH/g	NA	0.014	0.014	0.015	0.010	0.010	0.014
Moisture, ppm	NA	NA	NA	50	50	50	50
Ave. coefficient of expansion, cc/cc/$^{\circ}$C	NA	0.00071 (15°-40°C)	0.00073 (25°-100°C)	0.00068 (25°-65°C)	0.00070 (25°-65°C)	0.00066 (25°-65°C)	0.00067 (20°-100°C)
Specific gravity	1.362-1.372 (25°/15.5°C)	1.182-1.192 (25°/15.5°C)	1.270-1.280 (25°/15.5°C)	1.381-1.392 (25°/15.5°C)	1.405-1.415 (65°/15.5°C)	1.495-1.505 (65°/15.5°C)	1.555-1.566 (90°/15.5°C)
Density, lb/gal, 25°C	11.40	9.85	10.55	11.50	12.04	12.82	13.50
Solubility in H_2O, mg/l @ 25°C	0.016	0.8-5.8	0.062	0.016	0.016-0.04	0.01-0.012	0.00095
Boiling point, $^{\circ}$C							
Range @ 3 mm Hg.	155-195	109	NA	155-195	165-210	180-220	195-245
Average @ 760 mm Hg.	329	267	317	329	355	374	402.5
Vapor pressure, mm Hg							
@ 25°C	0.00057	NA	NA	0.00057	0.00018	0.000032	0.000013
@ 37.8°C	0.0020	NA	0.005	0.0020	0.00072	0.00015	0.000044

(continued)

TABLE 4. (continued)

Aroclor	1016	1221	1232	1242	1248	1254	1260
Antoine constants							
A	8.06573	7.86894	NA	8.06573	7.49507	7.34306	10.0201
B	2910.95	2426.18	NA	2910.95	2587.53	2501.24	5172.89
C	232.41	219.16	NA	232.41	205.4	186.35	322.04
w/temp.range, °C	25-330	89-270	NA	25-330	25-360	25-380	25-405
Specific heat, cal/gm-°C							
@ 10°C	NA	NA	NA	0.272	0.257	0.239	NA
@ 25°C	NA	NA	NA	0.293	0.277	0.261	0.228
@ 38°C	NA	NA	NA	0.282	0.265	0.245	NA
Heat vaporization @NBP, cal/gram	61	62.6	NA	61	54	50	48
Ideal gas heat capacity, cal/ gmole-K @ 25°C	51.22**	42.89*	47.08*	51.22*	55.41*	59.55*	63.71*
Enthalpy of formation, Kcal/gmole @ 25°C	20.72**	35.92*	28.32*	20.72*	13.12*	5.52*	NA
Entropy, Gibbs/gmole @ 25°C	120.09**	105.35*	112.72*	120.09*	127.46*	134.83*	142.20*
Heat of combustion, Kcal/gmole @ 25°C	-1351.62**	-1424.62*	-1388.12*	-1351.62*	-1315.12*	-1278.62*	-1242.12*
Critical pressure, atm.	26.**	30.*	NA	26.*	NA	NA	NA
Critical temp., K	859.2**	778.5*	NA	859.2*	NA	NA	NA
Critical compressibility, dimensionless	0.24**	0.25*	NA	0.24*	NA	NA	NA

(continued)

TABLE 4. (continued)

Aroclor	1016	1221	1232	1242	1248	1254	1260
Distillation range, °C, corrected (ASTM D-20, modified)	323-356	275-320	290-325	325-366	340-375	365-390	385-420
Evaporation loss, % 100°C, 6 hr	NA	1.0-1.5	1.0-1.5	0-0.4	0-0.3	0-0.2	0-0.1
(ASTM D-6, mod.) 163°C, 5 hr	NA	NA	NA	3.0-3.6	3.0-4.0	1.1-1.3	0.5-0.8
Flash point, °C	170	141-150	152-154	176-180	193-196	NTBP	NTBP
(Cleveland Open °F Cup)	NA	286-302	305-310	348-356	379-384	NTBP	NTBP
Fire point, °C	NTBP	176	238	NTBP	NTBP	NTBP	NTBP
(Cleveland Open °F Cup)	NTBP	349	460	NTBP	NTBP	NTBP	NTBP
Pour point, °C	NA	1(crystals)	-35.5	-19	-7	10	31
(ASTM E-97) °F	NA	34(crystals)	-32	2	19.4	50	88
Refractive index, n D-20 20°C	1.622-1.624 (@ 25°C)	1.617-1.618	1.620-1.622	1.627-1.629	1.630-1.631	1.629-1.641	1.647-1.649
Viscosity, seconds Saybolt Universal (ASTM D-83)							
100°F (37.8°C)	71-81	38-41	44-51	82-92	185-240	1800-2500	-
130°F (54.4°C)	-	35-37	39-41	49-56	73-80	260-340	3200-4500
210°F (98.9°C)	-	30-31	31-32	34-35	36-37	44-48	72-78

NA = Not available.
NTBP = None to boiling point.
* = Estimated.
** = Estimated based on Aroclor 1242 properties.

TABLE 5. CHEMICAL AND PHYSICAL PROPERTIES OF AROCLORS 1262 THROUGH 5460 [8]

Aroclor	1262	1268	1270	2565	4465	5442	5460
CAS registry no.	37324-23-5	11100-14-4			12642-23-8	12642-23-8	11126-42-4
Appearance	Light-yellow sticky viscous resin	White to off-white powder	White crystalline powder	Black, opaque brittle resin	Clear, light-yellow resin	Clear, yellow sticky resin	Clear, yellow-to-amber, brittle resin or flakes
Color, maximum	150 APHA	1.5 NPA	NA	NA	2 NPA	2 NPA	2 NPA
Weight % chlorine	61.5-62.5	68	71	65	65	42	58.5-60.6
Acidity, mg KOH/g	0.014	0.05	NA	1.4	0.05	0.05	0.05
Ave. coefficient of expansion, cc/cc/°C	0.00064 (25°-65°C)	0.00067 (20°-100°C)	NA NA	0.00066 (25°-65°C)	0.00061 (25°-65°C)	0.00123 (25°-99°C)	0.00179 (25°-124°C)
Specific gravity	1.572-1.583 (90°/15.5°C)	1.804-1.811 (25°/25°C)	1.944-1.960 (25°/25°C)	1.734 (25°/25°C)	1.670 (25°/25°C)	1.470 (25°/25°C)	1.670 (25°/25°C)
Density, lb/gal, 25°C	13.72	15.09	16.30	14.44	13.91	12.24	13.91
Distillation range; °C, corrected (ASTM D-20, modified)	390-425	435-450	450-460	NA	230-320 (4 mm Hg)	215-300 (4 mm Hg)	280-335 (5 mm Hg)
Evaporation loss, % 100°C, 6 hr	0-0.1	0-0.06	NA	NA	0-0.02	0.01	NA
(ASTM D-6 mod.) 163°C, 5hr	0.5-0.6	0.1-0.2	NA	0.2-0.3	0.2-0.3	0.2	0.03
Flash point, °C (Cleveland Open °F Cup)	NTBP NTBP	NTBP NTBP	NTBP NTBP	NA NA	NTBP NTBP	247 477	NTBP NTBP
Fire point, °C (Cleveland Open °F Cup)	NTBP NTBP	NTBP NTBP	NTBP NTBP	NA NA	NTBP NTBP	>350 >662	NTBP NTBP

TABLE 5. (continued)

Aroclor	1262	1268	1270	2565	4465	5442	5460
Pour point, °C	38-38	NA	NA	NA	NA	46	NA
(ASTM E-97) °F	99	NA	NA	NA	NA	115	NA
	115						
Softening point, °C	NA	150-170	249-300	66-72	60-66	46-52	98-105
(ASTM E-97) °F	NA	302-338	NA	149-162	140-151	115-126	208-222
Refractive index, n D-20 20 °C	1.6501-1.6517	NA	NA	NA	1.664-1.667	NA	1.660-1.665
Viscosity, seconds Saybolt Universal (ASTM D-83)							
100°F (37.8°C)	600-850	NA	NA	NA	NA	NA	NA
130°F (54.4°C)	(160°F; 71°C)	NA	NA	NA	90-150	NA	NA
210°F (98.9°C)	86-100	NA	NA	NA	(265°F; 130°C)	300-400	NA

NA = Not available.
NTBP = None to boiling point.

production because of widespread environmental concerns about PCBs. Monsanto marketed PCBs under the tradenames "Askarel" and "Aroclor."[8,13] Dielectric fluids containing PCBs have been marketed by several companies under a variety of tradenames which are listed in Table 6.

Before 1977, PCBs were produced by the chlorination of biphenyl with anhydrous chlorine, using iron filings or ferric chloride as catalysts. The crude product was purified to remove traces of hydrogen chloride and catalyst.[8] Commercially produced PCBs contained no major components other than chlorobiphenyls. Small amounts of chlorodibenzofurans have been detected in PCB mixtures, possibly as a result of aqueous alkaline washing and steam distillation in the production process. PCB mixtures were sold in two grades: a purified grade and a darker, less pure, technical grade.[15]

Uses of PCBs are presented in Figure 1. Prior to 1957, virtually all PCBs were used in the manufacture of electrical transformers and capacitors. As discussed earlier, PCBs exhibit low flammability, high heat capacity, and low electrical conductivity and are virtually free of fire and explosion hazards. Consequently, PCBs can be used where failures of oil insulated transformers would present a potential danger to life and property. PCBs were therefore used wherever fire protection was particularly important -- for about 5 percent of all transformers.[17]

The PCB containing fluids used in transformers are called "askarels."[18] These fluids typically contain from 60 to 70 percent PCBs by weight, and from 30 to 40 percent chlorobenzene.[19] The amount of askarel contained in a transformer varies with transformer size. The literature reports that the quantity ranges from 150 to 1,890 liters (40 to 500 gal) which weighs 235 to 2,932 kg (516 to 6,450 lb).[20]

PCBs have been used in electrical capacitors for many of the same reasons. They are needed for safety, reliability and long life and to achieve sizes compatible with equipment and installation requirements. PCBs were used principally in high voltage power capacitors for power factor correction in the distribution of electric power; in low voltage power capacitors installed in industrial plants (typically in large motors); in ballast capacitors to improve the efficiency of lighting systems; and in small industrial capacitors

TABLE 6. COMMON TRADE NAMES FOR PCB DIELECTRIC FLUIDS[13,14]

- Askarel
- Aroclor
- Aroclor B
- Asbestol
- Chlorextol
- Chlorinol
- Chlorphen
- Chlophen
- Diachlor
- Diacolor
- DK
- Dykanol
- EEC-18
- Elemex
- Eucarel
- Fenclor
- Hyvol
- Inerteen
- Kennechlor
- MCS 1489
- Nepolin
- No-Famol
- Phenoclor
- Pydraul
- Pyralene
- Pyranol
- Pyroclor
- Saf-T-Kuhl
- Santotherm
- Solvol
- Therminol

Biphenyl ($C_{12}H_{10}$) + Chlorine (Cl_2) ------------> Polychlorinated Biphenyl ($C_{12}H_{10-n}Cl_n$) ------------>

USE		PERCENT	
CATEGORY	PRODUCT	UNTIL 1971	AFTER 1971
Closed Electrical Systems	Transformers, Capacitors, Other (Minor) Electrical Insulating/Cooling Applications	61%	100%
Nominally Closed Systems	Hydraulic Fluids, Heat Transfer Fluids, Lubricants	13%	0%
Open-End Applications	Platicizers, Surface Coatings, Ink and Dye Carriers, Adhesives Pesticide Extenders, Carbonless Copy Paper, Dyes	26%	0%
		100%	100%

Figure 1. Chemical use trees for PCBs.[16]

for power factor improvement in such equipment as air conditioning units, pumps, fans, etc.[21] The large high voltage capacitors typically weigh 54 kg (120 lb) of which 11 kg (25 lb) are PCBs, while the small ballast capacitors weigh 1.6 kg (3.5 lb) of which 0.05 kg (0.1 lb) are PCBs.[22]

Transformers and capacitors continued to be the main products using PCBs after 1957, however, additional industrial applications began to absorb a share of PCB production at this time. The relative product use of PCBs for industrial application between 1957 and 1971, when Monsanto restricted sales to closed systems (capacitor and transformer applications), is shown in Figure 2. Additional PCB applications included uses in hydraulic fluids and lubricants, plasticizers, heat transfer fluids, investment castings, and in miscellaneous industrial applications. These applications are considered either "nominally closed" or "open systems" due to the ease with which the PCBs may enter the atmosphere during use (when compared to transformer/capacitor use). The grade of Aroclor used in each of the aforementioned applications is shown in Table 7. PCBs were employed in industrial hydraulic and lubricant applications because they exhibited good heat and fire resistance and they were relatively inexpensive additives that depressed fluid pour points. These qualities are essential when hydraulic fluids are used in or near a hot operating environment. For example, hydraulic dye casting machinery and aircraft engines are two applications where moderately high operating temperatures combined with a high probability for accidents often lead to hydraulic system leaks and the possibility of fire. PCBs were used as lubricants due to the previously mentioned qualities, and also because of their oxidation and foam resistance characteristics and their low vapor pressure.[25]

PCBs gained widespread use in plasticizers because PCBs are permanently thermoplastic, chemically stable, non-oxidizing, non-corrosive, fire resistant, and are excellent solvents. In addition, they are not normally attacked by acids, alkalines or water and are insoluble in water, glycerol and glycols. These compatibility properties are especially useful in plasticizers. A plasticizer is a material incorporated in a plastic to increase its workability and flexibility. A plasticizer typically is added to

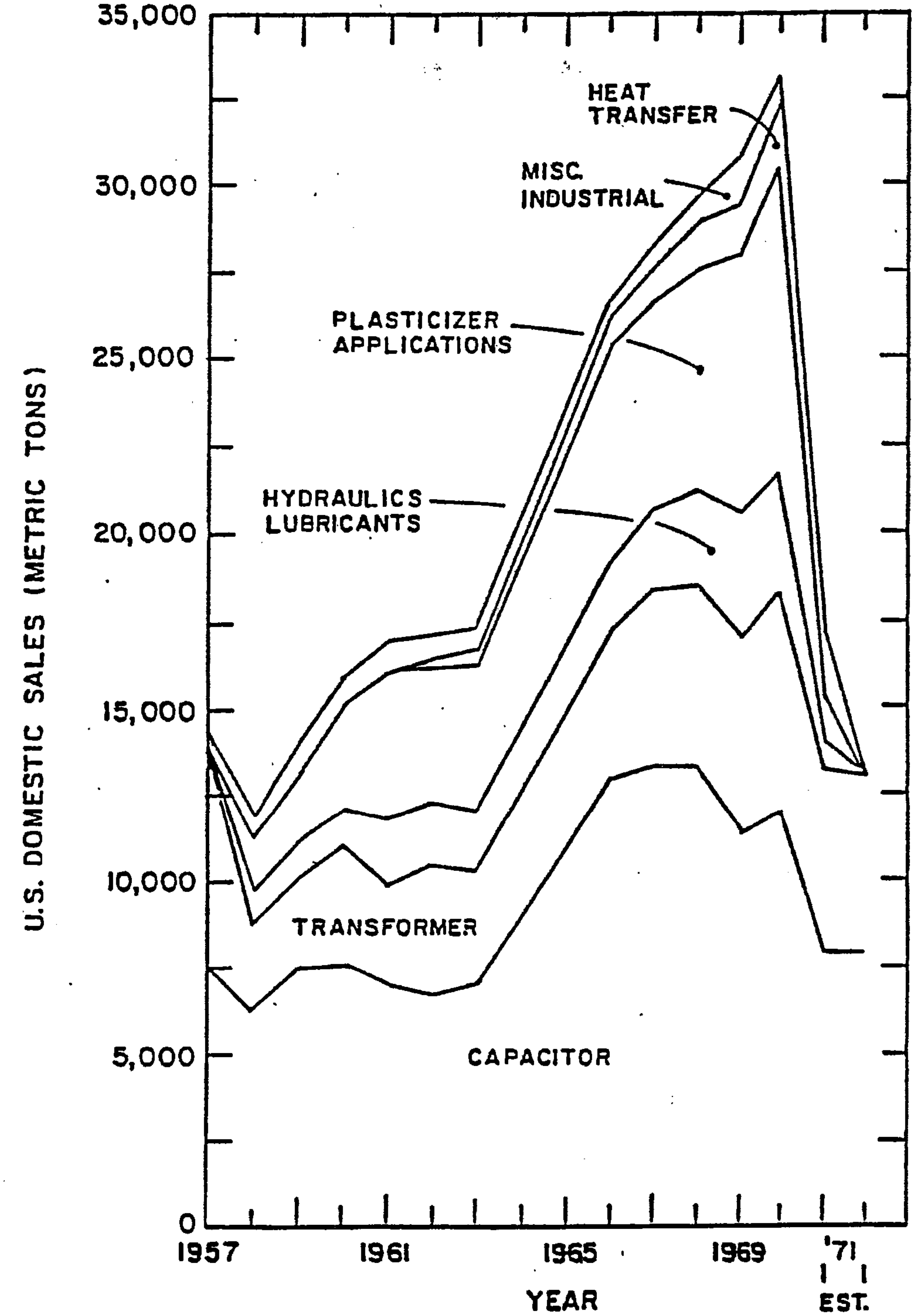


Figure 2. Domestic sales of Monsanto's Polychlorinated Biphenyls in the U.S. (by use).[23]

TABLE 7. THE USE OF PCBs PRIOR TO 1970[24]

Use	Grade(s) of Aroclor
Electrical capacitors	1221, 1242, 1254
Electrical transformers	1242, 1254, 1260
Vacuum pumps	1248, 1254
Hydraulic fluids	1232, 1242, 1248, 1254, 1260
Plasticizer in synthetic resins	1248, 1254, 1260, 1262 1268
Adhesives	1221, 1232, 1242, 1248, 1254
Wax extenders	1242, 1254, 1268
Pesticide extenders	1254
Inks	
Lubricants	
Cutting oils	
Carbonless copying paper	1242
Heat transfer systems	

change the viscosity, make the plastic softer (lower its elastic modulus) or impact some other specific property. PCBs added several of these properties at a relatively low cost.[26]

Heat transfer fluids are used to absorb thermal energy from a source and, by cooling or phase change, deliver heat to a place of utilization. PCBs have been used for these fluids due to their fire resistance, their low power and viscosities, their good thermal stability and their high heat capacity.[27] In addition, they are inert and are relatively inexpensive. However, the principle reason for use of PCBs as heat transfer fluids is their fire-resistance. This is a critical factor in cases where the possibility exists that fire from high temperature leaks could endanger life and property.

PCBs were also used by the investment casting industry in the production and subsequent use of PCB-filled pattern waxes. The investment casting process is a lost wax casting process. A pattern is molded by the injection of the molten casting wax into a metallic die where the wax cools and solidifies to form the desired shape. The wax pattern is then surrounded by a slurry containing a refractory ceramic (known as the investment) to form the final mold. After the model dries to an appropriate strength, the wax pattern is smelted in an autoclave and the wax is recovered for possible future use or disposal. Residues of wax remaining in the pores of the ceramics mold are burned out in a furnace at 1000°C to 1100°C. Molten metal may then be poured into the cavity of the ceramic mold to form a casting. Addition of fillers such as PCBs or polychlorinated triphenyls (PCTs) to investment casting waxes was a development of the 1960's. By reducing the wax content through addition of low shrinkage fillers, volumetric shrinkage of the ceramic mold may be controlled. Between 300,000 and 500,000 kg of PCBs were imported from Italy for this application in 1972.[28]

PCBs are also found used in a host of minor industrial uses. They were used in laminating adhesive formulations involving polyurethanes and polycarbonates to prepare safety and acoustical glasses. The laminates improved strength and resistance to delamination over a broad temperature range, and improved sound absorption and energy dissipation properties. PCBs were also used in adhesive formulas to improve toughness and resistance to oxidative and thermal degradation when laminating ceramics and metals.[29]

PCBs were employed with textile coating mixtures for ironing board covers, as coatings for polypropylene films and yarns and in sealing formulations to waterproof canvas. These applications took advantage of PCBs' ability to resist photochemical degradation, oxidation and fire.[30]

PCBs were used in paints and varnishes to impart weatherability, luster and adhesion. In combination with other plasticizers, they were employed to prepare film casting solutions for electrical coatings, insulating tapes and protective lacquer. PCBs are compatible with epoxy resins and give good final hardness and impact resistance to resin. These PCB resins were then used as protective coatings for metals. In addition, PCBs were used in sealing and caulking compositions to seal joints against water, dust, gas, heat and certain chemicals. Here, again, the good chemical and physical resistance properties of PCBs, their elasticity, weatherability and relative low cost made PCBs a valuable additive.[31]

Chlorinated biphenyls were employed as part of the formulations used to prepare pressure sensitive record and colored copying papers, including graphic duplicating processes, xerographic transfer processes and solvent free printing. PCBs used in this application later found their way into many paper products, when the carbonless copy paper was recycled into a host of other paper goods, including food packaging.[32]

Finally, PCBs were employed for an assortment of miscellaneous uses such as a soil erosion retardant, in combined insecticide and bactericide formulations, in plastic decorative articles, as a metal quencher and as an aid in fusion cutting of stacked metal plates.[33]

By 1970, 60 percent of PCBs sales were for closed system electrical and heat transfer uses, 25 percent for plasticizer applications, 10 percent for hydraulic fluids and lubricants, and less than 5 percent for miscellaneous applications such as surface coatings, adhesives, printing inks, and pesticide extenders. In late 1970 Monsanto confined PCB sales to closed systems. By 1971, 90 percent of all PCBs were used in this manner, and by 1972, 100 percent.[24] Monsanto ceased manufacture of PCBs completely in 1977 due to increased environmental concerns and the availability of replacement products to the electrical industry.[7]

On February 17, 1978, EPA issued a rule governing the marking and disposal of PCBs.[15] The rule applied to any substance, mixture, or item with 500 ppm or greater PCB concentrations. In 1979, EPA issued the PCB Ban Rule which superceded the previous labeling and disposal regulation and lowered the cut-off point from 500 ppm to 50 ppm. The final rule was published in the Federal Register on May 31, 1979, and specifically does the following:

(1) classifies the use of PCBs in transformers, capacitors, and electromagnets as "totally enclosed;"

(2) prohibits, unless authorized or exempted by EPA, the manufacturing, processing, distribution in commerce, and the use of PCBs except in a totally enclosed manner;

(3) provides authorizations for certain processing, distribution in commerce, and use of PCBs in a non-totally enclosed manner.

(4) prohibits waste oil containing any detectable concentrations of PCBs from being used as a sealant, coating, or dust control agent.

Also, the February 17, 1978 PCB Disposal and Marking Rule requirements were integrated into the PCB Ban Rule.[15]

Because the Toxic Substances Control Act (TSCA) considers the term "import" to be synonomous with "manufacture", no PCBs (except waste) could be imported or exported after July 2, 1979 under the Ban Rule unless an exemption was obtained. Anyone wanting an exemption from the PCB manufacturing/importation ban or the PCB processing/distribution ban must petition EPA for it. In some instances, individuals may not have to seek separate exemptions when the Agency grants "class" exemptions from certain processing and commercial distribution bans. EPA also could grant exceptions, known as authorizations, without a specific request from those who would benefit from the authorization to enable the continued processing, distribution, or use of PCBs in a non-totally enclosed manner after July 2, 1979. Exemptions are only valid for a maximum of one year, while authorizations may be granted for longer periods of time. Examples of non-totally enclosed PCB activities and uses which have been authorized by EPA are as follows:[14]

- Servicing PCB Transformers and PCB-Contaminated Transformers;
- Use in and Servicing of Railroad Transformers;
- Use in and Servicing of Mining Equipment;
- Use in Heat Transfer Systems;
- Use in Hydraulic Systems;
- Use in Carbonless Copy Paper;
- Pigments;
- Servicing Electromagnets;
- Use in Natural Gas Pipeline Compressors;
- Small Quantities for Research & Development;
- Miscroscopy Mounting Medium.

On October 30, 1980, in response to a petition from the Environmental Defense Fund, the U.S. Court of Appeals for the District of Columbia Circuit set aside portions of the May 31, 1979 Ban Rule. The court remanded the set aside portions to EPA for further action. Responding to the court order, EPA, on August 25, 1982, amended the May 31, 1979 rule by authorizing the totally enclosed use of PCBs in certain electrical equipment.[33] Among other things, this amendment authorizes the continued use of PCB small capacitors, the use of PCB large capacitors until 1988 or longer if certain conditions are met, and the use of PCB transformers and PCB-contaminated transformers, if certain conditions are met. The 1979 rule was further amended on October 21, 1982 when EPA issued a rule excluding from regulation the manufacture, processing, distribution in commerce, and use of PCBs created in closed manufacturing processes and controlled waste manufacturing processes.[33] EPA considers these PCBs to present very low risks. This rule permits the manufacture, processing, and distribution in commerce of PCBs without an exemption, provided that (1) the PCBs are released only in concentrations below the practical limits of quantitation for PCBs in air emission, water effluents, products, and process wastes and (2) the wastes from these manufacturing processes are controlled and disposed of in accordance with the methods for disposal specified in the rule.[33]

On July 10, 1984, a third amendment to the 1979 rule was issued by EPA that excludes from the TSCA ban on PCBs certain processes that inadvertently generate PCBs in low level concentrations. Other rules were issued by EPA on the same date which dealt with over 100 pending exemption petitions to manufacture, process and distribute PCBs in commerce and which authorized the use of PCBs in certain kinds of microscopy, and research and development situations. EPA believes that the PCBs permitted by these activities would not present an unreasonable risk to human health or the environment.[33]

Results from a study of the current distribution of PCBs in the United States are as follows:

Category	Amount	Percent
Presently in use	3.40×10^8 kg	60%
In landfills and dumps	1.32×10^8 kg	23%
Released to environment	0.68×10^8 kg	12%
Destroyed	0.25×10^8 Kg	5%
TOTAL	5.65×10^8 Mg	100%

The results indicate that of the 5.65×10^8 kilograms (1.25×10^9 lbs) sold between 1930 and 1977, 95 percent remains in service, in landfills, or at large in the environment.[13]

SECTION 4

PCB EMISSION SOURCES

The development of emission factors for PCBs presents unique problems not encountered with standard emission factor development. These problems can be summarized as follows:

- PCBs have not been produced (except for limited cases) in the U.S. since 1977;
- PCBs have not been used in "open systems" (those with maximum atmospheric release potential) since 1971;
- Atmospheric evaporation, transformation and degradation of PCBs are complex phenomena dependent upon many variables; and
- Little research has been conducted to quantify PCB emission rates from product use and/or disposal.

Due to the ban on PCB production and open system use, PCB emissions from these sources have effectively been halted. Release to the environment as a consequence of all PCB use occurred prior to 1970 and was, for the most part, unintentional. The major mechanisms by which PCBs are lost to the environment include aerosolization (during leaks and spills), adsorption onto particulates (during combustion), and volatilization. Prior to 1970, the major pathways by which PCBs were released during use included spillage and vaporization of PCB containing paints, coatings and plastics; migration and leaching from surface coatings and packaging; leakage from faulty heat exchange systems and partially sealed hydraulic systems; and burnout of PCB containing ballasts in fluorescent light fixtures.[34] As the PCB-containing products have been discarded, the major source of PCB emissions into the environment has shifted to disposal/destruction methods (e.g., incineration, landfilling). Incomplete combustion in an incinerator or boiler may result in the release of PCBs or PCB byproducts. Another source of PCB emissions is accidental release due to failure of an existing piece of PCB equipment (resulting in spills or leaks) or an accident (e.g., fire) to a piece of PCB equipment in service. This section discusses these activities and presents information on the potential for PCB releases from each.

DISPOSAL/DESTRUCTION METHODS

EPA's PCB regulations (40 CFR 761) set specific disposal requirements for PCBs and PCB items currently in service.[35] The requirements are summarized in Figure 3. The regulations make distinctions between PCBs, PCB articles (items that contain PCBs and whose surface(s) have been in direct contact with PCBs), and PCB containers (barrels, drums, containers, etc. that contain PCBs and whose surface(s) have been in direct contact with PCBs). Within these categories, the regulations make a further distinction based on the PCB concentration of the waste. Acceptable PCB disposal technologies are then based on this PCB concentration. There are a limited number of disposal options, summarized as follows:

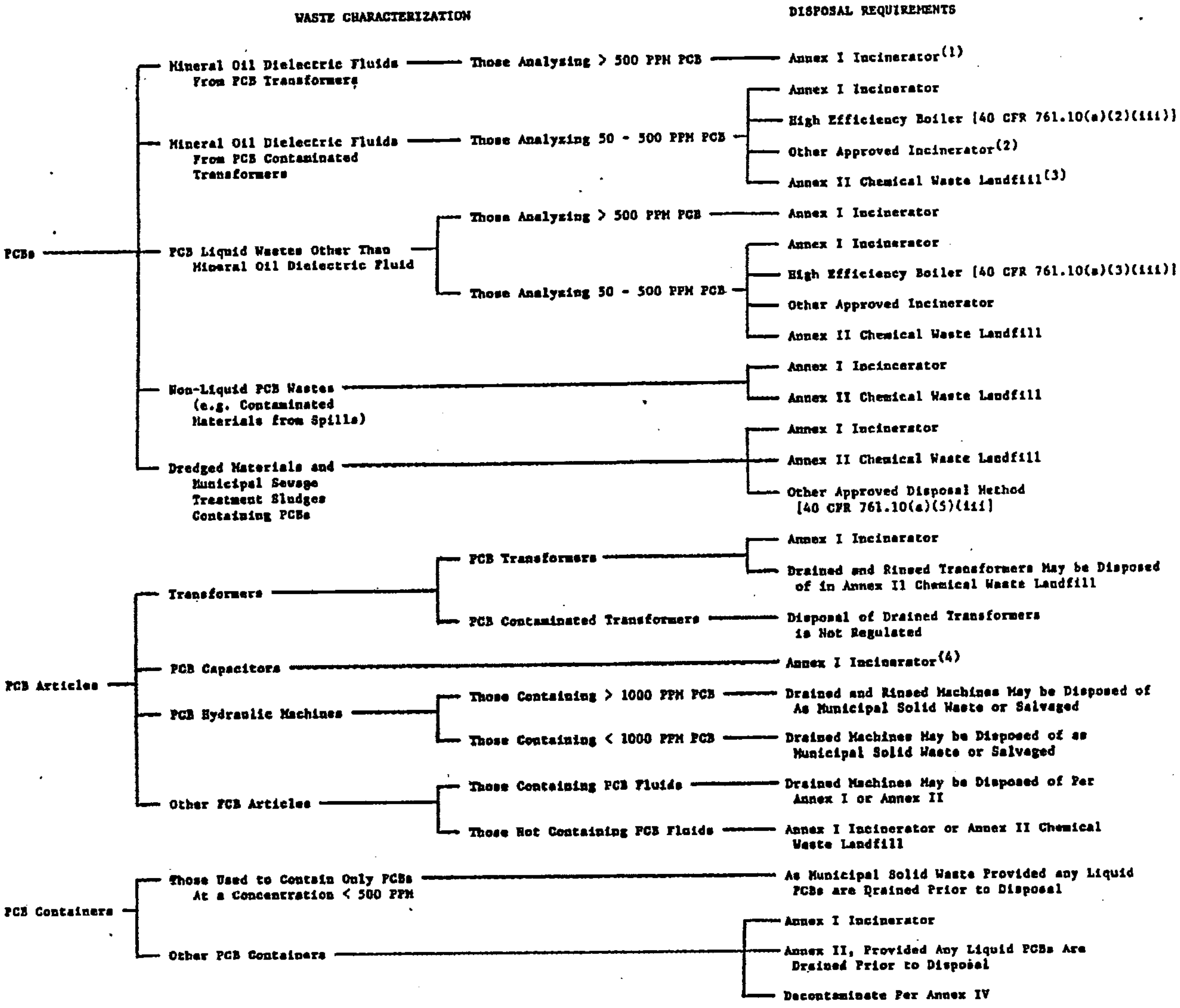
- "Annex I" Incinerators;
- High Efficiency Boilers;
- "Annex II" Chemical Waste Landfills; and
- Other Approved Disposal Methods.

A brief review of these disposal techniques will serve to highlight the principal characteristics of each.

Annex I Incinerators

Technology Descriptions--

These incinerators take their designation from the technical standards and other criteria that they are required to meet when destroying liquid PCB wastes. These standards and criteria are found in Annex I of EPA's PCB



(1) Annex I Incinerator defined in 40 CFR 761.40.
(2) Requirements for other approved incinerators are defined in 40 CFR 761.10(e).
(3) Annex II chemical waste landfills are described in 40 CFR 761.41. Annex II disposal is permitted if the PCB waste analyzes less than 500 ppm PCB and is not ignitable as per 40 CFR Part 761.41(b)(8)(iii).
(4) Disposal of containerized capacitors in Annex II landfills is permitted until March 1, 1981. Thereafter, only Annex I incineration is permitted.

Figure 3. Disposal requirements for PCBs and PCB items.[36]

regulations.[35] The minimum operating requirements for disposal of liquid wastes presented in Annex I include:

- 2 second dwell time at 1200°C (2190°F) and 3 percent excess oxygen; or
- 1.5 second dwell time at 1600°C (2910°F) and 2 percent excess oxygen.

The dwell time refers to the residence time of the PCBs in the combustion chamber, while the oxygen content is measured in the stack gas. Additional criteria, including monitoring requirements, approval conditions, and trial burn requirements, are also included in the Annex I citation. These requirements should be referenced directly to resolve any questions.

While the Annex I incinerators were established for liquid PCB wastes, they may also be employed for solid PCB disposal, provided a destruction and removal efficiency of 99.9999 percent is met. Reference 36 provides a complete description of operating principles, advantages and disadvantages and test data for each incinerator design.

Commercial or industrial incinerators that are intended to destroy liquid PCB wastes must demonstrate compliance with the Annex I requirements through a comprehensive trial burn program. As of 1986, four stationary commercial incinerators, eight industrial incinerators and two mobile incinerators were approved as Annex I incinerators under these requirements.[37-40] However, these numbers are subject to change as new approvals are granted, operations are terminated, and so on. The commercial units include those operated by Rollins Environmental Services in Deer Park, Texas; Energy Systems Company (ENSCO) in El Dorado, Arkansas; General Electric Company in Pittsfield, Massachusetts; and SCA in Chicago, Illinois. In addition to approval under the Annex I requirements, Rollins and ENSCO have been approved for solid PCB disposal under the 99.9999 percent destruction requirement.

The industrial PCB incinerators approved under Annex I are operated by the General Electric Company in Waterford, New York; by Dow Chemical in Freeport, Texas; Oster Creek, Texas; and Plaquemine, Louisiana; by Vulcan Materials in Geismar, Louisiana; by PPG in Lake Charles, Louisiana; by LaPort Chemical Corporation in Pasadena, Texas; and by Los Alamos Scientific in Los Alamos, New Mexico. The Annex I mobile incineration systems are operated by EPA, Edison, New Jersey; and by Pyrotech, Tullahoma, Tennessee. The Annex I mobile systems have been tested and approved to operate in all ten U.S. EPA regions.[40]

Finally, it must be mentioned that municipal sewage sludge incinerators are used to incinerate PCB-containing sludges at certain locations throughout the country. This condition has resulted from the inadvertent PCB contamination of municipal sewer systems resulting from historical PCB disposal. As sludge incinerators are not designed to operate in the temperature ranges specified for the Annex I requirements, they do not insure sufficient destruction of the PCBs. In addition, municipal waste incinerators have been identified as potential PCB emission sources due to their processing of PCB-containing wastes. Sewage sludge and municipal incinerators are discussed later in this section.

Emissions--

Approved Incineration of Liquid PCB Wastes-Published PCB destruction efficiency test data for 11 of the EPA approved Annex I liquid waste incinerators are presented in Table 8. The location and type of incinerator associated with each facility is also presented along with the PCB emission factor that results from applying the stated destruction efficiency on inlet PCB level for each unit. The units for the emission factors are grams of PCB emitted per kilogram of PCB charged (g/kg). As can be seen from the table, these emission factors vary as much as four orders of magnitude. However, this is not reflective of optimum Annex I incinerator performance. Several of these tests were not compliance determinations, but rather research and development efforts, and were not necessarily conducted under optimum conditions. Furthermore, several of the destruction efficiency values were reported to only two significant figures, making it impossible to calculate an emission factor less than 0.1 g/kg. For those test results that were reported to five or six significant figures, the corresponding emission factor is, in most instances, less than 0.001 g/kg. This level is indicative of optimum Annex I performance. The average PCB destruction efficiency for all stationary incinerator test data presented in the table is 99.997. This corresponds to an emission factor of 0.03 g/kg.

TABLE 8. PCB EMISSIONS FROM ANNEX I INCINERATORS BURNING LIQUID WASTES

Facility	Location	Type of incinerator	Type of PCB waste	Destruction and removal efficiency[a]	PCB emissions[a] (g/kg PCB charged)	Reference
<u>Stationary Incinerators</u>						
General Electric Company	Pittsfield, Massachusetts	Liquid injection	Liquids	99.9921-99.9995	0.005-0.079	42
General Electric Company	Waterford, New York	Liquid injection	Liquids	99.99	0.1	41
SCA Chemical Services	Chicago, Illinois	Rotary kiln	Liquids	99.99	0.1	41
SCA Chemical Services	Chicago, Illinois	Rotary kiln	Solids	99.99	0.1	41
Dow Chemical Company	Freeport, Texas	Liquid injection	Liquids	99.99999	0.001	41
Dow Chemical Company	Plaquemine, Louisiana	Liquid injection	Liquids	99.9971	0.029	41
Dow Chemical Company	Oster Creek, Texas	Liquid injection	Liquids	99.999998	0.00002	41

(continued)

TABLE 8. (continued)

Facility	Location	Type of incinerator	Type of PCB waste	Destruction and removal efficiency[a]	PCB emissions[a] (g/kg PCB charged)	Reference
Vulcan Materials	Geismar, Louisiana	Liquid injection	Liquids	99.99998	0.0002	41
LaPort Chemical Corp.	Pasadena, Texas	Liquid injection	Liquids	99.99999	0.0001	41
PPG	Lake Charles, Louisiana	Liquid injection	Liquids	99.99997 99.99998	0.0003 0.0002	41
			Average:	99.997	0.03	
<u>Mobile Incinerators</u>	<u>Home Base</u>					
EPA	Edison, New Jersey	Rotary kiln	Liquids	99.999	0.01	42
Pyrotech(Pyro-Magnetics)	Tullahoma, Tennessee	Rotary kiln	Liquids	99.9999	0.001	39,41

[a] Includes gaseous and particulate emissions, except as where noted. Note: As can be seen from the table, these emission factors vary by more than three orders of magnitude. However, this is not reflective of optimum Annex I incinerator performance. Several of these tests were not compliance determinations, but rather research and development efforts, and they were not necessarily conducted under optimum conditions. Furthermore, several of the destruction efficiency values were reported to only two significant figures, making it impossible to calculate an emission factor less than 0.1 g/kg. For those test results that were reported to five or six significant figures, the corresponding emission factor is, in most instances, less than 0.001 g/kg.

Approved Incineration of Non-Liquid PCB Wastes-Approved incinerators burning non-liquid PCB articles (such as PCB capacitors) have a mass PCB emission limitation of 0.001 g PCB/kg of PCB introduced into the incinerator. This is equivalent to a PCB destruction efficiency of 99.9999 percent and an emission factor of 0.001 g/kg.

Sewage Sludge and Municipal Waste Incineration-While neither approved nor recommended for PCB waste destruction, sewage sludge and municipal waste incinerators have been identified as potential PCB emission sources.[43-46] This can happen when sludge has been contaminated by past industrial discharges of PCBs or when municipal refuse contains miscellaneous PCB-laden trash such as fluorescent light ballast capacitors and carbonless copy paper. While these PCB-containing products are no longer being manufactured, they will continue to appear in waste streams until their economic life has been completed. With time, the quantities of PCB-contaminated sludge and PCB-containing wastes incinerated in municipal incineration facilities should slowly decrease. In addition, the presence of PCBs in these waste streams, especially sewage sludge, is highly site specific, dependent upon local manufacturing and waste discharge characteristics. Therefore, the PCB emission factors presented for these incineration facilities will not necessarily apply to a particular site.

Emission data for sewage sludge incinerators and municipal solid waste refuse incinerators are presented in Tables 9 and 10, respectively. As is clear from these tables, there is very little data on PCB emissions from either of these incinerator types. The New Bedford, Massachusetts and Palo Alto, California sewage sludge incinerator tests were conducted specifically to ascertain the PCB destruction efficiency of these units. Consequently, the PCB destruction efficiency of these units was reported and an emission factor,

TABLE 9. PCB EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATORS

Facility	Year of test	Incinerator design	Destruction efficiency	PCB emission factor[a] (g/kg PCBs)	PCB emissions (ug PCBs/kg sludge)	Reference
Sludges Known to Contain PCBs						
New Bedford, Massachusetts	1977	Multiple hearth	46.3 - 77.5	225 - 537	12 - 36	43
Palo Alto, California	1976	Multiple hearth	91.7 - 97.1	29 - 83	b	44
Detroit, Michigan	1980	Unknown	Unknown	Unknown	58 - 64	45
			Average:	220	43	
Sludges With Unknown PCB Contaminantion[c]						
Wyandotte, Michigan	1980	Unknown	Unknown	Unknown	4.2 - 7.2	45
Akron, Ohio	1980	Unknown	Unknown	Unknown	2.5 - 4.2	45
			Average	--	4.5	

[a] Emission factors in terms of grams PCBs emitted per kilogram of PCBs charged to the incinerator.

[b] PCB added to sludge for test.

[c] These data represent sludges in which the contamination of PCBs prior to testing was unknown or unclear.

TABLE 10. PCB EMISSION FACTORS FOR MUNICIPAL REFUSE INCINERATORS

Facility	Year of test	Incinerator design	Destruction efficiency	PCB emission factor[a] (g/kg PCB)	PCB emission factor (ug PCBs/kg refuse)	Reference
Chicago, Illinois	1976	Unknown	Unknown	Unknown	62	46
Chicago, Illinois	1980	Unknown	Unknown	Unknown	1.8 - 2.7	45
Sheboygan, New Jersey	1980	Unknown	Unknown	Unknown	4.4	45
				Average:	18	

[a] Emission factors in terms of grams PCBs emitted per kilogram of PCBs charged to the incinerator.

in terms of grams PCBs emitted per kilogram PCB charged, can be calculated. These factors are presented in Table 9 and show the poor PCB destruction efficiency that results from use of a sludge incinerator for PCB disposal. As the New Bedford, Massachusetts sludge routinely contains PCBs, it was also possible to calculate a PCB emission factor in terms of grams of PCBs per kg of sludge feed, and this value is presented in the table. For the Palo Alto, California test, PCBs were deliberately added to the sludge, so this sludge feed emission factor does not apply. Three other sewage sludge incinerator test results reported PCB emissions in the stack gas. These tests did not investigate the source of the PCBs, the sludge feed PCB concentration, or the PCB destruction efficiency of the incinerator. They addressed only PCB stack gas emissions and reported these emissions in terms of unit mass of PCBs per unit mass of sludge feed. These emission factors are also reported in Table 9 (shown as micrograms of PCBs per kilogram sludge in the table). Note the order of magnitude discrepancy that exists between the two highest and two lowest emission factors. For those sludge incinerators such as New Bedford and Detroit that are known to be processing PCB contaminated sludge, the emission factor is 43 micrograms per kilogram sludge (ug/kg). However, for the Wyandotte and Akron incinerators, where the source of PCBs is not known, the emission factor is 4.5 ug/kg sludge. Based on this limited data base, it is recommended that the larger emission factor be used when the sludge is known to contain PCBs, while the smaller value should be employed when the presence of PCBs is not known or unclear.

A similar lack of data on PCB emissions exists for municipal refuse incinerators.* Data for three incinerators are presented in Table 10. Averaging test results for the three incinerators gives an overall emission factor of 18 ug PCBs/kg refuse. Stack gas emissions of PCBs from the three incinerators were quantified without determining the incinerator's PCB destruction efficiency. While not stated, it is assumed that the PCBs were

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(*)Data concerning PCBs from municipal refuse incinerators are currently being developed by the Office of Solid Waste under the Agency's comprehensive study of municipal waste combustion.

contained in certain segments of the trash. This is confirmed by published research findings. The municipal refuse incinerator studied in Chicago in 1976 consisted of four identical furnaces of the water wall type with a reciprocating grate stoker and capacity of 400 tons refuse per incinerator per day.[46] No information was available on design or operation of the other incinerators tested.

As part of a recent study on the PCB emissions from burning of coal/refuse mixtures, the PCB content of various consumer paper products was analyzed.[47] This study indicates that such paper products as magazine covers and paper towels contained up to 139 micrograms of PCB per kilogram of paper (ug/kg). These levels, which were reported in 1981, were attributed to the repeated recycle of waste paper containing PCBs. For example, carbonless copy paper manufactured prior to 1971 contained PCB levels as high as 7 percent. This copy paper then became a component of waste paper which was recycled. The PCBs inevitably were introduced into other paper products, resulting in continued measurable levels in municipal refuse some 4 years after the PCB manufacturing ban was imposed. Refuse derived fuel (RDF) manufactured from these paper products had PCB levels of 8,500 ug/kg, indicating that this fuel is also a source of atmospheric PCBs. Therefore, it must be assumed that municipal refuse does contain detectable levels of PCBs, and that some of these PCBs will enter the atmosphere when the refuse is incinerated.

The average emission factor for these two municipal incinerator sets was 3.3 ug of PCBs emitted per kilogram of refuse. This is approximately equal to the emission factor for sewage sludge incinerators which have no obvious source of PCB contamination. As with sewage sludge incinerator discharges, PCB emissions from municipal incinerators are expected to gradually decrease as the consumer waste products containing PCBs outlive their useful life and are discarded, and as recycled PCB articles constitute an increasingly smaller portion of the incinerator's waste stream.

High Efficiency Boilers

Conventional industrial and utility boilers can be used to destroy PCBs if proper combustion conditions are maintained. These conditions are defined in the regulations, and include:[35]

1. The boiler must be rated at a minimum of 50 million Btu/hour.
2. The concentration of PCBs in PCB-contaminated fluid shall not exceed 500 ppm and the rate of PCB-contaminated fluid flow to the boiler shall not exceed 10 percent of the total fuel feed rate.
3. The waste feed rate to the boiler, the coal and/or oil feed rate and the total of both shall be recorded in regular intervals no greater than 15 minutes apart.
4. The PCB-contaminated fluids shall not be fed to the boiler until it is operating at normal operating temperature.
5. The carbon monoxide (CO) concentration in the stack gas shall not exceed 100 ppm for coal fed units, or 50 ppm for oil or natural gas-fired units.
6. The excess oxygen (O_2) in the stack gas shall not be less than 3 percent.
7. CO and O_2 will be monitored in the stack gas continuously when the unit is burning contaminated fluid and will be checked at least once every hour.
8. The fuel flow, CO and O_2 data recorded shall be retained in file for 5 years at the boiler address.
9. Records of the quantity of contaminated fluid burned in the boiler shall be kept on a monthly basis and kept in files at the boiler address for at least 5 years.

EPA has approved 18 high efficiency boilers for PCB disposal based on the criteria listed above.[38] The facilities that operate these boilers are listed in Table 11. It is uncertain, however, how many of these boilers have actually burned PCBs, and the total quantity of the PCB fluids destroyed. This list is subject to change as new approvals are granted, operations are terminated, and so on.

TABLES 11. HIGH EFFICIENCY BOILERS PERMITTED TO BURN PCB LIQUIDS*[39,41]

Company	Location
Public Service Company of New Hampshire	Merrimac Station, NH
New England Power Company	Salem Harbor Station, MA
Northeast Utilities	Middletown, CT
Baltimore Gas & Electric	Chase, MD
Potomac Electric & Power	Morgantown Station, MD
Carolina Power & Light	Moncure, NC
Duke Power Company	Riverbend Station, NC
Louisville Gas & Electric	Louisville, KY
Tennessee Eastman Co.	Kingsport, TN
TVA - Widow's Creek	Bridgeport, AL
General Motors Corp.	Bay City, MI
Hoosier Energy, Inc.	Bloomington, IN
Illinois Power Co.	Baldwin, IL
Northern States Power Company	Minneapolis, MN
Otter Tail Power Company	Fergus Falls, MN
Otter Tail Power Company	Big Stone, SD
Union Electric Company	St. Louis, MO
Washington Water & Power Company	Spokane, WA

*This list is subject to change as new approvals are granted, operations are terminated, and so on. Also, it is uncertain how many of these boilers have actually burned PCBs.

Emissions--

Of the boilers permitted to burn PCB liquids, six are known to have conducted a PCB destruction efficiency test, even though these tests are not required by EPA's PCB regulations.[38] These six test series results are presented in Table 12. In addition, two PCB destruction efficiency tests are also presented that were conducted on a Florida Power and Light boiler in 1974 and a Continental Can Company boiler in 1976. However, as of 1986, these units were not authorized to destroy PCBs.

Table 12 presents the year of the stack test, the type of primary fuel fired in the boiler, and the reported destruction efficiency. As with the Annex I incinerator test data, the boiler test results have been converted to an equivalent emission factor for this study. The units of this factor are also grams of PCB emitted per kilogram of PCB burned (g/kg).

Testing the PCB destruction efficiency of an industrial or utility boiler presents unique problems because EPA's PCB regulations require that PCB-contaminated fluids to be incinerated contain no more than 500 ppm of PCBs.[35] Furthermore, these contaminated fluids cannot represent more than 10 percent of the total fuel feed to the boiler.[35] Consequently, the total fuel burned by a high efficiency boiler cannot contain more than 50 parts per million (ppm) of PCBs. This ceiling on the PCB concentration fired by a boiler presents a challenge in determining PCB destruction efficiency. In order to ascertain if the boiler is achieving a predetermined destruction efficiency (e.g., 99.9 percent), a set amount of PCB must be captured from the stack gas. However, given current analytical PCB detection limits, and the rate at which stack gas samples can be collected, sampling times in excess of 4 to 6 hours per run are often needed to collect a sufficient sample. For all tests reported in Table 12, with the exception of the Continental Can test series, no PCBs were detected in the stack gas sample. Thus, for the purpose of determining a PCB destruction efficiency, the testing company assumed that PCBs were being emitted at a level identical to the minimum detection limits of the analytical methodology. Comparing this assumed maximum outlet PCB level with the known inlet PCB level in the fuel permits the calculation of an

TABLE 12. PCB HIGH EFFICIENCY BOILER TEST RESULTS

Facility	Date of test	Type of fuel	Destruction efficiency[a,b]	PCB emissions[b] (g/kg)	Reference
Florida Power & Light	1974	Oil	99.9997[a]	0.003	42
Continental Can Company	1976	Oil	99.1 - 99.9[a]	1.0 - 9.0	42
General Motors	1980	Oil	99.99	0.1	48
Northeast Utilities	1981	Oil	99.997	0.03	48
Average for oil-fired boilers			99.8	2.0	
Tennessee Eastman Company	1979	Coal	99.7 - 99.993	0.07 - 3.0	42
Union Electric	1981	Coal	99.95	0.5	48
Duke Power	1981	Coal	99.92	0.8	41
Tennessee Valley Authority	1981	Coal	99.95	0.5	41
Average for Coal-fired boilers			99.9	1.0	

[a] Includes gaseous and particulate emissions.

[b] No actual PCB emissions were detected during sampling. However, the maximum possible PCB emissions level was assumed to be equal to the minimum detection limits of the analytical methodology (0.2 ug/m^3). The destruction efficiencies and emission factors were calculated using this maximum PCB emissions level and fuel/waste PCB concentrations.

estimated minimum PCB destruction efficiency. These destruction efficiencies, as can be seen in the table, are generally limited to 99.99 percent. The existing PCB sampling and analysis methodologies prohibit the determination of higher PCB destruction efficiencies unless either the inlet PCB concentration is increased or the outlet (flue gas) PCB detection sensitivity is increased. These factors account for the destruction efficiency values in excess of 99.99 percent reported in Table 12. The PCB regulations currently limit the waste feed PCB concentration to 500 ppm, effectively capping this option. The PCB sensivitity of flue gas sampling can be increased by utilizing a high volume stack sampling train such as the Source Assessment Sampling System (SASS). This approach was successfully employed for the Northeast Utilities Test Program.

The PCB regulations do not specify a minimum PCB destruction efficiency for high efficiency boilers. Six of the approved boilers cited in Table 12 achieved efficiencies in excess of 99.9 percent. Testing at two of the boilers resulted in ranges of destruction efficiencies with a minimum value below 99.9 percent and a maximum value of 99.9 percent or higher. The emission factor corresponding to a 99.9 percent destruction efficiency (DE) is 1.0 gram per kilogram while a 99.99 percent DE is equivalent to an emission factor of 0.1 grams per kilogram. Averaging the emission factors in Table 12 results in values of 2.0 g PCB/kg PCB burned for oil-fired boilers and 1.0 g PCB/kg PCB burned for coal-fired boilers.

Annex II Landfills

Annex II chemical waste landfills can be used for some, but not all, PCB wastes. Table 13 lists those PCB wastes that can be disposed in this type of treatment facility. The technical requirements for a PCB landfill are set forth in Annex II of the PCB regulations.[35] These requirements address such factors as thickness and permeability of the soil, hydrology, flood protection, topography, ground water monitoring system, leachate collection, landfill operating and supporting facility standards. The reader should refer to Annex II landfill standards to resolve specific questions regarding these

TABLE 13. PCB CONTAMINATED MATERIALS ACCEPTABLE FOR LAND DISPOSAL[49]

Description of PCB type	Eligible for land disposal after January 1, 1980
<u>PCB Mixture Type</u>	
• Nonliquid PCB mixtures in the form of contaminated soil, rags or other solid debris	No
• Soil and solid debris contaminated with PCBs due to a spill or as a result of PCB placement in a disposal site prior to promulgation of final EPA regulations for PCB disposal (April 18, 1978)	Yes
• Dredged materials and municipal sewage sludge that contain PCBs	Yes
<u>PCB Articles</u>	
• Those articles technically infeasible for incineration, such as drained and flushed transformers[a]	Yes
• Sealed capacitors	No
<u>PCB Containers</u>	
• Drained containers	Yes

[a] Written application to EPA is required for landfilling articles other than transformers.

requirements. There are currently ten sites that are approved as Annex II chemical waste landfills. These sites are listed in Table 14. However, this list is subject to change as new approvals are granted, operations are terminated, and so on.

In addition to the currently operating sites, there are several sites throughout the country that have been given permission by the EPA Regional Offices to conduct a one-time disposal of PCB dredge spoils, contaminated debris, etc. It must be recognized that the operating and one-time landfills are known disposal sites of PCBs that have been reviewed and approved by EPA since promulgation of its PCB regulations in 1979. There are, however, many other conventional sanitary landfills, dumps and other unauthorized and as yet unidentified disposal sites where PCBs were disposed prior to enactment of the PCB rules. It is the PCB emissions from these unknown, unauthorized sites that cause a problem in estimating total PCB emissions from landfills and other disposal facilities. This aspect of the PCB emissions estimation procedure will be subsequently discussed.

Emissions--

Estimation of PCB emissions from land disposal facilities, including Annex II landfills, conventional sanitary landfills, and/or abandoned dump sites, is difficult. While data exist on ambient PCB levels in and around landfills,[50] little emission testing has been conducted to quantify mass emission rates of PCBs. Furthermore, to calculate PCB emissions from these sources, several site specific characteristics must be known. These factors include the amount, PCB concentration and location of the contaminated waste, the porosity, organic content and depth of the soil cover employed, and local temperature, wind speed, and precipitation data. If these data are available, then published diffusion equations can be used to calculate landfill emissions.[51] Generally, this information is known for only the newest, most regulated landfill sites - Annex II landfills. However, PCBs disposed of in these landfills are often placed in sealed containers, and PCB emissions from these sources should not be significant, regardless of site specific

TABLE 14. PCB ANNEX II CHEMICAL WASTE LANDFILLS[a],[40]

Company	Location
CECOS International	Niagara Falls, New York
SCA Chemical Waste Services	Model City, New York.
Chemical Waste Management	Emelle, Alabama
Chemical Security Systems	Arlington, Oregon
Envirosafe Services of Idaho	Mt. Home, Idaho
U.S. Ecology	Beatty, Nevada
Chemical Waste Management	Kettleman City, California
Casmalia Resources	Casmalia, California
CECOS International	Williamsburg, Ohio
U.S. Pollution Control	Oklahoma City, Oklahoma

[a] This list is subject to change as new approvals are granted, operations are terminated, and so on.

conditions. If sufficient data are available to calculate or estimate PCB emissions from individual disposal sites, then a point source emission estimate can be made.

Estimating PCB emissions from landfills is further complicated by the uncertainty regarding the amount and location of PCBs discharged to land disposal facilities prior to 1970. These data are available, in part, for PCB manufacturing facilities, but not for the disposal of PCB-containing products. Given the widespread use of such PCB-containing consumer items as paper containers and fluorescent light ballasts, it must be assumed that every public and commercial landfill site contains PCB products.

Certain aspects of land disposal of PCBs are known. If exposed directly to the atmosphere, a certain portion of the PCBs will be emitted to the atmosphere through volatilization, evaporation, and co-distillation.[52] In addition, PCBs may become adsorbed on fine dust in the soil. This dust may be entrained by wind, or PCB oil itself may form an aerosol in high wind. The specific amount released is dependent upon the PCB isomer, the type of soil in contact with the PCB mixture, and the ambient temperature and windspeed.[53] Published data indicate that the less chlorinated (those with four or fewer chlorine atoms) PCB isomers volatilize faster.[53] These less chlorinated isomers have higher vapor pressures and greater water solubilities and thus demonstrate increased vaporization and are more mobile in the environment.[54,55] Consequently, PCB wastes with a greater proportion of the lower isomers will demonstrate a greater loss to the atmosphere. The type of soil in contact with the PCB waste affects emissions as soils with greater organic content tend to bind the PCBs more strongly, while soils with little or no organic content (e.g., sand) lose PCBs through evaporation rapidly.[56] This is demonstrated graphically in Figure 4 with the amount of PCB evaporating varying greatly, depending on the type of soil. Virtually all of the PCBs are evaporated from sand, while less than 10 percent was evaporated from topsoil rich in organic matter.

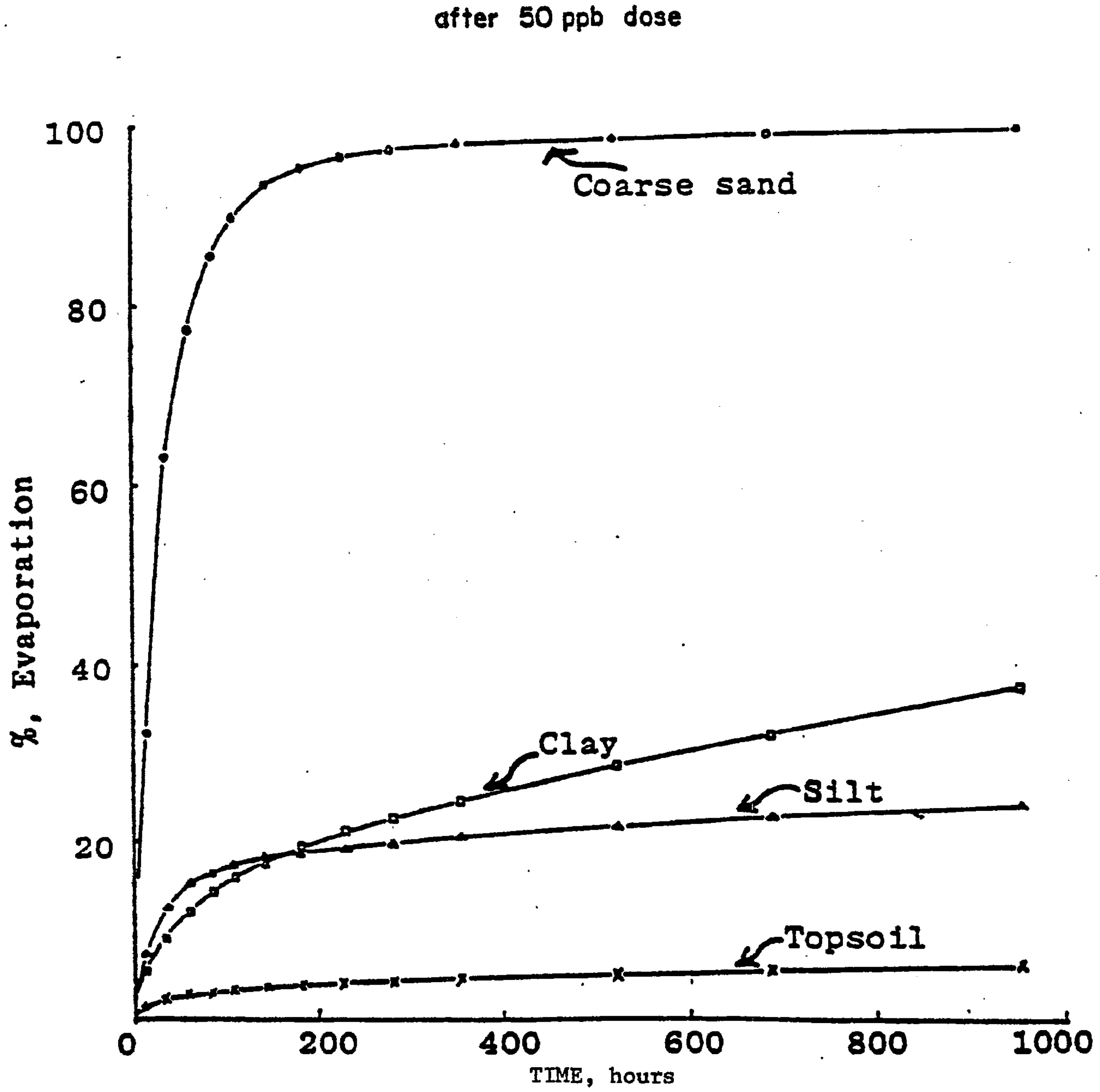


Figure 4. Evaporative loss of ^{14}C-Aroclor 1242.[63]

Since the vapor pressure of all PCB mixtures (Aroclors) increases with temperature,[57] the rate of PCB volatilization also increases with temperature. In addition, studies have shown that the volatilization will increase with wind speed.[58] One published PCB emission study attempted to quantify the effect of temperature and wind speed. This study was undertaken in conjunction with the dredging and subsequent land disposal of PCB sediments from the Hudson River in New York.[53] PCB emissions from landfills without covers and dump sites at this disposal operation were estimated to be 3,000 lb/yr for a total quantity of 700,000 lbs of PCBs landfilled. This translates to an emission factor of 4.286 g/kg of PCB landfilled. While this was an annual estimate, it is assumed that it is valid for only the first year after PCBs are placed on the land. Within this year, the relatively rapid volatilization of the lower PCB isomers would occur, the soil effects would be exhibited, and the seasonal variations in PCB emissions due to weather effects would be demonstrated. No estimate was given for the decrease of these emissions in the second or subsequent years after disposal of the contaminated dredge spoils, although a significant decrease would be expected.

PCBs covered by soil in a managed landfill setting are affected by additional factors. Soils slow diffusion of the PCBs to the atmosphere. This is especially true for finely divided soils and those with a higher moisture content. In addition, cover material with a higher organic content or with a lower porosity will also limit emissions. PCBs buried in the ground may also be affected by other factors which would affect their volatility and emission potential. Research studies indicate that microbial action and chemical decomposition may act on soil-based PCBs and reduce them to less chlorinated compounds.[59] These by-product compounds may subsequently migrate through the soil and be released to the atmosphere. One published estimate states "we conclude that most PCB isomers with four or fewer chlorine atoms have been degraded in the environment, possibly by microbial action."[60] Several other literature sources cite a PCB half-life in the soil (the time required to reduce the PCB concentration to one-half of its initial value) to be from 5 to 6 years.[61,62] The PCB reduction is attributed to volatilization, microbial action and/or chemical decomposition. These estimates remain to be proven in the field and are possibly contradicted by other published data. Two recent studies conducted following spills of PCB liquids noted no change in soil based PCB levels, even 2 years after the initial spill.[63,64] It is not known if the same PCBs were encountered in all these studies. This PCB reduction mechanism requires additional research.

Only one published reference estimated PCB mass emissions from landfills.[65] This study reported the results of sampling at seven different municipal landfills. Six of these samples were obtained in 1981 and they indicated an average PCB emission of 190 nanograms (190 x 10^{-9} g) of PCB per cubic meter of methane gas generated. The study stated that "based on an estimate that municipal landfills generate 2 x 10^{12} ft^3/yr of methane nationwide, the results found in this project indicate that such landfills contribute about 18 kg/yr of PCBs to the atmosphere."[65]

The many site specific and unknown factors involved with calculating PCB emission rates from landfills make determination of a generally applicable PCB emission factor for this source category difficult.*

Other Approved Disposal Methods

Thermal Method--

In addition to incinerators and boilers, the EPA Regional Administrators are given authorization by the PCB regulations to approve other thermal destruction techniques if these processes can effect destruction of PCBs equivalent to that of incinerators or boilers. The only technology to gain such an approval to date is the pyrolysis process operated by the Huber Corporation in Borger, Texas. This system will treat contaminated soils.

(*)Information related to emissions of toxic compounds from landfills is currently under development by the Emission Standards and Engineering Division of the Office of Air Quality Planning and Standards under the Agency's comprehensive study of hazardous waste treatment, storage, and disposal facilities.

Several thermal technologies, however, have received short duration (6 month) approval to conduct research and development projects. These include such diverse projects as use of a fluid wall reactor, a cement kiln, a diesel engine, a steam stripping operation, an aluminum melting furnace and a molten salt process.[41]

Chemical Dechlorination and Other Nonthermal Methods--

The PCB regulations also give the EPA Regional Administrators the authority to approve nonthermal PCB disposal methods if they achieve a PCB disposal/destruction equivalent to that of an Annex I incinerator. This mechanism has been used by 11 companies nationwide to gain commercial scale approval of their chemical dechlorination disposal processes.

Chemical dechlorination processes use chemical reagents to break apart the extremely stable PCB molecule, rearranging it to form other chemical compounds that are considered harmless and environmentally safe. These processes destroy the PCB molecule but do not break down the biphenyl structure of the molecule. Only the chlorine atoms which give the PCB molecule chemical and biological stability are removed.

Most chemical dechlorination processes use a sodium reagent to strip away the chlorine atoms from the PCB molecule. The wastes generated from the process are sodium chloride and nonhalogenated polyphenyls. The exact constituents of the polyphenyls are often not known, but indications show that the sodium chloride and polyphenyls can be disposed of safely.[66]

Most applications involve destruction of PCBs that contaminate otherwise valuable oil. The sodium dechlorination processes can be run at ambient or moderate temperature and, although they chemically destroy the PCBs contained in oil, they do not destroy the oil itself. Therefore, the oil can be recycled for reuse. Sodium dechlorination is limited in that it is only capable of economically dechlorinating PCBs in otherwise valuable oil.

Dechlorination of PCBs by sodium reagents must be conducted in nitrogen or similarly inert atmospheres to prevent excessive reagent consumption and fire hazard due to the hydrogen generation on contact with any water or moisture present in the oil.[66] These dechlorination processes are significant because they are widely used commercial scale technologies that offer the additional benefit of being mobile. They are currently employed for the decontamination of mineral oil dielectric fluids from transformers, although additional research is being conducted on other PCB wastes as well.

Other nonthermal PCB treatment technologies that have been investigated or actually approved for commercial scale PCB disposal include physical/chemical extraction techniques and biological reduction methods. The physical/chemical techniques extract the PCBs from transformers or capacitors and concentrate them for disposal. They do not destroy the PCBs. Four companies are currently permitted by EPA to extract the contained PCBs using these physical/chemical methods. These companies are Quadrex HPS, Inc. in Gainesville, Florida; Environmental International Electrical Services, Inc. in Kansas City, Kansas; Rose Chemical in Kansas City, Missouri; and PCB Treatment, Inc. in Kansas City, Missouri.[40] Quadrex has been approved for operation in all ten U.S. EPA regions.[40]

Many bench scale studies have investigated the biodegradability of PCBs. The PCB concentrations used in these tests have ranged from a few ppb to 1,000 ppm. In general, these studies have shown that biodegradation can occur, but the residence times are long and the actual rate of degradation is dependent on the specific PCB isomer and its chlorine content.[67] While not a principal commercial disposal technique or emission source at this time, biodegradability of PCBs may possibly be used to a greater extent in the future, especially with regard to spills cleanup. A commercial scale biodegradation approval has been issued by EPA Region VI to Detox, Inc. of Houston, Texas for the treatment of PCB contaminated soils and sludges although the process is not yet operational.[40,68]

Emissions--The 13 companies that are currently approved for chemical dechlorination of PCB fluids are presented in Table 15. The PCB concentration of the waste stream treated by each dechlorination technology is presented in the table. Because each technology was required to treat the contaminated fluids until an outlet PCB concentration of less than 2 ppm was achieved, the PCB destruction efficiency of each system can be calculated using the known input concentration and the 2 ppm value as a maximum outlet value. These destruction efficiency values are also shown on the table, together with an emission factor which is based on this destruction efficiency. The emission factor is in units of micrograms of PCBs released per kilogram of PCB treated.

Until April 1983, approval of these dechlorination methods was issued by EPA Regional Offices using a phased approval. A company typically applied for approval to dechlorinate PCBs at a specified level, e.g., 1,000 ppm. It was then tested to demonstrate destruction of PCBs to below 2 ppm (the generally accepted PCB detection limits for this technology). Certain dechlorination technologies require that the contaminated PCB fluids be recycled several times through the process in order to meet this 2 ppm outlet level. Upon successful demonstration of PCB removal, the technology was approved with such items as the maximum processing rate, the maximum inlet PCB concentration and the recycling rate specified in the approval. If the company subsequently requested approval to decontaminate fluids at a higher PCB level, it was required to conduct another PCB destruction efficiency test in the region handling the application. This test series was conducted in one EPA region and the resulting test data were usually accepted by all other regions.

Subsequent to April 29, 1983, all PCB disposal technologies (nonthermal and thermal alike) that are to be used in more than one EPA Region have to be approved by EPA Headquarters. Their approval procedure is expected to be similar to that previously outlined.

TABLE 15. PCB EMISSION FACTORS FOR CHEMICAL DECHLORINATION METHODS [a,37,40,41]

Company	Location	Inlet PCB concentration[b] (ppm)	Outlet PCB concentration (ppm)	PCB destruction efficiency[c]	PCB emission factor[d] (ug/kg)
Sunohio	Canton, OH[e]	2,500 - 4,500	<2	99.92 - 99.96	0.44 - 0.80
Acurex	Mountain View, CA[e]	7,500	<2	99.97	0.30
PPM	Tucker, GA[e]	1,100	<2	99.82	1.8
Transformer Consultants	Akron, OH[e]	5,000 - 10,000	<2	99.96	0.40
Franklin Institutes	Philadelphia, PA	7,406	<2	99.97	0.30
General Electric	Schenectady, NY	1,050	<2	99.81	1.9
Rose Chemical Company	Kansas City, MO	10,000	CBI[f]	CBI	--
T & R Electric	Coleman, SD	500	N/A[g]	N/A	--
Chemical Decontamination Corp.	Birdsboro, PA[e]	650	<2	99.60	4.0
Environmental International	Kansas City, KS	N/A	N/A	N/A	--
Environmental Resources Mgmt.	North Kansas City, MO	N/A	N/A	N/A	--
Exceltech, Inc..	Freemont, CA	N/A	N/A	N/A	--
Trinity Chemical Co.	Shawnee Mission, KS	N/A	N/A	N/A	--

[a] This list is subject to change as new facilities are approved, operations are terminated, and so on.

[b] Approved inlet concentration varies with EPA Region.

[c] Calculated using a maximum outlet value of 2 ppm.

[d] Emission factors in units of micrograms of PCBs released per kilogram of PCB treated.

[e] Facility is approved to operate in all ten U.S. EPA regions.

[f] CBI - Confidential Business Information.

[g] Not available.

Since all chemical dechlorination techniques require that the outlet PCB level be less than 2 ppm, the calculated PCB destruction efficiency is dependent upon the inlet PCB level. As shown in Table 15, these inlet PCB levels vary from 500 to 10,000 ppm, depending on the technology used. Consequently, the reported PCB destruction efficiencies range from 99.60 to 99.97. The PCB emission factors corresponding to these destruction efficiencies range from 4.0 to 0.3 g of PCBs emitted per kilogram of PCB processed.

ACCIDENTAL RELEASES

Description

In addition to the principal point and area sources previously discussed, incidental emissions of PCBs may result from intermittent, accidental releases such as spills, leaks, fires, etc. These accidental PCB discharges may enter the atmosphere through failure and subsequent rupture of an existing piece of PCB equipment or through an accident (e.g., fire) to a piece of PCB equipment in service. Both of these sources of PCB releases can be estimated on a national basis.

The PCBs that remain in active service at this time are those contained in "closed systems", i.e., those pieces of electrical equipment that completely enclose the PCBs and do not provide direct atmospheric access of the PCBs during normal use. This equipment includes PCB transformers, capacitors, voltage regulators, circuit breakers, and reclosures. The number of each of these items, the pounds of PCBs they contain, and the estimate of annual pounds of PCBs leaked and/or spilled was investigated by the Edison Electric Institute and by the Utility Solid Wastes Activity Group (EEI/USWAG) for EPA.[69] These data were subsequently reported in the April 22, 1982 Federal Register relative to a proposed modification to the PCB regulations.[70] These Federal Register data are presented in Tables 16 and 17. An additional column was added to Table 17 to update utility PCB spills/leaks to cover the entire population of electrical equipment including that owned by industrial firms. These tables indicate that over 99 percent of the total quantity of PCBs

TABLE 16. ESTIMATED PCB LEAKAGE/SPILLAGE FROM UTILITY INDUSTRY CLOSED SYSTEMS EQUIPMENT [70]

	Number of units in utility industry	Percentage of units containing 50 ppm or greater PCBs	Percentage of units containing 500 ppm or greater PCBs	Total pounds of PCBs	Percentage of total pounds	Upper bound estimate of annual pounds of PCBs leaked/spilled
PCB transformers (Askarel)	39,640	100	100	74,597,283	45.92	20,448[a]
Large PCB capacitors	2,800,619	100	100	87,552,960	53.90	369,251
Mineral oil transformers	20,227,428	11.8	1.1	262,230	0.16	826
Mineral voltage regulators	145,159	14.0	1.7	6,707	0.01	5
Mineral oil switches	385,768	14.0	0	329	0.01	80[b]
Mineral oil circuit breakers	180,939	1.8	0	12,685	0.01	51
Mineral oil reclosers	170,158	0	0	410	0.01	7[b]
Mineral oil electromagnets	76	--	--	0.64[c]	0.01	--
Mineral oil cable	6,545 miles	--	--	2,311[c]	0.01	--

[a] Assumes moderate leakage rates equal to mineral oil transformers.

[b] Assumes moderate leakage rates equal to mineral oil circuit breakers.

[c] Assumes an average PCB concentration of 10 ppm.

Note: Dashes indicate no data available.

TABLE 17. ESTIMATED PCB LEAKAGE/SPILLAGE FROM ALL CLOSED SYSTEMS EQUIPMENT (UTILITY AND NONUTILITY) [70]

	Percentage of equipment owned by utility industry	Percentage of equipment owned by non-utility industry	Estimated total number of units	Upper bound estimate of annual pounds of PCBs leaked/spilled based on total equipment population
PCB transformers (Askarel)	30[a]	70	132,133	68,160
Large PCB capacitors	85[b]	15	3,294,846	434,413
Mineral oil transformers	80[a]	20	25,284,285	1,033
Mineral voltage regulators	85[c]	15	170,775	6
Mineral oil circuit breakers	85[c]	15	212,869	60
Mineral oil reclosers	85[c]	15	200,186	8
Mineral oil cable	85[c]	15	7,700 miles	--
PCB electromagnets	1	99	200	--
Mineral oil electromagnets	1[d]	99[d]	7,600	--
Small PCB capacitors	e	e	500,000,000[f]	--

[a] Source: Microeconomic Impacts of the Proposed "PCB Ban Regulations", Versar, Inc., 1978.

[b] As reported by the National Electrical Manufacturers Association and referenced in the EEI/USWAG study.

[c] Assumes a distribution equal to that for large PCB capacitors.

[d] Assumes that electric utility industry rarely uses electromagnets.

[e] Small capacitors are used by industry and by consumers. EPA has no information indicating that distribution.

[f] Assumes 870 million existed in 1977 and 10 percent are removed from service annually, due to equipment or appliance obsolescence and capacitor failure.

Note: Dashes indicate no data available.

currently contained in electrical equipment are found in PCB transformers (those containing > 500 ppm of PCBs) and large PCB capacitors (those containing > 3 lbs of PCBs). The following discussion will, therefore, concentrate on these items, although it is applicable to all PCB equipment.

PCB transformers have an estimated operating life of 40 years,[19] while the life span of PCB capacitors is estimated at 20 years.[22] Until this equipment lives out its useful operating life and is eventually retired and replaced with a non-PCB substitute, it will pose a potential threat of PCB emissions from leaks and/or spills. Leaks/spills typically occur in transformers when the gasket joining the top to the body corrodes, tears, or physically fails. PCBs can then leak past this failed section and potentially spill onto the surrounding ground. PCB capacitors typically fail by rupturing, exposing the contained PCBs to the environment. This is due to environmental and weathering effects (e.g., lightning) or material failures (e.g., metal fatigue).

One additional intermittent source of PCBs that was investigated concerned fires involving PCB equipment. Transformer and capacitor fires are infrequent, but when they occur, they can release PCBs as well as toxic incomplete combustion byproducts such as dioxins and dibenzofurans.[71,72] Transformer fires have especially gained widespread attention recently due to the elevated PCB contamination levels that resulted from fires in the interior of buildings in Binghampton, New York and San Francisco, California.

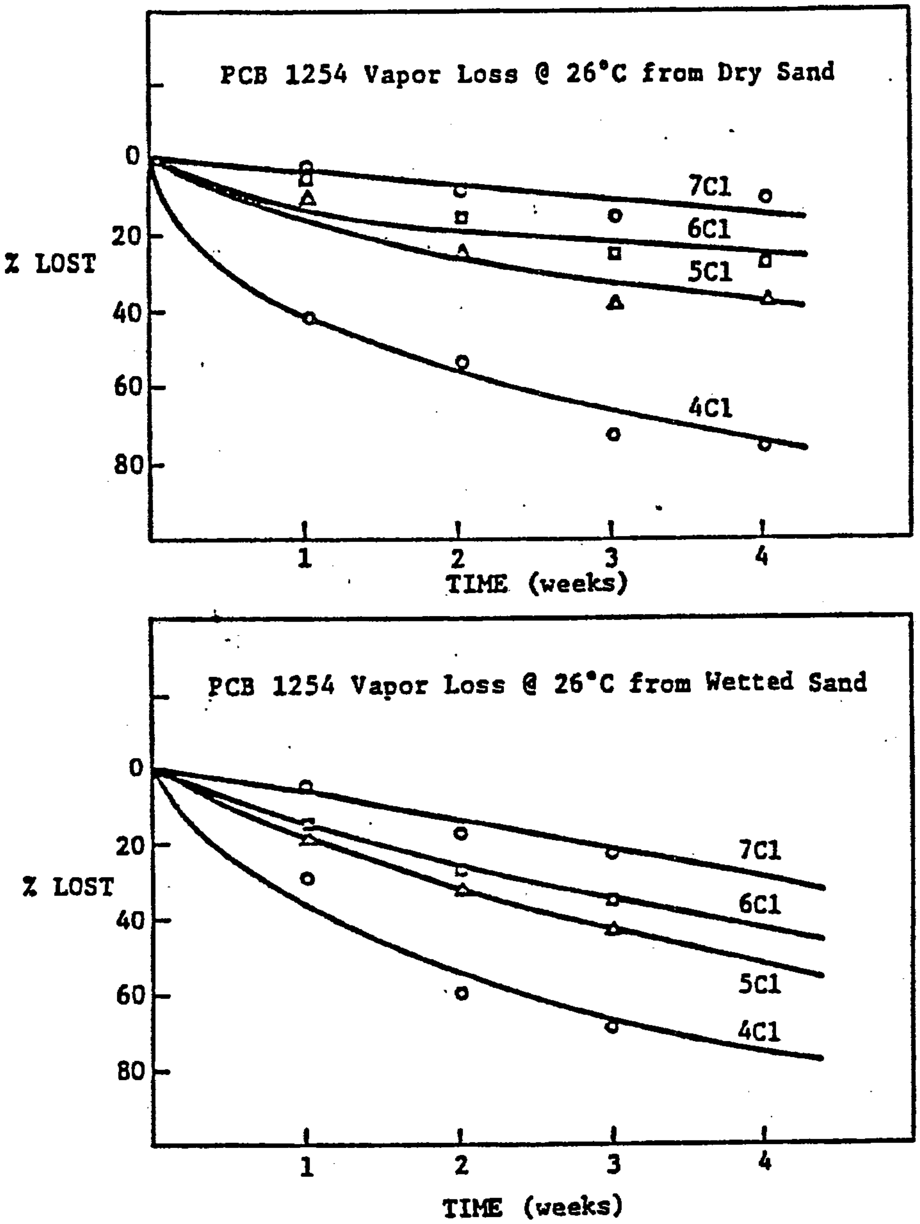
Emissions--

The EEI/USWAG report estimated that the average quantity of PCBs spilled when a PCB transformer leaks or spills varies from 0.56 to 64.5 pounds per incident, while the spill/leak rate for capacitors is 2.0 to 17.1 pounds per incident.[73] These data translate into the annual leak/spill quantities cited in Table 17. When these data are proportioned to account for non-utility (industrial) equipment as well, the total amount of PCBs spilled/leaked is estimated at 503,680 pounds, as indicated in Table 17. This is an upper-bound estimate of the potential PCBs released and, as such, does not take into account spill cleanup procedures which are designed to remove, contain, and dispose of fluid that has leaked or spilled.

The proportion of spilled PCB that enters the atmosphere will depend on the surface onto which the PCBs are spilled (concrete, soil), the PCB isomers that are spilled, the ambient temperature and windspeed, and the cleanup schedule. As discussed for landfills, PCBs will evaporate and volatilize more rapidly from a nonporous surface such as cement or sandy soil, than they will from an organic rich topsoil. Also, in dry conditions or high winds, PCBs may become entrained either as an aerosol or by being adsorbed on fine soil particles that are subject to entrainment.

Due to their nonflammability characteristics, PCB transformers are typically installed as safety precaution in urban settings where the consequences of a transformer fire would be most severe. These installations include schools, hospitals and office buildings. Consequently, it can be assumed that the average PCB unit is mounted on a solid base. This would enhance vaporization potential in the event of a leak or spill. In addition, PCB transformers and capacitors have historically used Aroclors 1242, 1254, and 1016.[8] The 1242 and 1016 mixtures contain up to 90 percent by weight of the lower isomer PCBs (less than four chlorine atoms), while Aroclor 1254 contains only 20 percent by weight of the lower isomer PCBs.[74] These lower isomers are more likely to be evaporated from an impervious surface. This is shown graphically in Figures 5 and 6. For both wet and dry sand, up to 80 percent of the PCBs are lost to the atmosphere within 4 weeks of the spill. These results indicate that for Aroclors 1016 and 1242, a majority of the spilled PCBs may be volatilized if the contaminated surface beneath the transformer or capacitor is sand or concrete and cleanup is not prompt. However, volatilization in actual field conditions may be less because of removal by other mechanisms such as run-off, percolation, and so on.

Temperature also plays an important role in the amount of PCB evaporated from a spill because of the increase in vapor pressure that occurs with increasing temperature.[75] Figure 7 shows the variation in volatilization rates for temperatures of 26°C (79°F) and 60°C (140°F).



Figures 5 and 6. Volatilization of PCB isomers from Ottawa Sand contaminated with Aroclor 1254.[75]

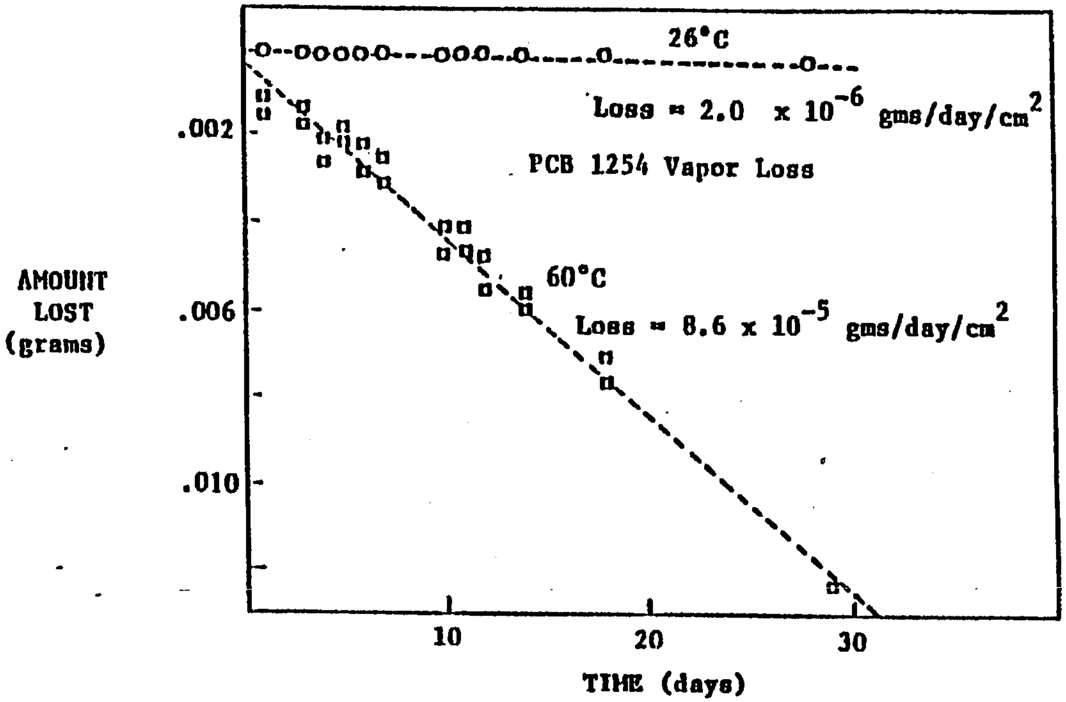


Figure 7. Surface volatilization of Aroclor 1254 from itself as a function of time.[75]

Finally, the rapidity with which spills are cleaned up will affect the amount discharged to the atmosphere. Final EPA regulations affecting PCB electrical equipment require quarterly inspections of PCB transformers, but no mandatory inspections for PCB capacitors.[76] The purpose of the inspections is to minimize environmental releases that result from spills and leaks. However, the utility industry has stated[77] that a large failure of a PCB transformer or capacitor would cause a service interruption and this would be addressed immediately, so the quarterly inspection is not necessarily an accurate indicator of the response time required for cleanup of a spill or leak. No estimate of the average response time for a PCB leak was found in the literature.

The number and diversity of factors affecting PCB emissions from spills and leaks makes estimation of an emission factor difficult. Immediate cleanup of a transformer spill that occurs in New England in mid-winter may result in a negligible release of PCBs, while a continuous leak that occurs in the middle of the summer in the southwest may lead to a substantial PCB release. Each case should be treated individually. Emissions from spilled PCBs are somewhat analagous to those from uncovered dredge spoils. Although the emission factor for dredge spoils is only a very rough approximation, it can be applied to PCB spills in lieu of additional data. An estimated PCB emission rate of 4.286 g/l of landfilled PCBs was reported for the dredge spoils cleanup project in New York (see Emissions from Annex II Landfills).

For fires involving PCB transformers or capacitors, the amount of PCBs released is dependent upon the extensiveness of the fire and the speed at which it is extinguished. A number of these fires have been documented. A New York fire involving 200 gallons of transformer fluid containing some 65 percent by weight PCBs resulted in a release of up to 1,300 pounds of PCBs.[78] A capacitor fire which burned uncontrolled for two hours in Sweden resulted in the destruction of 12 large utility capacitors containing an estimated 25 pounds of PCBs each, for a total potential release of 300 pounds. However, data are incomplete on the exact amount of PCBs released as a result of these two fires.

An ongoing EPA investigation into the annual number of PCB transformer fires sets this figure at approximately 20 per year.[79] The number of PCB capacitor fires is unknown. As these PCB items reach the ends of their economic lives or are retired due to premature failure, their susceptibility to fires will be eliminated and the overall number of PCB transformer and capacitor fires will be reduced.

SECTION 5

SOURCE TEST PROCEDURES

PCB emissions from industrial, sewage sludge, and municipal refuse incinerators can be measured using a modification of EPA Reference Method 5.[80] This method begins with a sample of gaseous and particulate PCBs being withdrawn isokinetically from the source through a series of four impingers with a Florisil absorbent tube between the third and fourth impinger, as shown in Figure 8.

The first and second impingers are of the Greenburg-Smith design. The final two impingers are of the Greenburg-Smith design modified by replacing the tip with a 1.3 cm (1/2 inch) ID glass tube extending to 1.3 cm from the bottom of the flask. The absorbent tube has a 2.2 cm inner diameter, is at least 10 cm long, and has four deep indentions on the inlet end to aid in retaining the absorbent. Ground glass caps are used to seal the absorbent-filled tube prior to and following sampling. The Florisil is activated by heating to 650°C for 2 hours in a muffle furnace. After allowing to cool to near 110°C, the clean, active Florisil should be transferred to a clean, hexane-washed glass jar, sealed with a TFE®-lined lid, and stored at 110°C, until taken to the field for use. If the Florisil is stored more than 1 month it must be reactivated before use.[80]

In assembling the sampling train, sealant greases should not be used. Place 200 ml of water in each of the first two impingers and leave the third empty. If the preliminary moisture determination shows that the stack gases are saturated or supersaturated, one or two additional empty impingers should be added to the train between the third impinger and the Florisil tube. Place 200 to 300 grams or more of silica gel in the last impinger. Weigh each impinger and record the weights. Crushed ice is placed around the impingers after the sample train is assembled.[80]

The sample is collected by pumping air through the sampling train. At the end of the sampling run, the probe is removed from the stack and proper cleanup procedures are followed. The first three impingers are removed, the outsides are wiped off, and the weights are recorded.[80]

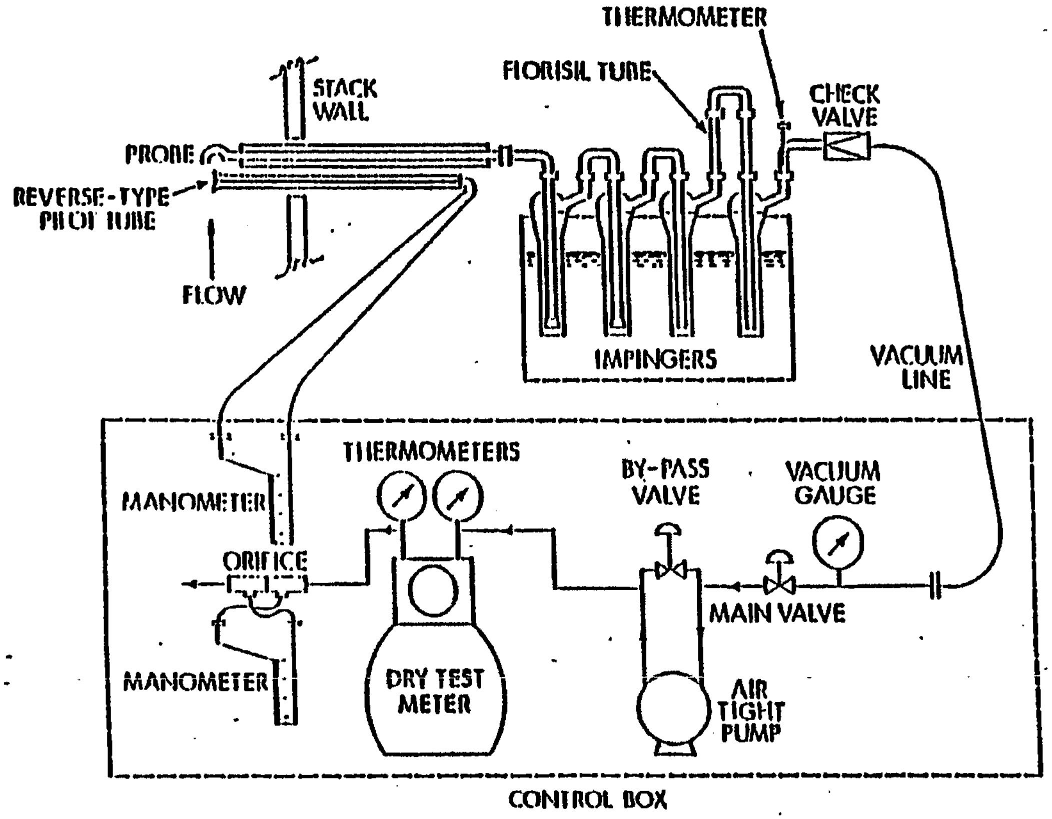


Figure 8. Method 5 sampling train modified for the measurement of PCBs from incinerators.[80]

The sample is extracted from the impingers and absorbent tube. The extract is dried and cleaned and is then perchlorinated with antimony pentachloride. Hexane is added to the reaction mixture to remove the residual antimony pentachloride. The solution is allowed to separate into layers and the upper layer is filtered through a column of anhydrous sodium sulfate.[80]

The filtered sample is then assayed for decachlorobiphenyl (DCB) by gas chromatography (GC). The recommended GC column is 2 mm ID by 1.8 m glass packed with 3 percent OV-210 on 100/120 mesh inert support such as supercoport® The GC should be fitted with an electron capture detector capable of operation at 300°C. Column temperature and carrier gas flow parameters of 240°C and 30 ml/minute are typically appropriate.[80]

The peak area corresponding to the retention time of DCB is measured and compared to peak areas for a set of standard DCB solutions to determine the DCB concentration. The concentrations of the standard solutions should allow fairly close comparison with DCB in the sample extracts. Standard concentrations of 25 to 50 picograms/microliter may be appropriate.[80]

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16. ABSTRACT

To assist groups interested in inventorying air emissions of various potentially toxic substances, EPA is preparing a series of documents such as this to compile available information on sources and emissions of these substances. This document deals specifically with Polychlorinated Biphenyls. Its intended audience includes Federal, State and local air pollution personnel and others interested in locating potential emitters of Polychlorinated Biphenyls and in making gross estimates of air emissions therefrom.

This document presents information on 1) the types of sources that may emit Polychlorinated Biphenyls, 2) process variations and release points that may be expected within these sources, and 3) available emissions information indicating the potential for Polychlorinated Biphenyls release into the air from each operation.

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Rates and Routes of Transport of PCBs in the Environment

by Ian C. T. Nisbet* and Adel F. Sarofim†

Polychlorinated biphenyls (PCBs) are one member of a class of chlorinated organic compounds which give rise to concern, because of their wide dispersal and persistence in the environment and tendency to accumulate in food chains, with possible adverse effects on animals at the top of the food webs, including man. In the past, attention has been concentrated on chlorinated hydrocarbon pesticides, such as DDT, dieldrin, heptachlor and HCH (hexachlorocyclohexane). More recently attention has been focused on PCBs and on chlorinated dibenzodioxins. Likely candidates for future attention are hexachlorobenzene, chlorinated dibenzofurans, and chlorinated phenols. In the past, such compounds have generally been studied individually. As the number of compounds giving rise to concern increases, there is an urgent need to establish uniform monitoring schemes and generalized models describing environmental transport and bioaccumulation which will be applicable to all compounds with these properties. Models such as the global monitoring scheme outlined by the SCEP study (1), and the global transport model outlined recently by Woodwell et al. (2), are needed in order to help identify sources of environmental contamination, to establish acceptable levels of discharge, and to estimate the effectiveness of different control strategies.

This paper summarizes the fragmentary knowledge available about production, uses, and losses of PCBs, and attempts to define the major routes of transport and reservoirs of PCBs in the environment. It discusses only production and uses within North America, and distribution of PCB residues in North America and adjacent seas (the eastern half of the North Pacific Ocean and the western half of the North Atlantic). It is expected that the picture will be generally similar for other areas where PCBs have been used extensively (i.e., industrialized regions, primarily in the North Temperate Zone), with minor differences depending on local patterns of use and disposal. However, references to studies made in Europe and Japan are made in this paper where they help to fill gaps in the North American picture.

Although we attempt to cover all the important environmental aspects of the use and distribution of PCBs, much of the discussion in this paper is extremely speculative. One of its main purposes is to point out the most important gaps in knowledge which must be filled before firm estimates can be made of present and future levels in the environment.

Production and Use in North America

The sole manufacturer of PCBs in North America is the Monsanto Company. Commercial mixtures are sold under the trade name Aroclor and are distinguished by numbers, in which the first two digits 12 specify polychlorinated biphenyls and the last two digits the approximate percentage of chlorine in the mixture (3). In November, 1971, Monsanto released figures for U.S. domestic sales of Aroclors during the period 1963–70, summarized here in Figs. 1 and 2, where they are divided according to category of use and grade of Aroclor.

Prior to Monsanto's voluntary reduction of sales in September, 1970, approximately 60% of

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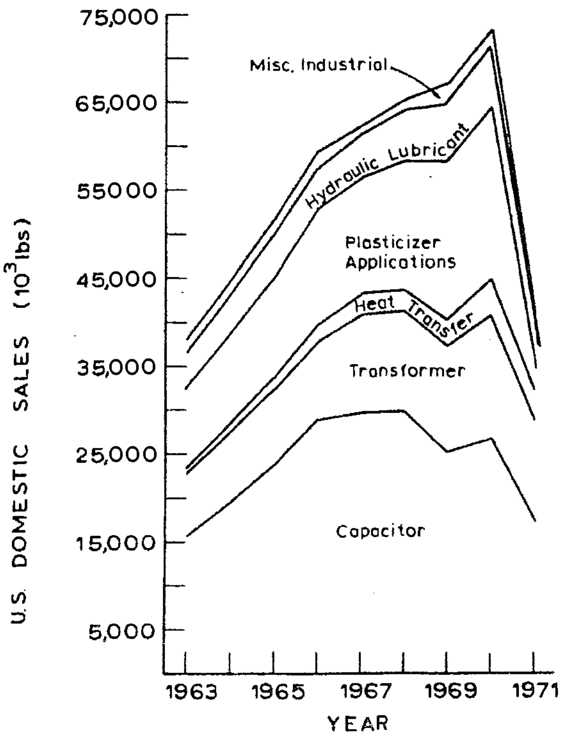

FIGURE 1. U.S. domestic sales of PCBs by category.

sales were for closed-system electrical and heat transfer uses, 25% for plasticizer applications, 10% for hydraulic fluids and lubricants, and less than 5% for miscellaneous applications such as surface coatings, adhesives, printing inks, and pesticide extenders. Exports by Monsanto have averaged 13% of domestic sales over the period 1963 to 1970. Imports are thought to be small, comprised primarily of plasticizers in resins and adhesives, transformer oils and capacitor fluid in electrical equipment. Exports to Canada should be of the order of 7% of U.S. sales and are included in this model of North America.

Monsanto has restricted sales of Aroclors based on consideration of either the possibility of contamination of food products or its inability to control or monitor possible losses into the environment. The fraction of sales for use in confined systems, primarily electrical applications, will increase to approximately 90 percent in 1971 and to 100% in 1972. The higher chlorinated Aroclors, 1254 and above, comprised approximately 30% of sales prior to 1971. Their share of the reduced sales in 1971 is expected to fall to 22%. Aroclor 1242 is being replaced with Aroclor 1016 having a similar composition but with isomers containing 5 or more chlorine atoms removed.

The breakdown by grade of the current uses of PCB is: electrical capacitors, mainly Aroclor 1016 with limited usage of Aroclor 1221 and Aroclor 1254; electrical transformers, Aroclors 1242, 1254 and 1260; vacuum pumps, Aroclor 1248 and 1254; and gas transmission turbines, Aroclor 1221 and 1242. The breakdown by PCB grade of former uses include Aroclors 1232, 1242, 1248, 1254, and 1260 for hydraulic fluids; Aroclor 1242 for heat transfer systems; Aroclors 1248, 1254, 1260, 1262, and 1268 for plasticizers in synthetic resins; Aroclors 1221, 1232, 1242, 1248 and 1254 for adhesives; Aroclors 1221, 1232, 1242, 1248, 1254 and 1268 for plasticizers in rubbers; Aroclors 1242, 1254 and 1268 for wax extenders; Aroclors 1254 and 1260 for dedusting agents; Aroclor 1254 for pesticide extenders, inks, lubricants, and cutting oils; and Aroclor 1242 for carbonless reproducing paper.

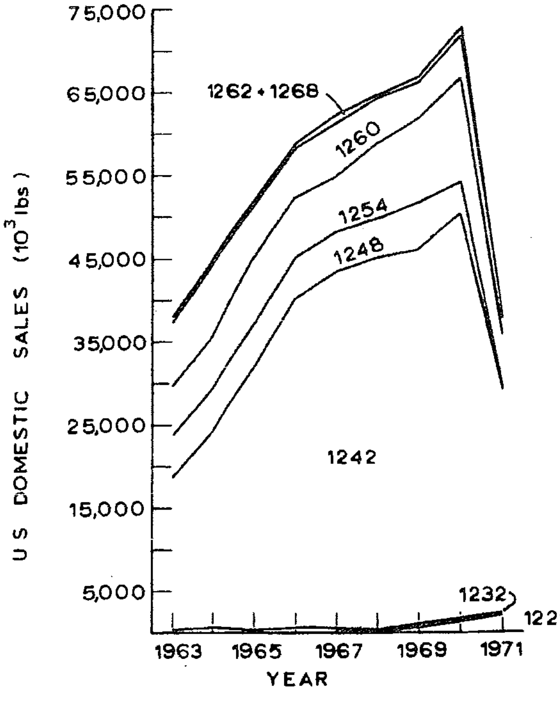

FIGURE 2. U.S. domestic sales by PCB grade.

Data on production outside the U.S. are not available. It has been estimated (4) that the Japanese production is 26 million pounds per year, 40–50% for capacitors, 15% for transformer oil, 10–15% for heat transfer fluid, 5% for plasticizers, 15% for carbonless duplicating paper, and 5—10% for export.

Routes into the Environment

As in the case of most industrial chemicals, loss figures for PCBs are practically non-existent. Possible routes into the environment include: (1) leaks from sealed transformers and heat exchangers; (2) leaks of PCB-containing fluids from hydraulic systems which are only partially sealed; (3) spills and losses in the manufacturing either of PCBs or PCB-containing fluids; (4) vaporization or leaching from PCB-containing formulations; (5) disposal of waste PCBs or PCB-containing fluids.

Examples of losses by each of these proposed routes include leaks from faulty heat exchangers in the contaminated Japanese rice oil (5) and contaminated chicken feed (Holly Farms) incidents; leakage of hydraulic fluid from an air compressor in Escambia Bay, Florida (6); the indirect evidence of possible losses during manufacture provided by the high level of PCBs in catfish in waters near Anniston, one of the two sites at which PCBs are manufactured in the U.S. (7); the leaching of PCBs from silos by sileage (7) and the use of waste electrical insulator containing PCBs as solvent in herbicide treatment of power rights-of-way near Martinsburgh, West Virginia (7). Other unreported disposal of scrap undoubtedly occurs into sewers (8). Statistical information on such losses is not available but could be generated by an accounting of PCB inventories and disposal by major users. To meet the problem of scrap disposal, Monsanto has set up a disposal system with a capacity of 10 million pounds per year for their customers. Within a year of announcement of the service, 500,000 pounds of waste PCBs had accumulated at the disposal site, where it was held in storage, pending the completion of an incinerator (9).

Another waste disposal problem is that of PCB-containing products including the PCB-impregnated paper in capacitors, caulking compounds, and carbonless duplicating paper. It has been postulated that the PCBs may be vaporized during incineration. Based on studies into the incineration of PCBs and pesticide residues, municipal incinerators meeting design guidelines of a residence time of 2 seconds at 2000°F are expected not to be a significant source of PCBs (9, 10). Poorly operated commercial and municipal incinerators, small domestic and apartment incinerators, and open-burning dumps may, however, be major sources of emission, but data are not presently available. Another problem is that of leaching from dumps. Again, data are scarce, but analysis (11) of stagnant water close to a sanitary landfill indicated levels below the detection limit of 4 ppb.

Quantitative Estimates of Rates of Loss into the Environment

It is unlikely that reliable quantitative estimates of past losses of PCBs into the environment will ever become available. However, in order to assess the biological significance of the PCBs now in the environment, it is necessary to make some numerical estimates, however rough. The following calculations are intended to provide order-of-magnitude estimates of rates of loss. Figure 3 shows qualitatively some of the many possible routes of loss into the environment.

Estimates of the rates of loss and disposal of Aroclors in 1970 will be based on rough guesses of the useful service life in different applications. Transformers are fairly permanent installations, and it is therefore estimated that only 10% of sales of transformer fluid is to replace oil that was scrapped and that the remaining 90% is for new units. The useful life of capacitors, especially those used in small items such as fluorescent light ballasts, is expected to be under a decade, and it is therefore estimated that the rate at which the capacitors are discarded, primarily into landfill dumps, is equal to half the rate of production. (Figure 1 indicates a doubling period for sales of about 10 years.) A similar figure is assumed for the scrapping of heat exchangers, but it is expected that the replacement of fluid decomposed under extreme thermal conditions would have led, in the past, to additional direct losses, primarily into sewers. It is estimated that the rate of vaporization of plasticizer amounts to 10 to 20% of

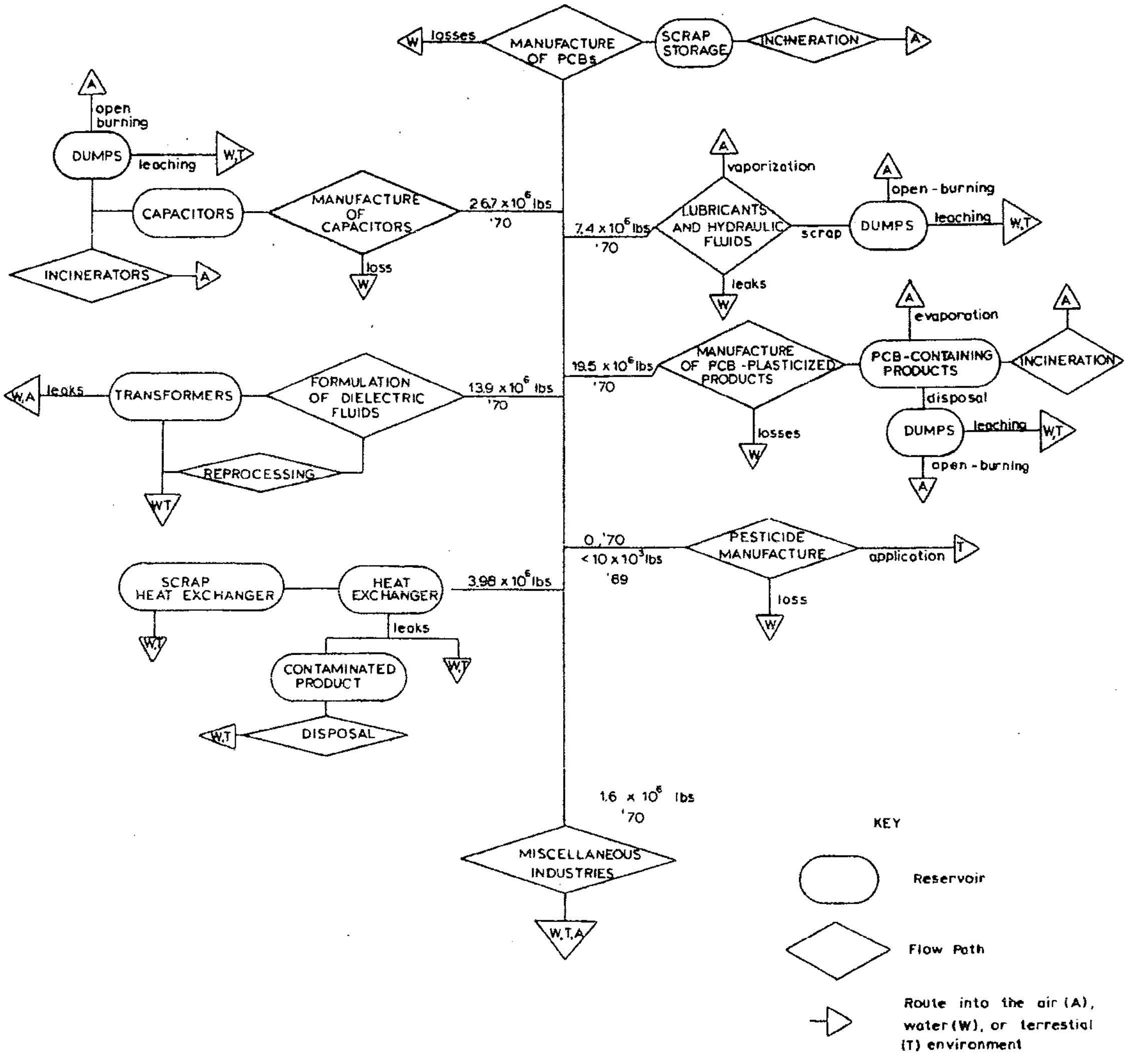

FIGURE 3. Possible routes of PCBs into the environment.

sales (12). Since many plastic objects have relatively short useful lives the rate of disposal of plasticizers into dumps is assumed to equal the residual 80 to 90% of sales. Hydraulic fluids and lubricants are rarely re-used, and it is therefore assumed that a major fraction of these fluids used for this purpose, together with those going into the miscellaneous applications, were scrapped at rates approximately equal to those of corresponding sales.

On the basis of these gross estimates, it appears that only about 20% of the 1970 sales in North America, some 7×10^3 tons, represented a net increase in the amount of PCBs in service, in transformers, heat exchangers and capacitors. The remainder is assumed to have been discharged into the environment, $1-2 \times 10^3$ tons by evaporation of plasticizers; $4-5 \times 10^3$ tons by leaks and disposal of hydraulic fluid and lubricant plus small amounts by disposal of heat transfer and trans-

Table 1. Gross Estimates of Rates of Input and Accumulation of PCBs in North America in 1970.

Category of input	Rates (tons/year)	PCB Grade
Vaporization of plasticizers	$1\text{–}2\times10^3$	Mainly 1248 to 1260
Vaporization during open-burning	4×10^2	Mainly 1242
Leaks and disposal of industrial fluids	$4\text{–}5\times10^3$	1242 to 1260
Destroyed by incineration and open burning	3×10^3	Mainly 1242
Disposal in dumps and landfills	1.8×10^4	1242–1260
Accumulation in service	7×10^3	1242–1254

Reservoir	Accumulation (tons)	
	PCBs	ΣDDT
Soil (excluding dumps)	1.5×10^4	3×10^6
Oceans (adjacent to North America)	1.5×10^4	10^6
Fresh water (dissolved or in suspension)	10^2	$\sim10^2$
Fresh water sediment	2×10^4	?
Biota	$<10^3$	$<10^3$

former oils, and 22×10^3 tons by disposal in incinerators, dumps and sanitary landfills. Of the latter, we estimate (13) that 10 to 20% (3×10^3 tons) were destroyed by burning, and 2% (4×10^2 tons) were vaporized, mainly by open burning of wire scrap, auto components, and material in dumps.

Routes into the Environment

The total rate of loss of PCBs is thus estimated to have been of the order of 1.5 to 2×10^3 tons/year into the atmosphere, 4 to 5×10^3 tons/year into fresh and coastal waters, and 1.8×10^4 tons/year into dumps and landfills. The input into soils via the use of Aroclors as pesticide extenders is believed to have been small, less than 10 tons/year, on the basis of reports of purchases for this purpose. The unauthorized and unrecorded use of scrap PCBs as pesticide extenders is difficult to estimate but has probably been small. Direct discharge into the oceans, e.g. by dumping of hydraulic fluids and lubricants from ships, has probably been of relatively small magnitude, but may have been locally significant (49).

Most of the PCBs discharged into the atmosphere will have been Aroclor 1248 to 1260 vaporized from plastic resins, augmented primarily by 1242 vaporized from burning dumps. The discharge into waters will be heavily weighted by the Aroclors used as hydraulic fluids and lubricants and is therefore likely to have included a mixture of Aroclors 1242 to 1260. The residual in dumps will have a large fraction of the Aroclor 1242 production.

Rates of Transport within the Environment

The modes of transport of the PCBs within the environment are complex. Vaporized PCBs will be partially adsorbed on particulates, transported with the prevailing winds, and deposited on land or water by particle sedimentation or rain-out. PCBs introduced into water streams may be adsorbed by the waterborne particulates or the benthos; the adsorbed PCBs will diffuse into the bottom sediment, redissolve in the water stream or be entrained with sediment eroded from the bottom surface.

The problem is further complicated by the assimilation, transport and degradation of PCBs by the biota. A major fraction of the PCBs discarded in dumps is encapsulated in sealed containers or plastic resins. The rate of loss from these will therefore be low until the confining material is degraded and the PCBs released. The PCBs will then slowly diffuse through the surrounding soil. In principle, the rates of transport may be calculated from knowledge of the physicochemical properties of the PCBs and the pertinent data on atmospheric conditions, particulate transport, hydraulic dispersion, bottom sediment transport, and biological degradation rates. At present, the data are too incomplete and the interactions between the different elements in the environment too complex to attempt a formulation of but the crudest of transport models. The similarity between the properties of the PCBs and DDT, summarized in Table 2, permits rough estimation of some of the otherwise unknown routes and rates of transport of PCBs from the corresponding information on DDT. In Fig. 4, a generalized model for the distribution and transport of the PCBs is outlined, without any indication of the transport down spatial gradients within the differ-

Table 2. Comparative Physical Properties of PCBs and DDT (Ref. 9, 23, 84, 85).

Molecular weight		Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260	DDT
	Range[a]	154–358	222–358	290–392	324–460	352
	Average	262	288	324	370	352
% Chlorine		42	48	54	60	50
Solubility[b] in H_2O (at 20°C ppb)		200	100	50	25 Est.	0.7
Vapor pressure[b] at 38°C (mm, Hg)		10^{-3}	3.7×10^{-4}	6×10^{-5}	2×10^{-7}	2×10^{-6}[c]
Vapor pressure at 20°C (mm. Hg)		10^{-4}[c]	3×10^{-5}[c]	3.6×10^{-6}[c]		1.5×10^{-7}

[a] Based on constituents present in amounts of 1 percent or more.

[b] The high values of the solubilities and vapor pressures of the PCBs are a consequence of the heavy weighting given the lower chlorinated species.

[c] Extrapolated.

ent compartments of the environment. An attempt is made in the following sections to estimate fluxes between and within each compartment.

Air Transport

The estimated emission of 1500 to 2500 tons a year of PCBs, mainly by vaporization and open burning, is expected to be concentrated in urban areas. By analogy to DDT (17, 18) it is expected that most of the airborne PCBs will be adsorbed on particles. Since roughly three quarters of total suspended particulates (TSP) in urban areas are of non-agricultural origin (19), and the emission of TSP within cities is of the order of 2×10^7 tons per year (20), this gives rise to a rough estimate of PCB level on urban particulates of 50 to 80 ppm.

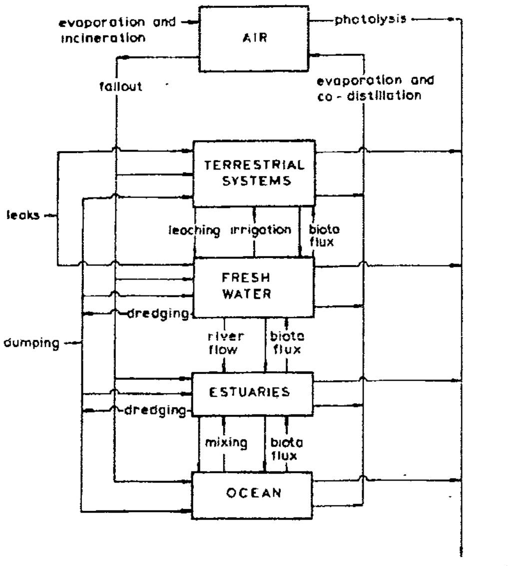

FIGURE 4. Environmental transport model.

The half-life of particulates in the air will depend greatly on the size of particles to which the PCBs are attached and the extent of atmospheric precipitation. (19) It is estimated that most of the vaporized PCBs will be deposited within 2 or 3 days, mostly onto the land mass and coastal waters surrounding urban areas. The small amounts of PCB attached to fine particulates will reside in the atmosphere for extended periods and be transported to remote areas.

Based on the above assumptions, the rate of terrestrial net input of PCBs by serial fallout in North America will be a little less than the rate of vaporization, about 1000 to 2000 tons/year. The vapor pressure of Aroclor 1254, the dominant airborne contaminant, is close to that of DDE (21), and it is estimated, by analogy to DDE (17) that the likely half-life of PCBs in soil is of the order of five years. The PCBs removed from the soil will become adsorbed to particulates, mostly of relatively short range, and be redeposited and vaporized one or more times until they reach the coast. By analogy to DDE (1, 2), the redistribution of PCBs by this mechanism is expected to have resulted in the redepostiion into the ocean of one quarter of the PCBs that originally fall out in the terrestrial environment. The deposition pattern will be influenced by the size distribution of particles to which the PCBs are attached, with a major fraction ending in coastal waters and a small amount being transported into remote regions.

It is expected that a negligible fraction of the PCBs reaching the oceans will be revaporized; their concentration will be too low.

Water Transport

On account of the low water solubility and high specific gravity of PCBs, it is expected that most of the PCBs discharged into the environment will be resting as sludges or adsorbed in the sediment at the bottom of rivers or lakes near their point of discharge, and that transport in streams will be primarily by means of waterborne particles. Evidence for this postulate is indirect, consisting mainly of the strong adsorption of PCBs by surfaces (22), the observation of PCB concentrations as high as five times the solubility limit (6), and the evidence that chlorinated hydrocarbon pesticides are removed from contaminated lakes by adsorption in sediments and codeposition with algal bloom (24).

The transport of PCBs within rivers is as described previously, by solution and readsorption in the sediment and by sediment transport. The data on partition coefficient between sediments and water and on diffusivity in bottom sediment are not available so that the transport models (25) developed for rivers cannot yet be applied. The only measurements reported on PCBs in ground sediment are for Escambia Bay (6, 26). The PCB concentration in the sediment 10 miles downstream from a discontinued source of PCB loss was found to remain constant over a year suggesting that the PCBs are strongly adsorbed to sediment.

The amount of PCBs transported to the ocean in solution or suspension in river water is estimated as 200 tons/year (49), a small amount compared to the estimated input into rivers. Irrigation waters amount to about $\frac{1}{15}$ of the total river flow and are expected to carry a correspondingly lower amount, about 15 tons/year, of PCBs to the terrestrial environment.

Dredging and Dumping

Dredging of inland rivers and harbors may lead to significant transfer of PCBs from contaminated sediments, especially when the dredge spoils are dumped at sea. According to the Council on Environmental Quality (27), some 13×10^6 tons of polluted dredged spoils are dumped at sea annually off the United States, 90% off the Gulf and Atlantic coasts. A high figure for PCB levels in polluted sediments is 30 ppm, the highest level recorded in the Escambia Bay incident away from the immediate vicinity of the discharge (26). If all the polluted dredge spoils were contaminated to this level, the total rate of transfer of PCBs to the oceans would be around 400 tons/year, mostly into the Atlantic Ocean and Gulf of Mexico. Based on the general level of contamination a more reasonable estimate of rate of transfer would be only 20 tons/year.

Biota Flux

The total quantity of PCBs stored in migratory animals is very small (see below), and their movements cannot account for a significant fraction of environmental transfer of PCBs. The movements with the greatest local significance are probably the migrations of seabirds from the northern to the southern hemisphere; these might account for the movement of about a ton/year (28). Human fishing is estimated to remove only 1–2 tons/year from the eastern North Pacific, the western North Atlantic and the Great Lakes (30).

Separation and Transformation of PCB Isomers in the Environment

There are three processes by which the compositions of PCB mixtures may change after release into the environment.

Fractionation

In general, the water solubilities and vapor pressures of PCB isomers decrease with increasing

Table 3. Percent Loss in Area of Seven Chromatogram Peaks of Aroclor 1254 After Steam Heating for 25 and 60 Minutes. [From Ref. 23]

Peak	25 Minutes	60 Minutes
1	66	83
2	41	74
3	22	73
4	40	54
5	14	51
6	0	15
7	0	33

chlorine content, although the decreases are not uniform (Table 2) (31). Hence the processes of evaporation, co-distillation and dissolution in water are expected to fractionate mixtures of PCBs, the lower isomers being much more mobile. This has been confirmed for co-distillation by the results of Freed (21, 23) (Table 3), which show that, after 60-min steam heating, the ratio of the first to the sixth of the seven major chromatographic fractions of Aroclor 1254 was reduced by a factor of 5. Thus environmental transport mechanisms involving these processes are expected to reduce the proportions of the lower isomers in environmental samples near to the point of release, and to augment them in samples from remoter areas.

Photolysis and Chemical Decomposition

Photolytic decomposition of certain PCB isomers has been reported by Risebrough et al. (32, 33), and Safe and Hutzinger (34, 35). The results of the latter suggest that in natural sunlight some higher isomers are more easily broken down than the lower isomers (35). Hence photolysis is expected to reduce the proportions of at least some of the higher isomers. Photolytic dechlorination is also expected to give rise to lower isomers, including some which may not be present in commercial mixtures (35).

Because of their high stability in industrial use, we assume that other forms of chemical (nonbiological) decomposition of PCBs are very slow in the environment.

Metabolism and Excretion

Published studies of the dynamics of PCBs in rats and birds (36–39) indicate that the higher isomers are generally taken up and/or retained more efficiently. In each case the proportions of pentachloro- and lower isomers found in the animals' tissues were generally lower than those in the Aroclor mixture to which they had been exposed, but there appears to have been little differentiation of the higher isomers except for one hexachloro-isomer (36–38). It is not clear in each case whether the deficiencies of the lower isomers resulted from metabolism or differential excretion, but it is likely that both occurred. Because of their higher solubility in water (see above), the lower isomers would be expected to be excreted more easily than the higher isomers. In one study on rats, loss of PCBs from the body was markedly retarded by administration of carbon tetrachloride (36), suggesting interference with metabolism in the liver. In another study with rats, hexachloro-isomers were found in disproportionate amounts in the urine (37), suggesting that the tetra- and pentachloro-isomers were metabolized and the hexachloro-isomers excreted in part, while the heptachloro-isomers were differentially retained. Two studies of metabolism of PCBs in fish (40, 41) gave inconsistent results but showed no marked tendency for the higher isomers to accumulate differentially.

Evidence from Environmental Samples

Veith (42) has found that the proportion of higher isomers increases downstream in some Wisconsin rivers and that certain isomers characteristic of lower Aroclors disappear. Since the lower isomers are unlikely to be differentially retained in sediments (see above), this suggests that they are decomposed rapidly in the river environment. Evidence of biodegradation of pesticides under anaerobic conditions (43) suggests the possibility that the degradation of the missing lower isomers may occur primarily by microbial metabolism in the bottom sediment. We recommend that higher priority be given to this aspect of decomposition of PCBs.

A number of writers have reported that PCB samples extracted from animals generally match Aroclors 1254 or 1260, but that the lowest isomers are sometimes relatively deficient or missing, especially in animals high in food chains (38, 44). Since substantial quantities of Aroclors 1242 and

Table 4. Relative Peak Heights in Gas-Liquid Chromatograms of Extracts from Sewage Sludges. [From Ref. 45]

Relative retention time	Sludge A	Aroclor 1254	Sludge B	Aroclor 1260
0.69	38	30	39	3
0.81	63	72	24	14
1.00	51	59	17	4
1.21	104	110	51	30
1.45	100	100	100	100
1.71	92	92	66	69
2.00	32	26	70	70
2.34	19	12	53	55
2.83	21	19	84	87
3.33	10	8	29	30
3.70	5	4	25	23

1248 must have been released into the environment (see above), these observations suggest that a large proportion of the lower isomers (those with 4 or fewer chlorine atoms) is missing from the animal samples. However, few critical data have been published. In one set of data from sewage sludge (45) (Table 4), none of the lower isomers is clearly deficient. In published chromatograms for birds (38, 46, 47) (Table 5), only the lowest isomers (tetrachlorobiphenyls) and one higher isomer were markedly reduced in comparison to Aroclor 1254. In human adipose tissue (48), however, pentachloro- and hexachloro-isomers were reduced or missing.

The higher isomer reduced in the bird samples (38, 46) is probably that reported as deficient in samples from the Gulf of California and Quebec and found to be degraded by ultraviolet light (32, 33). With this one exception, we conclude tentatively that higher isomers (pentachlorobiphenyls and higher) are not significantly differentiated as they pass through food chains up to fish and birds. Mammals appear to be able to excrete and/or metabolize penta- and hexachloro-isomers.

The lack of the lower isomers in samples from relatively contaminated areas could be accounted for either by metabolism or by their greater mobility. However, Risebrough and Berger (33) found that lower isomers were relatively deficient also in samples from fish in a remote lake in northern Canada. This suggests that differential metabolism is the primary mechanism in the environmental differentiation of isomers, outweighing the effects of differential photolysis and differential mobility, which would be expected to have reduced the proportion of higher isomers in remote samples.

Conclusions and Comments on Separation of PCB Isomers in the Environment

We conclude that most PCB isomers with four or fewer chlorine atoms have been degraded in the environment, possibly by microbial action. Decomposition of penta- and hexachloro-isomers appears to occur in birds and mammals, but this will have affected only a negligible fraction of the PCBs in the environment. Accordingly, we assume (3) that some 75% of the Aroclor 1242 released into the environment, 60% of Aroclor 1248, 20% of Aroclor 1254 and 5% of Aroclor 1260, have disappeared.

The above discussion has been confined to a general comparison of lower and higher isomers, because of the scarcity of data on relative proportions of individual isomers in environmental samples. In fact, the physical and chemical properties and biodegradability of PCB isomers depend on the positions of substitution as well as the total chlorine content. More precise data on the

Table 5. Relative Peak Areas (Peak 11 = 100) for Chromatogram of Extract of Eagle Carcass and Aroclor 1254. [From Ref. 47]

Peak No.	Relative retention rime[a]	Eagle carcass	Aroclor 1254
1	0.39	7.5	6.8
2	0.49	34.8	100.0
3	0.53	55.0	42.3
4	0.58	15.7	21.0
5	0.70	68.6	191.5
6	0.79	28.0	32.2
7	0.83	111.9	127.5
8	0.97	68.7	66.5
9	1.04	91.6	105.2
10	1.23	92.5	139.5
11	1.46	100.0	100.0
12	1.72	62.2	75.5
13	2.01	28.7	23.6
14	2.32	18.4	42.6
15	2.86	32.6	38.8
16	3.38	15.4	22.2

[a] p, p′-DDE = 1.00

exact quantities of individual isomers in environmental samples would permit more precise conclusions about the sources and routes of contamination. We urge that numerical characterization of individual peaks should be published whenever possible.

Cumulative Input into the Environment

From an extrapolation of the sales curve in Fig. 1 to zero production in 1930, it is estimated that the cumulative sales in North America over the period 1930–1970 were 5×10^5 tons. Assuming that the proportions of sales for different uses were similar throughout the period, the cumulative losses may be estimated as about 3×10^4 tons into the air, 6×10^4 tons into fresh and coastal waters, and 3×10^5 tons into dumps and landfills. Using the results of the previous section, it may be estimated that roughly one-third of the PCBs released into the air and one-half of those released into water have now been degraded. It is difficult to estimate the extent of degradation in dumps, because some of the PCBs there may still be in sealed containers, but we assume in any case that leaching from dumps into fresh waters has so far been negligible.

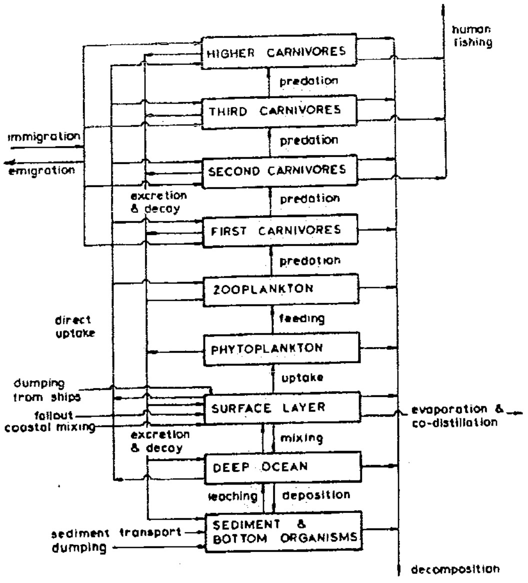

FIGURE 5. Ocean sub-model.

Table 6. Range of concentrations of PCBs in samples from the Irish Sea and Firth of Clyde, Scotland, October 1969 and subsequently [Ref. 58]. All figures are in ppm except those for seawater.

	Sample size	PCB	ΣDDT[a]
Seawater	53	<10 ppt	<1–5 ppt
Zooplankton	7	0.01–0.03	0.01
Mussels	c.200	0.05–0.5	0.01
Norway lobster	33	0.01–0.1	0.01–0.1
Herring	154	0.01–2.0	0.01–1.0
Whiting: muscle	18	0.01–0.4	0.01
liver	15	1.0–7.0	1.0–2.0
Cod: muscle	5	0.3–1.8	0.4–0.52
liver	5	4.5–50.	2.3–12.
Other fish	83	0.1–1.0	0.04–1.0
Razorbill livers	7	2.–44.	5.–13.
Guillemot livers:			
birds found dead	49	2.–880.	1.7–26.
birds shot	5	0–2.	0.1–0.8

[a] These figures, as given in the original source, include dieldrin as well as DDT and its metabolites, but dieldrin comprised only 4% of the total in the case of the guillemots.

Of the PCBs released into the air, we have assumed that most would have been adsorbed onto particulates soon after volatilization and would therefore have fallen out relatively close to the source. By analogy with DDT residues, PCBs in soil would be expected to have a half-life of the order of 5 years (2, 17). Again using the analogy with DDT and its metabolites, we may estimate that roughly one-quarter (1) of the total (i.e., 5×10^3 tons) will have been transferred into the sea, mainly into the Atlantic Ocean, and the remainder (1.5×10^4 tons) distributed over terrestrial North America, with a negligible fraction having fallen into fresh waters. Other inputs to the sea are difficult to estimate but have probably been of the order of 10^4 tons (49). The remainder (2×10^4 tons) is assumed to have accumulated in lakes and rivers.

PCB Levels and Σ DDT/PCB Ratios in the Environment

In this section we compare the above estimates of cumulative input into the environment with measurements of PCB levels in physical and biological samples. The purposes of this comparison are: (1) to use the observed distribution of PCBs in the environment to check the consistency of our

Table 7. PCB levels in Swedish marine organisms 1965–68 [From Ref. 44]. Figures given are the mean (ppm in extractable fat), with range and sample size in parentheses; ΣDDT is the total of DDT and its metabolites.

	Baltic Sea				Stockholm Archipelago			
	Mean	Range	N	ΣDDT/PCB	Mean	Range	N	ΣDDT/PCB
Mussel	4.3	(1.9–8.6)	(40)	1.4	5.2	(3.4–7.0)	(15)	0.6
Herring	6.8	(0.5–23)	(18)	2.5	5.1	(3.3–8.5)	(4)	1.5
Seal	35.	(16–44)	(3)	3.4	30.	(16–56)	(3)	5.7
Guillemot eggs	250.	(140–360)	(9)	2.3		—		
Heron					9400.		(1)	1.5
White-tailed Eagle:								
breast muscle					14000.	(8400–17000)	(4)	1.8
brain					910.	(490–1500)	(3)	2.1
eggs					540.	(250–800)	(5)	1.9

models of environmental transport; (2) to define the types and locations of input to the environment which are responsible for the most serious contamination of the biota.

Uptake and Biological Magnification of PCBs in Food Chains

A large fraction of the reported measurements of PCB concentrations in environmental samples have been from animals, especially fish and birds high in marine food chains. Figure 5 outlines schematically a model for the transport of PCBs within a simple marine ecosystem. Laboratory experiments (6, 41, 55) indicate that aquatic invertebrates and fish can accumulate PCBs to levels between 3×10^3 and 7×10^4 times higher than those in the ambient water. It is not yet clear whether concentrations of PCBs are consistently increased as they pass up food chains from invertebrates to fish and from fish to fish (57). However, PCB levels are clearly magnified within food chains involving birds and mammals by a factor on the order of 10 to 100 at each step (32, 44, 56, 57, 58). Hence, in the long food chains characteristic of marine systems (59), the levels in the top predators may be 10^7 times higher than those in the ambient water (Tables 6 and 7). In extreme cases, such as the starved guillemots in Table 6, or the eagle fat in Table 7, the concentration factors may be as high as 10^8 or 10^9. Because of the extreme variability observed both within and between samples, it is difficult to use measured levels in animals as a direct measure of levels in the environment. However, it is possible to compare levels in the same species or in ecologically equivalent species to define spatial gradients in contamination (29, 44).

ΣDDT/PCB Ratios

Another approach (32, 56) utilizes the similarity in properties between the persistent PCBs and the persistent metabolites of DDT, primarily DDE. (In the remainder of this section, DDT and its metabolites DDE and DDD are grouped together as ΣDDT). Experiments suggest that PCBs and ΣDDT are accumulated by aquatic animals to an extremely similar degree from ambient water (41), and measurements in the same areas indicate that the ratios ΣDDT/PCB are very similar in animals from different levels in the food chain (Tables 6 and 7) (32, 56, 75). Hence the ratio ΣDDT/PCB in environmental samples, even in animals at the top of food chains, can be used to infer the ratio in the substrate, at least to order of magnitude (32, 56). Then the extensive information about the environmental distribution and transport of ΣDDT (2, 17) can be used to make inferences about the distribution and transport of PCBs.

Air

The only numerical measurements available of PCB levels in air are some estimates of levels in total suspended particulates (TSP) in four U.S. cities between 1968 and 1970 (E.P.A., unpublished data). The mean level of PCBs was about 50 ppm, with levels in one city substantially higher. This is at least consistent with our earlier estimate based on rates of transport in the environment.

Risebrough et al. (60) were unable to detect PCBs in a sample of marine air off the California coast. This suggests that long-range (inter-continental) transport of PCBs in air may be negligible.

Land

We have estimated the cumulative net input into terrestrial North America as of the order of 1.5×10^4 tons. For comparison, the total quantity of ΣDDT remaining in terrestrial North America is of the order of 3×10^5 tons, as estimated by two methods: total application minus estimated total losses to the sea (1); mean levels of 2–3 ppm in a wide variety of treated soils, and lesser amounts in untreated soils (2, 17, 61). Hence the continental mean ΣDDT/PCB ratio should be of the order of 20. However, PCBs are expected to be distributed primarily around urban areas and downwind from them, whereas ΣDDT is still concentrated in the agricultural and forested areas where it was applied (61).

A nation-wide monitoring scheme using starlings (*Sturnus vulgaris*) and woodcocks (*Philohela minor*) is in progress. Early results show mean PCB levels in pooled samples of fat from woodcock wings from eastern states in the range 4–7 ppm (62). ΣDDT levels from these pools are not yet available, but fat from woodcocks in Canada contains 6–130 ppm, depending on the local history of application (29). Woodcocks feed on earthworms and should be a good indicator for soil concentrations.

Other data from terrestrial birds may be biased towards low ΣDDT/PCB ratios, because the birds were obtained in industrialized regions. The median ΣDDT/PCB ratio in a small sample of terrestrial birds from California was 4 (32). Terrestrial birds of prey in five European countries have very high levels of PCBs, with ΣDDT/PCB ratios in the range 0.3–5 (63–67).

In human food, market basket surveys in the United States suggest a ΣDDT/PCB ratio of about 4 (68). Ratios in human milk (69, 70) and human blood plasma (71) are in the same range. However, except for sporadic instances of contamination, most of the human intake of PCBs appears to be in fish (68), whereas ΣDDT is much more widely distributed in the diet (72). If the fish and shellfish portions of the diet are excluded, the ΣDDT/PCB ratio would probably be greater than 10. Similar data have been reported from Sweden, where the ΣDDT/PCB ratio in total diet samples and in human milk is about 7 (73).

Fresh Waters

Measurements of PCB levels in water are available only for relatively polluted rivers and bays and are summarized in note (50). Table 8 summarizes PCB levels and ΣDDT/PCB ratios in freshwater fish and birds. PCB levels are both absolutely and relatively high in industrial rivers and in the Great Lakes; within the Great Lakes there is a gradient in ΣDDT/PCB ratios from west to east. Levels of PCBs are lower in the three samples from lakes in less industrialized areas listed at the bottom of Table 8. These data are consistent with our conclusion that most PCBs in fresh water systems result from local discharges by industries, but that there is also widespread aerial fallout of small quantities.

Based on our assumptions of mean concentrations in fresh waters (50), we estimate that the water of the Great Lakes contains a quantity of PCBs of the order of 100 tons; the total quantity

Table 8. PCB Levels and ΣDDT/PCB ratios in North American Fresh Water Vertebrates.

Area	Mean PCB level in fish (ppm)	ΣDDT/PCB ratio in fish and/or fish-eating birds	Reference
U.S.: industrialized rivers	1–213	0.005–0.35	55
Lake Ontario	19	0.08–0.2	55, 74
Lake Michigan	20	0.4–1	55
Lake Huron (Georgian Bay)	—	0.8	75
Lake Superior	—	2.4	75
Ontario:			
Lake Nipigon	0.1	1–4	75
U.S. & Canada:			
Prairie Lakes	<0.1	2	76
N. Quebec:			
Lake Minto	0.1	1	33

in other lakes would be negligible. The quantity carried in river water would be only of the order of 3 tons. It is difficult to estimate the total quantity in the biota, but since the Great Lakes' fisheries probably remove less than a ton of PCBs per year (30), the total quantity in fish is probably only of the order of 10 tons. These quantities are negligible in comparison to the estimated cumulative input of 2×10^4 tons after allowing for degradation. Hence we conclude that almost all the PCBs that have been released into fresh waters are adsorbed onto bottom sediments. There are no data to indicate the rate at which they are being released into water and into the biota or being biodegraded.

It is expected that PCB levels in ground water will be negligible, since any PCBs in water percolating through the soil should be adsorbed onto soil particles (77).

The Sea

According to our estimates, the total input of PCBs into the seas around North America has been of the order of 1.5×10^4 tons, mostly into the Atlantic Ocean, in part by localized discharge and in part by aerial fallout. For comparison, the total input of ΣDDT into the oceans has been estimated as of the order of 5×10^5 tons (1), of which a disproportionate quantity, probably more than 10^5 tons, would have fallen into the North Atlantic Ocean, because of the heavy use of DDT in North America (17). Thus, on these arguments, the total quantity of ΣDDT in the oceans would exceed that of PCBs by several times, especially in the eastern North Pacific. However, ΣDDT has been introduced over large areas (1, 2), so that it should be more uniformly distributed than the PCBs, the discharges of which are localized near industrialized coasts.

Available measurements of PCB levels and ΣDDT/PCB ratios, summarized in Table 9, are generally consistent with these predictions, although the pattern is less clear than that in Table 8, in part because of the wide variability between species (cf. Tables 6 and 7). The highest PCB levels and the lowest ΣDDT/PCB ratios have generally been in areas close to industrial activity. At least in the Pacific, PCB levels decrease and ΣDDT/PCB ratios increase with increasing distance offshore. Data on marine birds summarized by Keith and Gruchy (29) show that these offshore gradients exist in both the Atlantic and Pacific, and show further that PCB levels in the Atlantic seabirds are 5–10 times higher than those in the same or ecologically equivalent species in the Pacific. The correlation of high PCB levels with industrial activity has been demonstrated most clearly in Europe, where it has been observed along the coasts of Sweden (65, 81), the Netherlands (38) and Great Britain (82).

The only major discrepancy from this general picture is the observation (57) of extremely low ΣDDT/PCB ratios (of the order of 0.01) in zooplankton over a wide area in the North Atlantic Ocean. ΣDDT/PCB ratios in fish in the same area were of the order of 0.2 to 0.5. It is almost inconceivable that aerial fallout of PCBs could have exceeded that of ΣDDT by such large factors over such a large area; hence to explain the discrepancy, it is necessary to assume either selective removal of ΣDDT or a local source of PCBs. A likely local source is dumping or leakage from ships. PCBs introduced into the ocean in this way would frequently be mixed with oil, would tend to mix with surface slicks (83), and hence would be peculiarly subject to uptake by plankton. Further study is necessary to confirm this suggested explanation or otherwise explain the anomalous low ΣDDT/PCB ratio in the Atlantic Ocean.

Table 9. PCB Levels and ΣDDT/PCB ratios in Marine Vertebrates.

Area	Mean PCB level in fish (ppm)	ΣDDT/PCB ratio in fish, fish-eating birds and/or mammals	Reference
Long Island Sound	1.2	0.08–0.18	78
Bay of Fundy	0.5	0.4	29, 79, 80
Atlantic Ocean	0.1	0.2–0.5	57
Puget Sound	0.16	1.1	56
San Francisco Bay	0.1–1.2	1–3	32, 56
Californian Coast	0.02–1	5	32, 56
Gulf of California	—	10	32
Gulf of Panama	—	1–2	32
Pacific Ocean (Galapagos & Hawaii)	0.03	>10	56

Assuming the standing crop of fish in the eastern North Pacific to be of the order of 10^8 tons, and that in the western North Atlantic to be of the order of 5×10^7 tons (derived from 59), we may estimate the corresponding loads of PCBs to be of the order of 10 and 15 tons respectively. Assuming the standing crop of plankton to be five times larger than that of the fish (1, 2), the corresponding load of PCBs might be of the order of 100 tons. In the case of ΣDDT, it has been estimated that the total load in marine plants may be several times larger than that in marine animals (2); this may be true for PCBs also, but we know of no measurements to support it. In any case it seems unlikely that more than a few $\times 10^2$ tons of PCBs are stored in the marine biota of the area considered, a very small fraction of the total quantity introduced. This fraction may be significantly greater than the corresponding fraction for ΣDDT (1), because of the extraordinarily high levels of PCBs in the zooplankton.

We know of no measurements of PCB levels in sea water. However, as in the case of fresh water, it seems likely that most of the PCBs would be attached to sediments or to floating particles. Observations on sediments (6, 26) are in accord with this.

As for ΣDDT, the deep oceans represent an ultimate sink for PCB residues. There is no information from which to estimate the rate of transfer of either to the deep oceans.

Summary and Conclusions

According to the estimates made in this paper, the PCBs released into the North American environment in the past are now concentrated in three major compartments in the environment: (a) buried in landfill dumps (roughly 3×10^5 tons, without allowing for degradation); (b) attached to sediments in rivers and the Great Lakes (roughly 2×10^4 tons); (c) attached to sediments on the continental shelf (roughly 10^4 tons). A further substantial quantity (of the order of 2×10^4 tons) has been widely distributed over the land and sea by aerial fallout and by disposal from ships. All the numerical estimates are expected to be valid to order of magnitude only.

Transfer of PCBs within the environment is expected to take place by the following main routes: (a) volatilization, aerial transport on particulates, and fallout; (b) leaching from dumps; (c) sediment transport in rivers and in the shallow sea; (d) sedimentation in the ocean. Uptake and transport by the biota is probably a quantitatively unimportant route of transfer of PCBs but is of major biological significance. Virtually no evidence is available on the rate of transport by any of these routes, but it is expected that all are very slow. In particular, PCBs in sediments in rivers and lakes are likely to move downstream and augment those in the shallow sea for a long period into the future.

As a result of Monsanto's restrictions on distribution, several inputs into the environment are likely to have been sharply reduced. As existing products containing PCBs are scrapped, the remaining inputs into the North American environment are expected to decline gradually over a period of the order of ten years.

As in the case of DDT and its metabolites, the total quantities of PCBs accumulated by the biota are an extremely small fraction (less than one percent) of those in the environment. This raises the possibility that the dissemination of relatively small fractions of the PCB production into sensitive areas may be primarily responsible for locally high levels of contamination of the biota. Evaluation of the long-term effects of the accumulation of PCBs and of the change in use patterns and production will require the development of environmental transport models more sophisticated than those currently in use, together with the requisite data.

The following aspects of environmental transport of PCBs should have high priority for future research:

1. *Properties and Rates*. Data are needed on the solubilities and vapor pressures of individual isomers; on the partition coefficients between water and sediments, water and fats; on the rate of photochemical decomposition and aerobic and anaerobic biodegradation; diffusion coefficients in sediment.
2. *Routes*. The magnitude of leaching from dumps and aerial transport of PCBs must be established by direct measurements of concentrations in ground waters, airborne

particulates, and rainfall. Data are needed on the magnitude of industrial losses in the past.

3. *Transport Models.* Data are needed on the transport of PCBs in contaminated sediments in rivers and shallow seas, including the dynamics of uptake from shallow sediment and losses to the ocean floor.
4. *Levels.* Additional data, including quantitative evaluation of the fractionation of isomers, are needed for fresh waters, soils, terrestrial plants and animals.
5. *Bioaccumulation model.* Inasmuch as the period since the first commercial application of PCBs is less than the lifetime of a number of species, including man, and the use and discharge pattern has been variable, there is a need to project the long-range impact of the PCBs on the different elements of the ecosystem.

Emphasis should be on coordinated approaches to sampling and modelling rather than a statistical accumulation of data.

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13. Approximately 190×10^6 tons of municipal waste and an equivalent amount of industrial solid waste are disposed of annually in the U.S.A., mostly in dumps. Some 4.7×10^6 tons of industrial solid waste are dumped at sea (27). Of the remainder, 18×10^6 tons are burned in municipal incinerators, 14×10^6 tons in commercial incinerators, and 14×10^6 tons in open-burning dumps (14). Emission of PCBs from these sources may be gauged indirectly from measurements of the emission of combustible matter and polynuclear aromatics. From measurements reported by A. D.

Little (15) and Hein and Engdahl (16) it is estimated that 0.25 percent of solid waste is emitted by municipal incinerators and up to 20 percent by open burning. If it is assumed that the fraction of PCBs in the organic matter evolved from these sources is equal to the fraction of PCBs in the solid waste, the rate of emission of PCBs will be of the order of two tons per year from municipal incinerators and 200 tons/year from open burning dumps. Commercial incinerators and burning of automobile components each contribute a total quantity of polynuclear aromatic compounds (a rough gauge of incomplete burning) similar to that emitted by open burning (14). The estimate of 200 tons/year of PCBs from the burning of commercial waste and auto components is based on the relative magnitude of combustible pollutants from these different sources, weighted by the estimate of the fraction of total PCB production disposed of in open dumps. These estimates are highly speculative but are considered sufficient to discount the burning of wastes as the major source of PCB emissions.

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3

EPA-305-X-04-002

Polychlorinated Biphenyl Inspection Manual

August 2004

Office of Compliance
Office of Enforcement and Compliance Assurance
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW (MC 2224-A)
Washington, D.C. 20460

http://www.epa.gov/compliance/resources/publications/monitoring/manuals.html

1.0 PCBs: Facts

1.1 Background

Polychlorinated biphenyls (PCBs) are synthetic organic chemical compounds (aromatic hydrocarbons) produced by substituting chlorine atoms for the hydrogen atoms on a biphenyl molecule. PCBs have ideal properties for industrial applications. They are one of the most stable synthetic compounds known, are inflammable, are resistant to breakdown, and exhibit low electrical conductivity. PCBs can also extend the temperature range of operating fluid and can provide long-lasting heat at a consistent temperature. Accordingly, the majority of PCBs manufactured in the U.S. were used in electrical equipment because their properties made them ideal dielectric and heat transfer fluids. PCBs were used widely in transformers, transformer bushings, capacitors, voltage regulators, hydraulic systems, small PCB capacitors in fluorescent light ballasts, and heat transfer systems. In addition, PCBs were sometimes used in electrical cable, switches, breakers, vacuum pumps, gas turbines, natural gas pipelines, carbonless copy paper, paints, adhesives, caulking compounds, and investment casting wax.

Extensive research has shown a link between PCBs and various human health effects (acute and chronic), including the formation of malignant and benign tumors, fetal deaths, reproductive abnormalities, mutations, liver damage, and skin irritation (chloracne). In addition, experiments have shown that PCBs attack the immunological system and affect the production of enzymes.

PCBs are pervasive throughout the environment. Measurable amounts of PCBs have been found in soils, water, fish, milk of nursing mothers, and human tissue. In addition to being a known hazard to humans, PCBs also present a serious threat to the environment. PCBs have an affinity to be adsorbed onto organic matter and sediments and have been found in significant concentrations in waterways and sediments throughout the world. They are widely spread contaminants of fish and wildlife resources because of their pronounced tendency to bioconcentrate in the tissues or lipids of living organisms. PCBs are highly toxic to aquatic organisms in relatively low concentrations. The following is a list of potential PCB contamination scenarios.

- Spills
  - Maintenance operations
  - Decontamination operations
  - Transport operations
  - Draining, refilling operations
  - Contamination of waste oil
  - Drainage systems, storm water systems, discharge points, sumps, and areas adjacent to surface waters
  - Disconnection/disassembly of railroad transformers
  - Lack of spill containment provisions in work pits/servicing areas

  - Poor housekeeping practices.
  - Improper storage.

- Leaks
  - Normal wear of equipment in service (e.g., valves, gaskets, and fittings)
  - Malfunctioning equipment
  - Dismantling/reassembly of equipment
  - Damaged equipment
  - Cracked or damaged transformer bushings
  - Containers used for storage and transport
  - Equipment stored for disposal or reuse.

- Improper storage of PCB-containing and/or PCB-contaminated equipment.

- Illegal importation of PCBs.

- Inadvertent manufacture of PCBs during chemical processing.

- Low Level of Worker Knowledge of Hazards
  - Spread of contamination through insufficient protective clothing and equipment
  - Improper handling techniques
  - Improper disposal of defective PCB-containing and/or PCB-contaminated equipment.

- Other
  - Contaminated waste liquids
  - Contaminated rags, filter media, and debris gathered during cleanup operations
  - Contaminated parts
  - Contaminated soil
  - PCBs discarded prior to TSCA regulations
  - Fires.

The number and location of the chlorine atoms attached to the biphenyl ring determine the physical properties and characteristics of the PCB congener. Generally, commercial PCBs tend to be viscous and heavy (11 to 13 pounds per gallon), but also may be solid and waxy. In the United States, the only large producer of PCBs was Monsanto Chemical Company, which manufactured them from 1929 to 1975 under the name Aroclor™. Monsanto Chemical Company assigned a four-digit number to each Aroclor PCB product. The last two numbers indicate the approximate percentage by weight of chlorine (for example, Aroclor 1260 is approximately 60 percent chlorine by weight).

Chapter Four

Equipment-Specific Information

Tables

4.0 Equipment-Specific Information

An inspector may encounter several types of PCB-containing equipment during a PCB inspection. This equipment consists chiefly of five major categories: transformers, capacitors, other electrical equipment, hydraulic systems, miscellaneous (e.g., fluorescent light ballasts, heat transfer systems), and other equipment. This chapter provides the inspector with general information on these major categories of regulated PCB equipment for which EPA authorizes certain activities (e.g., servicing and/or use), in accordance with Section 6(e) of TSCA.

For each type of PCB equipment discussed, this chapter provides information on the typical economic sectors using the equipment and a list of manufacturers and trade names. This chapter also includes information on inspections relating to specific equipment and the risk of contamination from exposure to such equipment.

The sections below summarize those regulations pertaining only to activities authorized for the specific equipment. Section 761.30, "Authorizations" describes these authorization provisions. General regulatory requirements (e.g., provisions concerning disposal and storage, marking, and recordkeeping) also apply to authorized uses of such equipment. Inspectors should refer to Chapters Three and Four as well as the regulations when preparing to conduct inspections.

Each section in this chapter contains a list of manufacturers and trade names used for PCBs or materials containing PCBs. Appendix E contains a comprehensive listing of PCB manufacturers and the trade names they used for PCB materials.

4.1 Transformers [§761.30(a) and (b)]

4.1.1 Background

Transformers increase or decrease the voltage level of an electric current. Electrical transformers are often filled with a dielectric liquid that increases the resistance of the unit to arcing and acts as a heat transfer medium, helping to cool the coils. Today, most transformers are filled with mineral oil or silicone.

PCBs are chlorinated fire-resistant fluids that meet the definition established in the National Electrical Code (NEC) for askarel, the generic name for non-flammable synthetic chlorinated hydro-carbons used for insulating media. Askarel transformers, containing 40 to 60

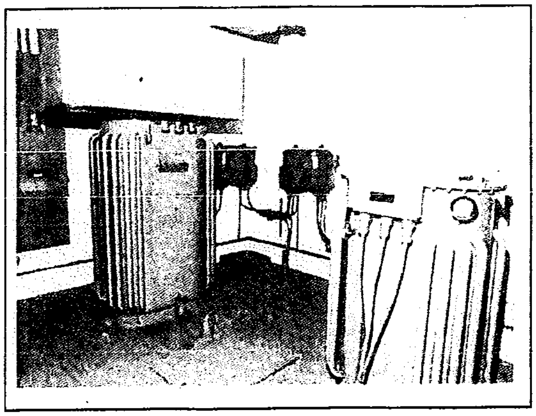


Figure 4-1. Two PCB Transformers.

percent PCBs, with the remainder of the fluid being chlorobenzenes, were manufactured in the United States from 1929 to 1978. Askarel transformers were made in a variety of sizes, containing from three to 3,000 gallons (average 235 gallons) of liquid. They were generally used in locations where flammability was a concern. Many mineral oil transformers may have been contaminated with PCBs through servicing or at the time of manufacturing. Figure 4-2 shows an oil filled transformer and a non-oil filled transformer.

The regulations define *PCB* and *PCBs* as any chemical substance that is limited to the biphenyl molecule that has been chlorinated to varying degrees or any combination of substances which contains such substances. The regulations define a *PCB Transformer* as any transformer containing 500 ppm PCBs or greater. *PCB-Contaminated Transformers* contain PCBs at concentrations greater than or equal to 50 ppm and less than 500 ppm. The inspector should be aware that the PCB concentration of transformer bushings may differ from the transformer.

The inspector should note that regulations pertaining to railroad transformers are separate from those relating to other transformers. Therefore, the information pertaining to railroad transformer regulations, as well as to maintenance, repair, and inspection of railroad transformers, is presented separately, later in this chapter.

4.1.2 Transformer Locations

As of August 28, 1998, owners/operators of PCB Transformers in use, or in storage for reuse, must register those transformers with EPA. Owners/operators of a transformer who failed to register in 1998 are still required to register. This registration is a one-time requirement. When an owner/operator of a company removes PCB Transformers from service and disposes of them, it need not update its original registration. EPA has developed a database of the registered PCB Transformers (the PCB Transformer Registration Database) which can be accessed at www.epa.gov/pcb/data.html. Based on a simple analysis of the company names in the October 2001 version of this database, the industries listed in the table below registered the most transformers. The inspector should use the information below only as a general guide to which industries commonly have PCB Transformers, as opposed to an exact count of the transformers in use. Some owners of PCB Transformers may not have registered, while others incorrectly registered.

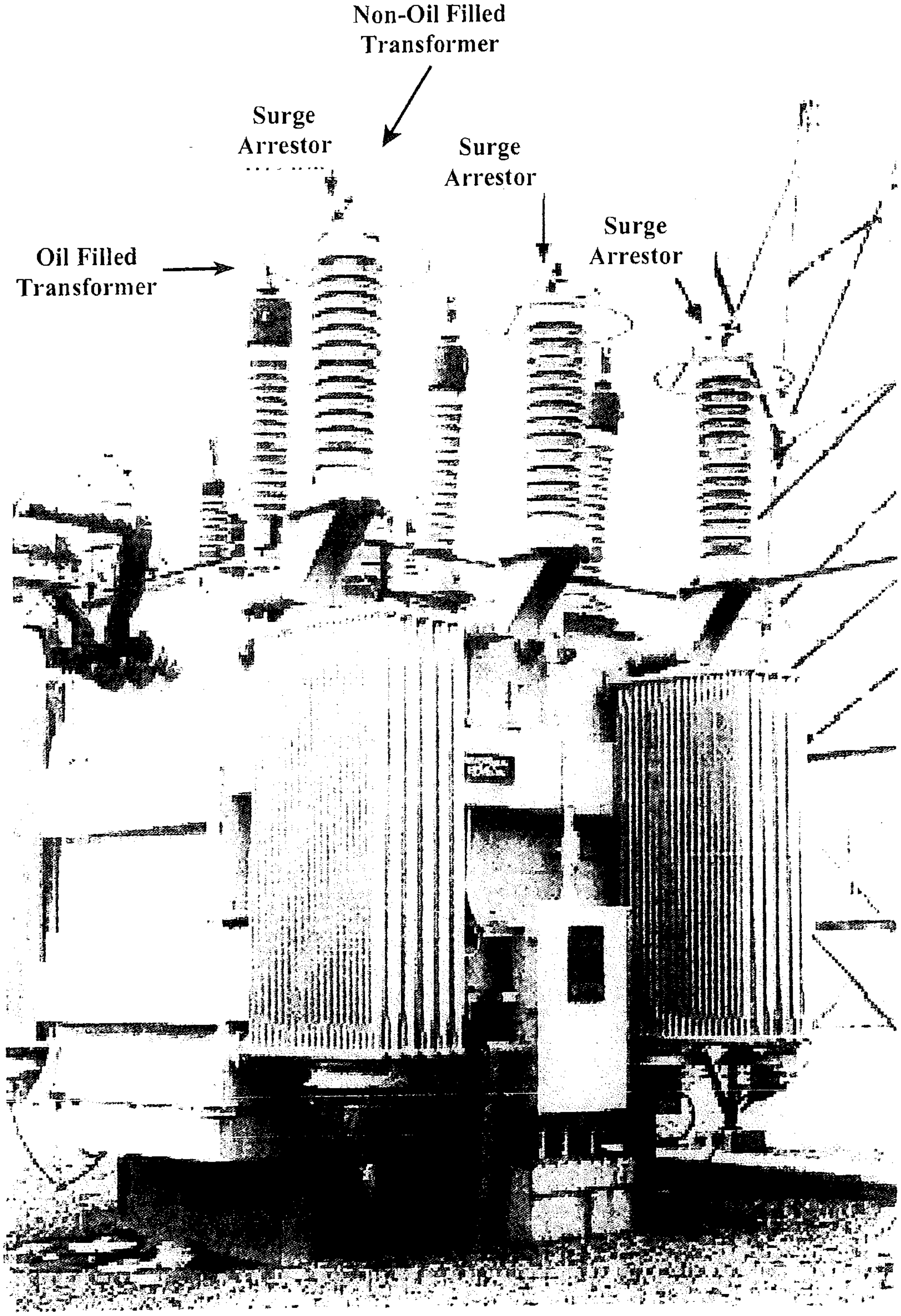


Figure 4-2. Oil filled and non-oil filled transformers.

Table 4-1. Estimate of the Number of Registered Transformers by Industry Sector

Industry Sector	Number of Registered Transformers
Utilities	10,644
Steel	1,968
Federal	1,805
Metal	1,292
Automotive	1,063
Paper and Paper Products	391
Tire and Rubber	344
Mining	340
Education	308
Transportation	287
Textiles	221
Durable Goods	215
Chemicals and Polymers	208
Cement and Concrete	179
Non-Federal Government	164
Fertilizer and Allied Products	150
Glass	135
Pharmaceutical	113
Oil/Gas/Refinery	111
Building Materials	102
Other	1,814
Grand Total	21,854

PCB Transformers are in use in a wide variety of locations, often including:

<u>Utilities</u>

- PCB Transformers can be found in:
  - Distribution substations
  - Generating facilities (including coal, gas, and nuclear facilities).

Mines

- Transformers are usually located within the power substation that supplies electricity to the entire mine. (See Appendix F for more information regarding the use and distribution of PCBs in underground mines and training and safety issues for inspectors visiting mines.)

Industrial and Other Sectors

- Industries with high-power requirements or equipment are likely to have PCB Transformers. Likely locations of PCB Transformers include:
  - In electrical substations
  - Inside, around, or on top of buildings
  - In powerhouses that generate and distribute electrical power throughout the facility
  - In underground vaults.

- Transformers can also be found in the broadcasting industry.

Commercial Buildings

- PCB Transformers often are used inside commercial buildings to meet fire code restrictions or to reduce fire insurance premiums. Most commercial building owners contract the servicing of their transformers to transformer maintenance and repair companies. However, commercial building owners may not own PCB Transformers. The electric utility providing service to the building often owns such units. The inspector should determine who owns and is responsible for the unit.

- Neon signs may also contain PCB Transformers and may be found on old or abandoned commercial buildings or in scrap yards.

Railroads and Subways

- Railroad companies used PCBs in on-board transformers in electric locomotives and self-propelled cars in service in the Northeast Corridor (Washington to Boston). The transformers reduce the high voltage current from overhead lines. Subway systems used PCB Transformers to distribute power to subway cars. Transformers are generally underground.

4.1.3 Maintenance and Repair of PCB Transformers

PCB Transformers (both railroad and others) require periodic maintenance and repair, which may be handled by facility staff or by independent contractors.

- Independent firms may contract to maintain and repair transformers for all types and sizes of industries, including small firms (e.g., commercial buildings).

- Maintenance divisions of larger industries may operate facilities to maintain and repair transformers. These divisions occasionally service transformers for other firms.

Maintenance operations take place both onsite (at the operating location of the equipment) and offsite (at a special shop or facility operated by the firm or by the contractor).

- Onsite maintenance and repair may involve considerable handling of PCBs, including:
  - Transport of items such as waste liquids and contaminated rags to storage or disposal.
- Offsite maintenance may occur in specific facilities used only for transformer maintenance or in shops that handle other maintenance as well. The handling includes:
  - Removal of the transformer from the operating site
  - Transport of damaged or leaking equipment
  - Transport of waste to storage or disposal site
  - Reinstallation of repaired equipment.

PCB Transformer Maintenance

PCB Transformers (excluding railroad transformers, which are discussed below) require service periodically and repair when out-of-order. Maintenance includes:

- Sampling fluid to test dielectric strength
- Topping off fluid (historically a source of PCB contamination)
- Replacing gaskets, bushings, insulators, etc., which may involve partial draining of the unit
- Removing and filtering the dielectric liquid and refilling the unit
- Removing PCB liquid and refilling with replacement dielectric fluid
- Generating waste liquid, contaminated rags, equipment, etc., which must be disposed of in accordance with the regulations.

Railroad Transformer Maintenance

Railroad transformers require additional and more frequent maintenance because of their unique installation and operating circumstances:

- On-board transformers are subject to severe conditions (high loads, cramped space) and require a high level of maintenance.
- Pumps circulate oil containing PCBs through the transformers, where the oil absorbs heat, to a series of finned radiators which dissipate the heat.
- Transformers and the cooling apparatus located in the undercarriage are subject to damage from objects dislodged from the roadbed. Inspectors should be aware that leaks can cause exterior surfaces to become contaminated.

Maintenance frequently takes place in repair pits, which can become severely contaminated with PCBs. Operations are similar to those listed for other PCB Transformers, but include additional activities, such as:

- Repairing/replacing circulating pumps and damaged, leaking cooling systems and radiators
- Dismantling/disconnecting cooling systems filled with PCB fluids
- Decontaminating the system and equipment surfaces.

4.1.4 Manufacturers and Trade Names

Many manufacturers of PCB askarel liquid identified the substance by a trade name. PCBs have been used since 1929, and many of the early manufacturers have gone out-of-business.

Table 4-2. Transformer Manufacturers and PCB Fluid Trade Names

Transformer Manufacturer	PCB Fluid Trade Name
Allis-Chalmers	Chlorextol
American Corporation	Asbestol
Cornell Dubilier	Dykanol
Electro Engineering Works	
Envirotech Buell	
ESCO Manufacturing Company	Askarel*
Ferranti-Packard Limited	Askarel*
General Electric	Pyranol
H.K. Porter	
Helena Corporation	
Hevi-Duty Electric	Askarel*
ITE Circuit Breaker Company	Non-flammable Liquid
Kuhlman Electric	Saf-T-Khul
Maloney Electric	
Mitsubishi	Kennechlor, Santotherm
Monsanto (fluid only)	Aroclor
Niagara Transformer Corporation	Askarel*, EEC-18
Power Zone Transformer	EEC-18
Research-Cottrell	Askarel*
Standard Transformer Corporation	
Uptegraff Manufacturing Company	
Van Tran Electric	
Wagner Electric	No-Flamol
Westinghouse	Inerteen
--------------------------	Nepolin

* Generic name for non-flammable insulating liquids.

Note: There may be other manufacturers and PCB fluid trade names that are not listed.

4.2 Capacitors [§761.30(l)]

4.2.1 Background

Capacitors regulate the flow of electric current. PCBs were the dielectric fluid used in approximately 95 percent of U.S.-produced, liquid-impregnated capacitors manufactured prior to 1978. The regulations require that all capacitors be disposed of as a PCB Capacitor except when a specific capacitor is known not to contain PCBs based on a label or nameplate, manufacturers' literature, or chemical analysis. To assist in this determination, EPA regulations required all non-PCB, large low voltage capacitors, small capacitors, and fluorescent light ballasts manufactured between July 1, 1978, and July 1, 1998, must bear a "No PCBs" label [§761.40(g)].

There are two general types of capacitors containing PCBs: (1) capacitors built into electrical equipment, such as fluorescent lights, televisions, and small motors, which are smaller in size; and (2) capacitors used as separate units in electrical power distribution systems, which are larger in size (see Figure 4-3).

The PCB regulatory program under TSCA defines three types of PCB Capacitors in 40 CFR 761.3:

- A small capacitor contains less than 1.36 kg (3 pounds) of dielectric fluid.
- A large high voltage capacitor contains 1.36 kg (3 pounds) or more of dielectric fluid and operates at 2,000 volts (AC or DC) or above.
- A large low voltage capacitor contains 1.36 kg (3 pounds) or more of dielectric fluid and operates below 2,000 volts AC or DC.

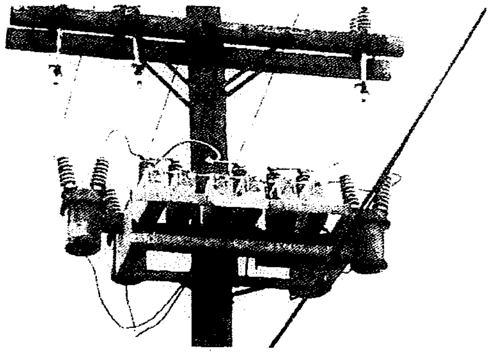


Figure 4-3. Six large high voltage capacitors.

4.2.2 Locations

The following is a list of likely locations, by economic sector, of capacitors. Within these sectors, the capacitors may be located almost anywhere.

Electric Utilities

- Capacitors are usually located in distribution substations.

Manufacturing

- Capacitors are:
  - Located in banks or individually.
  - Located in underground pump stations.
  - Used for power factor correction on motor control circuits and as part of the circuitry of electric induction furnaces.
  - Used for power correction or startups of large motors as used commonly with water pumps for large air conditioning systems or lift stations.
  - Used for startup of any large motor associated with manufacturing (e.g., drills, saws).

Subway Systems

- Large capacitors are used:
  - In conjunction with underground transformers.
  - On subway cars.

Mines

- Capacitors are:
  - Usually located within the power substation that supplies electricity to the entire mine
  - Located underground in skid-mounted or wheel-mounted power centers or individually
  - Often installed in control boxes for large electrical motors.

4.2.3 Maintenance and Repair

Facilities replace rather than repair non-functioning capacitors. Short-circuiting units can rupture and leak.

4.2.4 Manufacturers and Trade Names

Several companies manufactured PCB Capacitors in the United States from 1929 until 1978. Many of the manufacturers identified the PCB dielectric liquid by trade name. The following list of manufacturers and trade names is not necessarily complete and, therefore, should be used only as a guide.

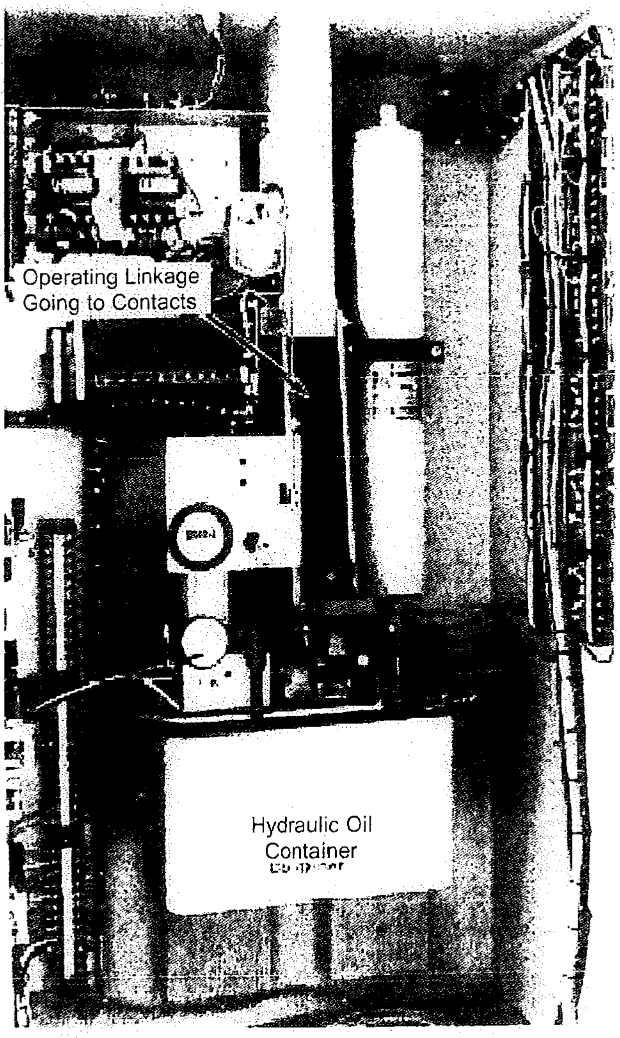
Table 4-3. Capacitor Manufacturers and PCB Fluid Trade Names

Capacitor Manufacturer	PCB Fluid Trade Name
Aerovox	Hyvol
Axel Electronics	
Capacitor Specialists	
Cornell Dubilier	Dykanol
Electrical Utilities Corporation	Eucarel
Electromagnetic Filter Company	
Federal Pacific	Non-flammable liquid
General Electric	Pyranol
Jard Corporation	Clorphen
McGraw Edison	Elemex
Monsanto (fluid only)	Aroclor, Capacitor 21, MCS 1489
P.R. Mallory & Company	Arclor B
R.F. Interonics	
Sangamo Electric Company	Diaclor
Sprague Electric Company	Clorinol
Tobe Deutschmann Labs	
Universal Manufacturing Corporation	Askarel*
Westinghouse	Inerteen
York Electronics	

* Generic name for non-flammable insulating liquids.

4.3 Other Electrical Equipment [§761.30(h) and (m)]

Other PCB-Contaminated Electrical Equipment includes circuit breakers, reclosers, voltage regulators, switches (including sectionalizers and motor starters), and electromagnets. The inspection guidelines are similar to those for capacitors. Figure 4-4 shows a circuit breaker system and location where PCB-contaminated oil may be found.



4.4 Hydraulic Systems [§761.30(e)]

4.4.1 Background

Hydraulic systems are machines that operate by the force exerted by pressurized and confined liquid. Many steel manufacturing and die casting plants used PCBs in hydraulic systems to reduce fire hazards on machines that handled hot metals. These systems included hydraulic systems for metal dye casting equipment, trim presses, induction hardening machines, heat treating furnaces, forge furnaces, and forge presses. The PCB regulations authorize the use of hydraulic systems containing PCBs below 50 ppm. Owners drained and flushed hydraulic systems in an attempt to reduce PCB contamination. However, systems may still be contaminated with residual PCBs that remained after refilling with non-PCB fluid. Hydraulic systems normally leak several times their capacity each year because the fluid is often pressurized to several thousand pounds per square inch causing the system to leak at connection joints and piston rings.

4.4.2 Manufacturers and Trade Names

The following list of hydraulic fluid trade names may not contain all trade names. PCBs have been used since 1929, and many of the early manufacturers have gone out-of-business.

Table 4-4. Hydraulic Fluid Manufacturers and Trade Names

Manufacturer	Hydraulic Fluid Trade Names	
Monsanto	Pydraul A-200	Pydraul 230
	Pydraul A-200-B	Pydraul 230-A
	Pydraul AC*	Pydraul 280
	Pydraul AC-A*	Pydraul 312
	Pydraul AC-28	Pydraul 312-A
	Pydraul F-9	Pydraul 540
	Pydraul F-9-A	Pydraul 540-A
	Pydraul 135	Pydraul 540-B
	Pydraul 135-A	Pydraul 625
	Pydraul 150	Pydraul 625-A
	Pydraul 150-A	Turbinol 153
	Santovac 1	Santovac 2

* These were reportedly used as lubricating fluids in some natural gas pipelines as well.

4.5 Other PCB Equipment

4.5.1 Fluorescent Light Ballasts

Light ballasts are the primary electric components of fluorescent light fixtures and are generally located within the fixture under a metal cover plate. The PCBs are located in the light ballasts' small capacitor or in the potting material, the insulating material inside the ballast. Since 1978, EPA has required manufacturers of fluorescent light ballasts to mark ballasts that do not contain PCBs with the statement "No PCBs." Inspectors should assume that light ballasts contain PCB small capacitors if they were manufactured before 1978 or do not have a "No PCBs" statement. Table 4-5 indicates the disposal requirements for fluorescent light ballasts. Please note that after July 1, 1998, fluorescent light ballast manufacturers are no longer required to mark fluorescent light ballasts with the statement "No PCBs."

Table 4-5. TSCA Disposal Requirements for Fluorescent Light Ballasts

PCB Capacitor	PCB Potting Material	Labeling, Transportation, and Manifesting for Disposal	Disposal Reference in §761	Disposal Options
"No PCBs" label		Not regulated under TSCA.	N/A	Not regulated under TSCA.
None*	< 50 ppm	Not regulated under TSCA.	N/A	Not regulated under TSCA.
Intact and non-leaking or none*	≥ 50 ppm	-Is a PCB bulk product waste. -No labeling is required. -Manifesting is required for disposal in accordance with §761.62(a); is not required under §761.62(b); may be required under §761.62(c).	.50(b)(2)(ii) .62(a)-(c)	-TSCA incinerator** -TSCA/RCRA landfill Alternate Destruction Method. -Decontamination (§761.65(d) storage may be required). -Coordinated approval. -State-approved landfill (leach test required). -Risk-based approval.
Intact and non-leaking	< 50 ppm	No labeling or manifesting required.	.50(b)(2)(i) .60(b)(2)(ii)	Dispose as municipal solid waste (§761 Subpart D options).
Leaking	< 50 ppm or ≥ 50 ppm	-Disposal as PCB bulk product waste. -No labeling is required. -Manifesting is required for disposal in accordance with §761.62(a); may be required under §761.62(c).	.62(a) or (c)	-TSCA incinerator* -TSCA/RCRA landfill Alternate Destruction Method- -Decontamination (§761.65(d) storage may be required). -Coordinated approval. -Risk-based approval.

* "None" means that the capacitor contains no PCB's or was manufactured after 1978.

** A TSCA incinerator is one approved by the Regional Administrator or by the Director of NPCD to handle TSCA waste.

Source: www.epa.gov/pub/guidance.html (EPA PCB Website)

4.5.2 Heat Transfer Systems [§761.30(d)]

Heat transfer systems use fluids of high heat capacity to remove unwanted heat or to transfer heat from one place to another within a system. They are commonly used to provide heat in chemical manufacturing where temperatures greater than that provided by steam are needed. Heat transfer systems in certain applications used PCBs as a heat transfer fluid. Heat transfer systems that contained PCB fluid were refilled with non-PCB fluid approximately 90 percent of the time. Despite this refilling, most systems contained residual PCBs. Leaks usually occur through pump motor seals.

Inspectors of facilities using PCB heat transfer fluid should ensure that all systems are below the 50 ppm limit by checking records or sampling (if it is safe to sample). Inspectors should also review disposal records such as manifests for PCB-contaminated fluid drained from the systems to determine if the facility properly stored the fluids for disposal or disposed of the fluids by incineration and visually check for PCB contamination and current releases of PCBs on site due to prior spills or disposal of the PCB fluids.

The following is a list of heat transfer fluid manufacturers although it may not contain all trade names. PCBs have been used since 1929, and many of the early manufacturers have gone out-of-business.

Table 4-6. Heat Transfer Fluid Manufacturers and Trade Names

Manufacturer	Heat Transfer Fluid Trade Names	
Geneva Industries	Monsanto FR-1	
Monsanto	Therminol FR-0 Therminol FR-LO Therminol FR-1	Therminol FR-2 Therminol FR-3

4.5.3 Natural Gas Pipelines [§761.30(i)]

A number of gas pipeline companies used PCBs as a working fluid in their compressors between 1950 and the early 1970's. There are several sources of PCBs associated with natural gas transmission pipelines. The use of PCBs in turbine compressors leaked PCBs (Arolcors 1221, 1242 and 1248) into the transmission pipelines and contaminated the existing natural gas pipeline liquids (water and condensate). The condensate fraction consists of heavier hydrocarbons that may be ignitable, BTEX (benzene, toluene, ethyl benzene and xylenes) and naphthalenes. The PCB contamination spread to other interconnected pipeline systems. The improper disposal of PCB contaminated condensate into open pits, via spills and venting caused significant contamination at natural gas companies such as Texas Eastern and Transwestern compressor stations. The historical use of waste oils, contaminated with PCBs, to "fog" or lubricate the old pipelines and use (probably minor) of a Rockwell plug valve sealant/grease containing PCBs (Aroclor 1268) also contaminated existing natural gas pipeline condensate. The use of PCBs (Aroclors 1221, 1242, 1248 and 1254) in reciprocating air compressors and associated blowdowns resulted in onsite surface soil and wastewater drainage system PCB contamination. This use did not result in transmission pipeline PCB contamination. This occurred at Texas Eastern, Tenneco, Columbia Gas, Texas Gas and other companies.

Current regulations (761.30(i)) authorize the use of PCBs in natural gas pipelines at concentrations of less than and greater than 50 ppm PCBs under certain conditions. These (761.30(i)) are the rules that now govern the PCBs that still remain in the various natural gas transmission pipelines. The old PCB/Compliance Monitoring Program (CMP) was terminated when this rule was promulgated in 1998. Additional NGP information and details of the 1981 and 1996 PCB CMP are found in Appendix G of this manual.

4.5.4 Electric Motors

In the late 1960s and early 1970s, Reliance Electric for Joy Manufacturing Company manufactured electric motors that contained PCBs. Liquid-filled motors were used because they were smaller and lighter than air-cooled motors. Manufacturers chose a PCB mixture for the liquid because it was non-flammable, provided adequate lubrication, and possessed the best overall combination of electrical properties, chemical stability, and cost.

Mining machine electric motors used on certain underground continuous loaders built by Joy contain PCBs as a coolant fluid in the large cutting head motors and traction motors. Previous versions of the regulations established a deadline of January 1, 1982, for phasing-out the use of these motors. The current regulations [§761.30(c)] allow the use of PCB-containing mining equipment only under 50 ppm.

Submersible well pump motors manufactured before 1979 may contain up to five ounces of PCB dielectric fluid in their capacitors. PCBs may leak out of these submersible well pump motors during normal wear-and-tear or when the pump suddenly fails due to lightening strikes or electrical failures or shorts. Appendix H contains the manufacturer's models and serial numbers of some of the submersible pump units that contain PCBs.

4.5.5 Electromagnets [§761.30(h)]

Regulations prohibit servicing, including rebuilding, of PCB electromagnets with a PCB concentration of 500 ppm or greater that requires the removal of internal components.

4.5.6 Products Containing PCBs

Other products that may contain PCBs include:

- Investment casting wax
- Carbonless copy paper
- Resins
- General sealants and coatings, including windshield sealant and silo sealant
- Lubricants, including bridge bearings and additives to transmission fluids
- Paint, including marine paint
- Electrical cable insulation
- Gaskets
- Roofing materials.

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An Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States for the Years 1987, 1995, and 2000

National Center for Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Washington, DC 20460

10. SOURCES OF DIOXIN-LIKE POLYCHLORINATED BIPHENYLS (PCBs)

The purpose of this chapter is twofold: (1) to identify sources that release dioxin-like PCB congeners into the environment and (2) to derive national estimates for releases from these sources in the United States. PCBs have been found in all media and in all parts of the world. PCBs were manufactured in relatively large quantities for use in commercial products such as dielectrics, hydraulic fluids, plastics, coatings and paints, and although PCBs are no longer commercially produced in the United States, they continue to be released to the environment through the use and disposal of these products. PCBs may also be inadvertently produced as by-products during the manufacture of certain organic chemicals and also as products of the incomplete combustion of some waste materials.

10.1. GENERAL FINDINGS OF THE EMISSIONS INVENTORY

Table 10-1 provides a compilation of known or suspected dioxin-like PCB-emitting source categories in the United States for which emission measurements of dioxin-like PCB congeners, Aroclors, or PCB congener groups have been reported in government, industry, and trade association reports; conference proceedings and journal articles; and comments submitted to EPA on previous versions of this document. The intent of Table 10-1 is to clearly identify those source categories and media (air, water, land, and products) for which the available data are adequate for reliably quantifying emissions of dioxin-like PCBs and those for which the data are inadequate.

Nationwide emission estimates for the United States inventory are presented in Table 10-2 (emissions to air, water, land, and product) for those source categories for which estimates can be reliably quantified (the category has been assigned a confidence rating of A, B, or C) (see Section 1.2.3 for details on confidence ratings). Table 10-2 also lists preliminary estimates of the potential magnitude of emissions from "unquantified" sources (i.e., sources assigned a confidence rating of D) in reference year 2000. Because of large uncertainties for these Category D estimates, they are not included in the quantitative inventory.

Currently, no significant releases of newly formed dioxin-like PCBs are occurring in the United States. Unlike CDDs/CDFs, PCBs were intentionally manufactured in the United States in large quantities from 1929 until production was banned in 1977. Releases to the environment of "old" dioxin-like PCBs (dioxin-like PCBs manufactured prior to the production ban) can occur from ongoing use and disposal practices. Prior to regulations enacted beginning in the late 1970s that limited the manufacture/use/disposal of PCBs, significant quantities were released to the environment in association with (a) the manufacture of PCBs, (b) the manufacture of products containing PCBs, and (c) the use and disposal of products containing PCBs as well as

Table 10-1. Confidence rating classes for 2000 for releases from all known and suspected source categories of dioxin-like PCBs[a]

Source category	Air	Land	Water
Approved PCB disposal	E		
Accidental PCB releasees	E	E	E
Municipal wastewater treatment sludge		A	
Municipal waste combustion	E		
Industrial wood combustion	E		
Medical waste incineration	E		
Tire combustion	E		
Cigarette combustion	D		
Sewage sludge incineration	C		
Backyard barrel burning	E		
Petroleum refining catalyst regeneration	E		

[a] Blank cells mean not applicable or no data.

A= Characterization of the source category judged to be adequate for quantitative estimation with high confidence in the emission factor and high confidence in the activity level.
C= Characterization of the source category judged to be adequate for quantitative estimation with low confidence in the emission factor and/or the activity level.
D= These are preliminary indications of the potential magnitude of emissions from "unquantified" sources in Reference Year 1995. These estimates were assigned a "confidence category" rating of D and are not included in the Inventory.
E= Not quantifiable.

materials that may have been contaminated with trace levels of PCBs from prior PCB use or disposal. Following the ban on PCB production, releases from these first two categories ceased. The third type of releases, those associated with product use and disposal, will continue in at least four ways:

1. Disposal of products containing greater than 2 lb of PCBs (e.g., dielectric fluids in transformers and large capacitors), which is controlled by disposal regulations that have minimized environmental releases;

2. Disposal of products containing small quantities of PCBs (e.g., small capacitors, fluorescent lighting fixtures) or trace quantities of PCBs (e.g., wastepapers), which is subject to disposal as municipal solid waste but which may result in some release to the general environment;

Table 10-2. Inventory of contemporary releases of dioxin-like PCBs in the United States for 1987, 1995, and 2000 and preliminary release estimates of dioxin-like PCBs for 2000 (g TEQ_p-WHO_{98}/yr)

Emissions source category	2000 Inventory			1995 Inventory			1987 Inventory			Preliminary estimate for 2000
	A	B	C	A	B	C	A	B	C	D
Releases to air										
Combustion sources										
Cigarettes										0.01
Sewage sludge incineration			0.7			1.1			0.4	
Total quantified releases to air			0.7			1.1			0.4	0.01
Releases to land										
Municipal sludge (land application and farming)	18.8				77.4			51.1		
Total quantified releases to land	18.8				77.4			51.1		
Releases to products										
Municipal sludge as soil ammendment	0.5				2.0			1.7		
Total quantified releases to products	0.5				2.0			1.7		

A= Characterization of the source category judged to be adequate for quantitative estimation with high confidence in the emission factor and high confidence in the activity level.

C= Characterization of the source category judged to be adequate for quantitative estimation with low confidence in the emission factor and/or the activity level.

D= These are preliminary indications of the potential magnitude of emissions from "unquantified" sources in Reference Year 1995. These estimates were assigned a "confidence category" rating of D and are not included in the Inventory.

E= Not quantifiable.

3. Leaks and spills of still-in-service PCBs; and
4. Illegal disposal of PCBs.

Although it has been demonstrated that small quantities of dioxin-like PCBs can be emitted into the air during waste combustion, no strong evidence exists that they are emitted in significant quantities as by-products during combustion. The widespread occurrence of dioxin-like PCBs in the U.S. environment most likely reflects past releases associated with PCB production, use, and disposal. Further support for this finding is based on observations of reductions since the 1980s in PCB concentrations in Great Lakes sediment and in other areas.

10.2. RELEASES OF COMMERCIAL PCBs

PCBs were commercially manufactured by the direct batch chlorination of molten biphenyl with anhydrous chlorine in the presence of a catalyst, followed by separation and purification of the desired chlorinated biphenyl fractions. The degree of chlorination was controlled by the chlorine contact time in the reactor. Commercial PCB production is believed to have been confined to 10 countries. Total PCBs produced worldwide since 1929 (the first year of known production) has been estimated at 1.5 million metric tons.

Initially, PCBs were used primarily as dielectric fluids in transformers. After World War II, PCBs found steadily increasing use as dielectric fluids in capacitors, as heat-conducting fluids in heat exchangers, and as heat-resistant hydraulic fluids in mining equipment and vacuum pumps. PCBs also were used in a variety of "open" applications (i.e, uses from which PCBs cannot be recollected), including plasticizers, carbonless copy paper, lubricants, inks, laminating agents, impregnating agents, paints, adhesives, waxes, additives in cement and plaster, casting agents, dedusting agents, sealing liquids, fire retardants, immersion oils, and pesticides (DeVoogt and Brinkman, 1989).

U.S. production peaked in 1970, with a volume of 39,000 metric tons. In 1971, Monsanto Corporation, the major U.S. producer, voluntarily restricted the sale of PCBs for all applications, with the exception of "closed electrical systems." Annual production fell to 18,000 metric tons in 1974. Monsanto ceased PCB manufacture in mid-1977 and shipped the last inventory in October of that year. Regulations issued by EPA beginning in 1977, principally under the Toxic Substances Control Act (TSCA) (40 CFR 761), have strictly limited the production, import, use, and disposal of PCBs. The estimated cumulative production and consumption volumes of PCBs in the United States from 1930 to 1975 were 635.03 million kg produced, 1.36 million kg imported (primarily from Japan, Italy, and France), 568.35 million kg sold in the United States, and 68.04 million kg exported (ATSDR, 1993; DeVoogt and Brinkman, 1989). The reliability of these values is +5% and –20% (Versar, Inc., 1976).

Monsanto Corporation marketed technical-grade mixtures of PCBs primarily under the trade name Aroclor. The Aroclor mixtures are identified by a four-digit numbering code in which the last two digits indicate the chlorine content by weight percent. The exception to this coding scheme is Aroclor 1016, which contains only mono- through hexachlorinated congeners with an average chlorine content of 41%. From 1957 until 1972, Monsanto also manufactured several blends of PCBs and polychlorinated terphenyls (PCTs) under the trade names Aroclor 2565 and Aroclor 4465; manufacture and sales volumes are not available for these blends. Listed below are the percentages of total Aroclor production during the years 1957 to 1977 by Aroclor mixture, as reported by Brown (1994).

Aroclor	1957–1977 U.S. production (%)
1016	12.88
1221	0.96
1232	0.24
1242	51.76
1248	6.76
1254	15.73
1260	10.61
1262	0.83
1268	0.33

The trade names of the major commercial PCB technical-grade mixtures manufactured in other countries included Clophen (Germany), Fenclor and Apirolio (Italy), Kanechlor (Japan), Phenoclor and Pyralene (France), Sovtel (USSR), Delor and Delorene (Czechoslovakia), and Orophene (German Democratic Republic) (DeVoogt and Brinkman, 1989). The mixtures marketed under these trade names had similar chlorine content (by weight percent and average number of chlorines per molecule) to those of various Aroclor mixtures. Listed below are comparable mixtures in terms of chlorine content marketed under several trade names.

Aroclor	Clophen	Pyralene	Phenoclor	Fenclor	Kanechlor
1232		2000			200
1242	A-30	3000	DP-3	42	300
1248	A-40		DP-4		400
1254	A-50		DP-5	54	500
1260	A-60		DP-6	64	600

Major advances in analytical separation and resolution techniques beginning in the 1970s enabled various researchers to identify and quantify PCB congeners present in Aroclors, Clophens, and Kanechlors (Jensen et al., 1974; Albro and Parker, 1979; Huckins et al., 1980; Albro et al., 1981; Duinker and Hillebrand, 1983; Kannan et al., 1987; Tanabe et al., 1987; Duinker et al., 1988; Schulz et al., 1989; Himberg and Sippola, 1990; Larsen et al., 1992; deBoer et al., 1993; Schwartz et al., 1993; Frame et al., 1996a, b; Frame, 1997). Schulz et al. (1989) were the first to identify and quantify all PCB congeners present in a series of Aroclors and Clophens. Frame (1995) reported preliminary results of a nearly completed round robin study, one goal of which was to determine the distribution of all PCB congeners above 0.05 weight percent in various Aroclors (1221, 1016, 1242, 1260, and 1262) using 18 state-of-the-art gas chromatography/mass spectrometry (GC/MS) or electron capture detector (GC/ECD) systems.

Table 10-3 presents mean summary statistics on the concentrations of the dioxin-like PCBs in each mixture group (e.g., Aroclor 1248, Clophen A-40, and Kanechlor 400 are in one mixture group) reported by these researchers. Table 10-3 also presents the mean TEQ concentration of each congener in each mixture group as well as the total mean TEQ concentration in the mixture group. Because of the wide variability in the reported results, the uncertainty associated with these mean concentrations is very large.

For each mixture group, the congeners detected were generally similar. There was, however, wide variability in the concentrations reported by some researchers for some congeners. Brown et al. (1995) compiled similar statistics using a somewhat different set of studies and derived significantly lower mean concentrations of some congeners in several Aroclors. Frame (1995) and Larsen (1995) attributed such differences to either potential limitations in the GC columns used by various researchers to separate similar eluting congeners or actual differences in the congener concentrations in the Aroclor, Clophen, and Kanechlor lots analyzed by various research groups.

The congener distributions also vary among the different mixtures. Therefore, the calculated TEQs also vary. The congener distributions for various lots of Aroclor 1254, and the corresponding TEQs, are presented in another study (Frame, 1999) in which the relative TEQs for late production lots were reported to be much higher than those for the earlier production lots; however, the late production lots were estimated to account for only about 1% of the total production volume of Aroclor 1254. Therefore, the data for the later production lots were not included in the average TEQ calculation for Aroclor 1254 in Table 10-3.

In the environment, PCBs also occur as mixtures of congeners, but their composition differs from those of the commercial mixtures because after release to the environment the mixtures change over time through partitioning, chemical transformation, and preferential bioaccumulation (U.S. EPA, 1996f). Dioxin-like PCB congeners differ by up to one to two

Table 10-3. Weight percent concentrations of dioxin-like PCBs in Aroclors, Clophens, and Kanechlors

Dioxin-like PCB congener	IUPAC number	No. of samples analyzed	No. of detections	Mean conc. (nondetect set to zero) (g/kg)	TEQ$_P$-WHO$_{98}$ conc. (nondetect set to zero) (mg/kg)	Mean conc.[a] (nondetect set to ½ detection limit) (g/kg)	TEQ$_P$-WHO$_{98}$ conc.[a] (nondetect set to ½ detection limit) (mg/kg)
Aroclor 1016							
3,3',4,4'-TCB	77	5	0	0	0	0	0
3,4,4',5-TCB	81	3	0	0	0	0	0
2,3,3',4,4'-PeCB	105	4	1	0.0375	0.00375	0.109	0.011
2,3,4,4',5-PeCB	114	4	0	0	0	0	0
2,3',4,4',5-PeCB	118	4	1	0.0125	0.00125	0.091	0.009
2',3,4,4',5-PeCB	123	4	0	0	0	0	0
3,3',4,4',5-PeCB	126	4	0	0	0	0	0
2,3,3',4,4',5-HxCB	156	4	0	0	0	0	0
2,3,3',4,4',5'-HxCB	157	4	0	0	0	0	0
2,3',4,4',5,5'-HxCB	167	4	0	0	0	0	0
3,3',4,4',5,5'-HxCB	169	5	0	0	0	0	0
2,2',3,3',4,4',5-HpCB	170	4	0	0	0	0	0
2,2',3,4,4',5,5'-HpCB	180	4	0	0	0	0	0
2,3,3',4,4',5,5'-HpCB	189	4	0	0	0	0	0
Total TEQ$_P$-WHO$_{98}$					0.005		0.0200
Total TEQ$_P$-WHO$_{94}$					0.005		0.0200
Aroclor 1221							
3,3',4,4'-TCB	77	4	4	1.075	0.1075	1.078	0.108
3,4,4',5-TCB	81	4	1	0.0875	0.00875	0.116	0.012
2,3,3',4,4'-PeCB	105	4	3	0.3875	0.03875	0.4	0.04
2,3,4,4',5-PeCB	114	4	0	0	0	0	0
2,3',4,4',5-PeCB	118	4	4	1.725	0.1725	1.725	0.173
2',3,4,4',5-PeCB	123	4	0	0	0	0	0
3,3',4,4',5-PeCB	126	4	0	0	0	0	0
2,3,3',4,4',5-HxCB	156	4	0	0	0	0	0
2,3,3',4,4',5'-HxCB	157	4	0	0	0	0	0
2,3',4,4',5,5'-HxCB	167	4	0	0	0	0	0
3,3',4,4',5,5'-HxCB	169	4	0	0	0	0	0
2,2',3,3',4,4',5-HpCB	170	3	0	0	0	0	0
2,2',3,4,4',5,5'-HpCB	180	3	0	0	0	0	0
2,3,3',4,4',5,5'-HpCB	189	4	0	0	0	0	0
Total TEQ$_P$-WHO$_{98}$					0.328		0.333
Total TEQ$_P$-WHO$_{94}$					0.749		0.752

Table 10-3. Weight percent concentrations of dioxin-like PCBs in Aroclors, Clophens, and Kanechlors (continued)

Dioxin-like PCB congener	IUPAC number	No. of samples analyzed	No. of detections	Mean conc. (nondetect set to zero) (g/kg)	TEQ$_P$-WHO$_{98}$ conc. (nondetect set to zero) (mg/kg)	Mean conc.[a] (nondetect set to ½ detection limit) (g/kg)	TEQ$_P$-WHO$_{98}$ conc.[a] (nondetect set to ½ detection limit) (mg/kg)
Aroclor 1242, Clophen A-30, and Kanechlor 300							
3,3',4,4'-TCB	77	15	15	3.3	0.33	3.301	0.33
3,4,4',5-TCB	8	7	6	1.09	0.11	1.089	0.109
2,3,3',4,4'-PeCB	105	11	11	4.02	0.4	4.024	0.402
2,3,4,4',5-PeCB	114	8	5	1.13	0.57	1.201	0.601
2,3',4,4',5-PeCB	118	9	9	8.04	0.8	8.044	0.804
2',3,4,4',5-PeCB	123	9	7	1.12	0.11	1.157	0.116
3,3',4,4',5-PeCB	126	14	8	0.049	4.94	0.094	9.404
2,3,3',4,4',5-HxCB	156	9	8	0.39	0.2	0.424	0.212
2,3,3',4,4',5'-HxCB	157	8	2	0.021	0.011	0.096	0.048
2,3',4,4',5,5'-HxCB	167	8	2	0.021	0.00021	0.096	0.001
3,3',4,4',5,5'-HxCB	169	14	2	0.000013	0.00013	0.048	0.476
2,2',3,3',4,4',5-HpCB	170	6	2	0.19	0	0.244	0
2,2',3,4,4',5,5'-HpCB	180	5	2	0.16	0	0.218	0
2,3,3',4,4',5,5'-HpCB	189	7	0	0	0	0	0
Total TEQ$_P$-WHO$_{98}$					7.47		12.5
Total TEQ$_P$-WHO$_{94}$					8.70		13.74
Aroclor 1248, Clophen A-40, and Kanechlor 400				4.36	0.44	4.36	0.44
3,3',4,4'-TCB	77	13	13	1.76	0.18	1.77	0.18
3,4,4',5-TCB	81	6	4	10.12	1.01	10.12	1.01
2,3,3',4,4'-PeCB	105	9	8	3.39	1.69	3.4	1.7
2,3,4,4',5-PeCB	114	7	6	20.98	2.1	20.98	2.1
2,3',4,4',5-PeCB	118	8	8	1.48	0.15	1.48	0.15
2',3,4,4',5-PeCB	123	7	7	0.11	10.55	0.14	13.51
3,3',4,4',5-PeCB	126	11	6	1.13	0.56	1.13	0.56
2,3,3',4,4',5-HxCB	156	8	8	0.19	0.09	0.2	0.1
2,3,3',4,4',5'-HxCB	157	7	3	0.16	0.0016	0.16	0.0016
2,3',4,4',5,5'-HxCB	167	7	3	0.01	0.1006	0.041	0.41
3,3',4,4',5,5'-HxCB	169	12	3	0.96	0	0.97	0
2,2',3,3',4,4',5-HpCB	170	5	4	1.24	0	1.24	0
2,2',3,4,4',5,5'-HpCB	180	4	4	0.0018	0.0001833	0.06	0.006
2,3,3',4,4',5,5'-HpCB	189	6	1				
Total TEQ$_P$-WHO$_{98}$					16.87		20.16
Total TEQ$_P$-WHO$_{94}$					18.55		21.83

Table 10-3. Weight percent concentrations of dioxin-like PCBs in Aroclors, Clophens, and Kanechlors (continued)

Dioxin-like PCB congener	IUPAC number	No. of samples analyzed	No. of detections	Mean conc. (nondetect set to zero) (g/kg)	TEQ$_P$-WHO$_{98}$ conc. (nondetect set to zero) (mg/kg)	Mean conc.[a] (nondetect set to ½ detection limit) (g/kg)	TEQ$_P$-WHO$_{98}$ conc.[a] (nondetect set to ½ detection limit) (mg/kg)
Aroclor 1254, Clophen							
A-50, and Kanechlor 500				0.8	0.0795	0.83	0.08
3,3',4,4'-TCB	77	15	12	7.85	0.79	7.86	0.79
3,4,4',5-TCB	81	6	1	35.83	3.58	35.83	3.58
2,3,3',4,4'-PeCB	105	12	11	12.17	6.08	12.23	6.11
2,3,4,4',5-PeCB	114	9	6	81.65	8.17	81.65	8.17
2,3',4,4',5-PeCB	118	11	11	4.59	0.46	4.59	0.46
2',3,4,4',5-PeCB	123	8	8	0.99	99.46	1.02	101.7
3,3',4,4',5-PeCB	126	14	12	11.08	5.54	11.08	5.54
2,3,3',4,4',5-HxCB	156	10	10	1.91	0.95	1.93	0.97
2,3,3',4,4',5'-HxCB	157	9	8	2.74	0.0274	2.74	0.03
2,3',4,4',5,5'-HxCB	167	10	9	0.08	0.8	0.12	1.23
3,3',4,4',5,5'-HxCB	169	14	6	5.06	0	5.06	0
2,2',3,3',4,4',5-HpCB	170	8	8	5.79	0	5.79	0
2,2',3,4,4',5,5'-HpCB	180	7	7	0.045	0.0045429	0.13	0.013
2,3,3',4,4',5,5'-HpCB	189	7	2				
Total TEQ$_P$-WHO$_{98}$				125.94			128.67
Total TEQ$_P$-WHO$_{94}$				126.04			128.78
Aroclor 1260, Clophen							
A-60, and Kanechlor 600							
3,3',4,4'-TCB	77	15	6	0.13	0.01256	0.17	0.017
3,4,4',5-TCB	81	6	1	0.08	0.0075	0.1	0.01
2,3,3',4,4'-PeCB	105	11	10	1.59	0.16	1.59	0.16
2,3,4,4',5-PeCB	114	9	4	0.71	0.35	0.77	0.39
2,3',4,4',5-PeCB	118	11	10	9.51	0.95	9.51	0.95
2',3,4,4',5-PeCB	123	8	1	0.0005	0.00005	0.08	0.008
3,3',4,4',5-PeCB	126	14	7	1.81	180.89	1.84	183.82
2,3,3',4,4',5-HxCB	156	11	11	6.89	3.45	6.89	3.45
2,3,3',4,4',5'-HxCB	157	8	8	1.59	0.79	1.59	0.79
2,3',4,4',5,5'-HxCB	167	10	9	2.87	0.03	2.87	0.03
3,3',4,4',5,5'-HxCB	169	14	5	0.16	1.64	0.19	1.92
2,2',3,3',4,4',5-HpCB	170	8	8	32.94	0	32.94	0
2,2',3,4,4',5,5'-HpCB	180	7	7	82.61	0	82.61	0
2,3,3',4,4',5,5'-HpCB	189	8	8	1.74	0.1739792	1.74	0.17
Total TEQ$_P$-WHO$_{98}$					188.45		191.71
Total TEQ$_P$-WHO$_{94}$					192.62		195.89

Table 10-3. Weight percent concentrations of dioxin-like PCBs in Aroclors, Clophens, and Kanechlors (continued)

[a] Calculated for a congener only when at least one sample contained detectable levels of that congener.

Sources: Adapted from Schulz et al. (1989); Duinker and Hillebrand (1983; deBoer et al. (1993); Schwartz et al. (1993); Larsen, et al. (1992); Kannan et al. (1987); Huckins et al. (1980); Albro and Parker (1979; Jensen et al. (1974); Albro et al. (1981); Duinker et al. (1988); Tanabe et al. (1987); Himberg and Sippola (1990); Frame et al. (1996a, b); Frame (1997).

orders of magnitude in their water solubility, vapor pressure, K_{ow} value, and Henry's Law constant. Thus, although all the dioxin-like PCB congeners are poorly soluble in water and have very low vapor pressures, they will volatilize and leach at different rates. Similarly, because the congeners differ somewhat in their rates of biodegradation, bioaccumulation, and photodegradation, the congener patterns found in environmental media and biota will vary from those found in commercial mixtures.

Although environmental mixtures are often characterized in terms of Aroclors, this characterization can be both imprecise and inappropriate. Qualitative and quantitative errors can arise from judgements in comparing GC/MS peaks for a sample with the characteristic peak patterns for different Aroclors, particularly for environmentally altered patterns (U.S. EPA, 1996f). For the same reason, it can be both imprecise and inappropriate to infer concentrations of dioxin-like PCB congeners in an environmental sample on the basis of characterization of the sample's Aroclor content and knowledge of the dioxin-like congener content in the commercial Aroclor. Safe (1994) wrote, "Regulatory agencies and environmental scientists have recognized that the composition of PCBs in most environmental extracts does not resemble the compositions of the commercial product." Similarly, ATSDR (1993) stated, "It is important to recognize that the PCBs to which people may be exposed are likely to be different from the original PCB source because of changes in congener and impurity composition resulting from differential partitioning and transformation in the environment and differential metabolism and retention."

10.2.1. Approved PCB Disposal/Destruction Methods

In 1978, EPA began regulating the disposal of PCBs and PCB-contaminated waste under TSCA, PL 94-469. The disposal regulations, published in the Code of Federal Regulations, 40 CFR, Part 761, state that the preferred disposal method is incineration at 1,200°C or higher. If the waste contains material that cannot be destroyed by incineration, EPA clearance must be obtained to dispose of the waste in a chemical waste landfill or by another approved manner.

The PCB disposal regulations describe disposal of three distinct types of PCB waste: PCBs, PCB articles (items containing PCBs), and PCB containers. Within these categories, further distinctions are made on the basis of the PCB concentration in the waste, with the acceptable disposal methods being based on the concentrations in the specific waste to be destroyed. The acceptable disposal methods are Annex I incinerators, high-efficiency boilers, Annex II chemical waste landfills, and other approved methods. The following paragraphs and Table 10-4 provide brief descriptions of these disposal methods. More complete descriptions of the specific methodologies are provided in 40 CFR, Part 761.

Table 10-4. Disposal requirements for PCBs and PCB items

PCBs/items	Waste characterization		Disposal requirements
PCBs	Mineral oil dielectric fluids from PCB transformers	Those analyzing >500 ppm PCB	Annex I incinerator[a]
	Mineral oil dielectric fluids from PCB-contaminated transformers	Those analyzing 50–500 ppm PCB	Annex I incinerator High-efficiency boiler (40 CFR 761.10(a)(2)(iii)) Other approved incinerator[b] Annex II chemical waste landfill[c]
	PCB liquid wastes other than mineral oil dielectric fluid	Those analyzing >500 ppm PCB	Annex I incinerator
		Those analyzing 50–500 ppm PCB	Annex I incinerator High-efficiency boiler (40 CFR 761.10(a)(2)(iii)) Other approved incinerator[b] Annex II chemical waste landfill[c]
	Nonliquid PCB wastes (e.g., contaminated materials from spills)		Annex I incinerator Annex II chemical waste landfill
	Dredged materials and municipal sewage treatment sludges containing PCBs		Annex I incinerator Annex II chemical waste landfill Other approved disposal method, 40 CFR 761.10(a)(5)(iii)
PCB articles	Transformers	PCB transformers	Annex I incinerator Drained and rinsed transformers may be disposed of in Annex II chemical waste landfill
		PCB contaminated transformers	Disposal of drained transformers is not regulated
	PCB capacitors[d]		Annex I incinerator
	PCB hydraulic machines	Those containing >1,000 ppm PCB	Drained and rinsed machines may be disposed of as municipal solid waste or salvaged
		Those containing <1,000 ppm PCB	Drained machines may be disposed of as municipal solid waste or salvaged

Table 10-4. Disposal requirements for PCBs and PCB items (continued)

PCBs/items	Waste characterization		Disposal requirements
	Other PCB articles	Those containing PCB fluids	Drained machines may be disposed of by Annex I or Annex II
		Those not containing PCB fluids	Annex I incinerator or Annex II chemical waste landfill
PCB containers	Those used to contain only PCBs at a concentration <500 ppm		As municipal solid waste provided any liquid PCBs are drained prior to disposal
	Other PCB containers		Annex I incinerator Annex II, provided any liquid PCBs are drained prior to disposal Decontaminate per Annex IV

[a] Annex I incinerator is defined in 40 CFR 761.40.

[b] Requirements for other approved incinerators are defined in 40 CFR 761.10(e).

[c] Annex II chemical waste landfills are described in 40 CFR 761.41. Annex II disposal is permitted if the PCB waste contains less than 500 ppm PCB and is not ignitable as per 40 CFR Part 761.41(b)(8)(iii).

[d] Disposal of containerized capacitors in Annex II landfills was permitted until March 1, 1981; thereafter, only Annex I incineration has been permitted.

Source: U.S. EPA (1987d).

10.2.1.1. *Approved Incinerators/High-Efficiency Boilers*

PCB Annex I incinerators must meet the specific technical standards and criteria listed in Annex I of EPA's PCB regulations. The minimum operating requirements for disposal of liquid wastes are 2 sec at 1,200°C with 3% excess oxygen (measured in the stack gas) or 1.5 sec at 1,600°C with 2% excess oxygen (measured in the stack gas). Monitoring requirements, approval conditions, and trial burn requirements are prescribed in Annex I. Operators of commercial or industrial incinerators who intend to destroy liquid PCB wastes must demonstrate the incineration's compliance with the Annex I requirements through a comprehensive trial burn program. Annex I incinerators operating at optimum performance level should destroy 99.997% of liquid PCB waste, with a resulting maximum emission factor of 0.03 g/kg.

Criteria for Annex I incinerators were established for the destruction of liquid PCB wastes; however, these incinerators also may be used for disposal of nonliquid PCB items (such as capacitors), provided that a destruction and removal efficiency of 99.9999% and a maximum emission factor of 0.001 g/kg are met.

High-efficiency boilers may be used to destroy PCBs and PCB-contaminated waste with PCB concentrations not exceeding 500 ppm. Conventional industrial and utility boilers may be designated as high-efficiency boilers if they are operated under the prescribed combustion conditions defined in the PCB disposal regulations. The PCB regulations do not specify a minimum destruction efficiency for high-efficiency boilers; however, EPA-approved boilers operated according to the regulations have reported destruction efficiencies in excess of 99.99%, with a corresponding maximum emission factor of 0.1 g/kg (U.S. EPA, 1987d).

10.2.1.2. *Approved Chemical Waste Landfills*

Approved chemical waste landfills can be used for the disposal of some but not all PCB wastes. PCB-contaminated materials acceptable for land disposal in an approved landfill include PCB mixtures (e.g., certain PCB-contaminated soil/solid debris, PCB-contaminated dredged materials, and PCB-contaminated municipal sewage sludge), PCB articles that cannot feasibly be incinerated (e.g., drained and flushed transformers), and drained PCB containers. Written approval must be obtained from EPA in order to landfill PCB articles other than transformers. PCB-contaminated materials not acceptable for land disposal in an approved landfill include nonliquid PCB mixtures in the form of contaminated soil, rags, or other solid debris, and sealed capacitors. Typically, PCBs disposed of in these landfills are placed in sealed containers, thereby minimizing any PCB emissions.

10.2.1.3. *Other Approved Disposal Methods*

Other thermal and nonthermal destruction techniques may be approved by EPA Regional Administrators if these processes can effect a level of destruction of PCBs equivalent to that of incinerators or boilers. After April 29, 1983, all other PCB disposal technologies (thermal and nonthermal) used in more than one EPA Region had to be approved by EPA Headquarters. Examples of thermal technologies approved for commercial-scale use or for research and development projects include a pyrolysis process to treat contaminated soils, a fluid wall reactor, a cement kiln, a diesel engine, a steam-stripping operation, an aluminum melting furnace, and a molten salt process. Examples of approved nonthermal processes include chemical dechlorination processes, physical/chemical extraction techniques, and biological reduction methods. The physical/chemical techniques extract the PCBs from transformers or capacitors and concentrate them for disposal; they do not destroy the PCBs.

10.2.2. Emission Estimates

Tables 10-5 and 10-6 list the amounts of PCBs reported in EPA's Toxics Release Inventory (TRI) as transferred off site for treatment, energy recovery, or disposal and the amounts released between 1988 and 2000, respectively. These quantities do not necessarily represent entry of PCBs into the environment. If it is assumed that all transferred PCBs are incinerated in high-efficiency boilers with a destruction and removal efficiency of 99.99%, then annual emissions of PCBs to air during 1988, 1995, and 2000 could have been as high as 264 kg, 31 kg, and 15 kg, respectively. Because no stack testing data are available for dioxin-like PCBs, it is not possible to estimate what fraction of these potential PCB releases would have been dioxin-like congeners.

10.2.3. Accidental Releases of Still-in-Service PCBs

After the 1977 ban on production of PCBs, releases of commercially produced PCBs to the environment (aside from minimal releases occurring during approved disposal or destruction) have been limited to accidental release of in-service PCBs (U.S. EPA, 1987d). Accidental releases are the result of leaks or spills during failure/breakage of an existing piece of PCB-containing equipment or of incomplete combustion during accidental fires involving PCB-containing equipment. These two types of accidental releases are discussed in the following sections.

Table 10-5. Off-site transfers of PCBs reported in the Toxics Release Inventory (TRI) (1988–2000)

Year	No. of TRI forms filed	Reported transfers (kg)		
		Transfers to POTWs	Transfers for treatment/disposal	Total transfers
2000	NA	102	150,888	150,990
1999	NA	0	434,666	434,666
1998	NA	0	386,903	386,903
1997	NA	a	471,319	471,319
1996	NA	0	160,802	160,802
1995	NA	0	308,347	308,347
1994	NA	0	466,948	466,948
1993	16	120	463,385	463,505
1992	20	0	766,638	766,638
1991	26	0	402,535	402,535
1990	NA	0	1,181,961	1,181,961
1989	NA	0.5	2,002,237	2,002,237
1988	122	113	2,642,133	2,642,246

[a] Facilities left that particular cell blank on the Form R submissions.

NA = Not available
POTWs = Publicly owned treatment works

Sources: U.S. EPA (1993f, 1995h, 1998b, 2003c).

10.2.3.1. *Leaks and Spills*

PCBs that remain in active service at this time are those contained in "closed systems" (i.e., those pieces of electrical equipment that completely enclose the PCBs and do not provide direct atmospheric access for the PCBs during normal use). This equipment includes PCB transformers, capacitors, voltage regulators, circuit breakers, and reclosures. With the exception of PCB transformers—and probably small PCB capacitors—the majority of the PCB-containing electrical equipment in service during 1981 was owned by the electrical utility industry. Approximately 70% of the estimated 140,000 PCB transformers in service in 1981 were owned by nonutilities. No information was available on the relative distribution of small PCB capacitors (Versar, Inc., 1988).

Table 10-6. Releases of PCBs reported in the Toxics Release Inventory (TRI) (1988–2000)

Year	No. of TRI forms filed	Reported releases (kg)					
		Fugitive or nonpoint air emissions	Stack or point air emissions	Surface water discharges	Underground injection	On-site releases to land	Total on-site Releases
2000	NA	158	2,497	13	0.5	648,128	650,796.5
1999	NA	0	0	[a]	[a]		0.0
1998	NA	0	0	0	[a]	60,854	60,854.0
1997	NA	0	0	0	[a]	3,081	3,081.0
1996	NA	2.3	114	0	0	4,179	4,295.3
1995	NA	0	0	0	0	0	0.0
1994	NA	0	0	0	0	0	0.0
1993	16	0	0	0	0	120	120.0
1992	20	0	0	0	0	0.5	0.5
1991	26	0	0	0	0	0	0.0
1990	NA	2.3	0	0	0	32,372	32,374.3
1989	NA	0	0	120	0	453	573.0
1988	122	2.7	0	4.5	0	341	348.2

[a] Facilities left that particular cell blank on the Form R submissions.

NA = Not available

Sources: U.S. EPA (1993f, 1995h, 1998b, 2003c).

The number of each of these items owned by the utility industry, the quantity of PCBs contained in each, and an estimate of the annual quantity of PCBs leaked and/or spilled were investigated by the Edison Electric Institute and the Utility Solid Wastes Activity Group (EEI/USWAG) for EPA in 1981. The findings of this investigation, which were reported in a proposed modification to the PCB regulations (Federal Register, 1982a), indicated that more than 99% of the total quantity of PCBs contained in utility-owned electrical equipment in 1981 (73,700 metric tons) was in 40,000 PCB transformers (those containing >500 ppm of PCBs) and large PCB capacitors (those containing >3 lb of PCBs). An upper-bound estimate of the mass of PCBs that leached or spilled from this equipment in 1981 was 177 metric tons. Approximately 95% of the estimated releases were the result of leaks from large PCB capacitors (Federal Register, 1982a). Leaks/spills typically occur in transformers when the gasket joining the top to the body corrodes, tears, or physically fails. PCBs can then leak past this failed section and potentially spill onto the surrounding ground. PCB capacitors typically fail by rupturing, exposing the contained PCBs to the environment. Failure is caused by environmental and weathering effects (e.g., lightning) or material failures (e.g., metal fatigue).

As of mid-1988, the total population of in-service PCB transformers and large PCB capacitors was estimated to have decreased from 140,000 to 110,000 and from 3.3 million to 1.9 million, respectively (Versar, Inc., 1988). PCB transformers have normal operating lifetimes of 30 years and 40 years, respectively. EPA's PCB Electrical Use Rule (Federal Register, 1982b) required the removal of 950 food/feed industry transformers by 1985 and 1.1 million unrestricted-access large PCB capacitors by October 1988. In addition, EPA's PCB Transformer Fires Rule (Federal Register, 1985b) required the removal by 1990 of 7,600 480-volt network transformers.

More recent inventories of PCB-containing electrical equipment are not available. However, an Information Collection Request submitted by EPA to the Office of Management and Budget for information on uses, locations, and conditions of PCB electrical equipment estimated that there may be 150,000 owners of PCB-containing transformers used in industry, utilities, government buildings, and private buildings (Federal Register, 1997b). It is expected, and is demonstrated by the reported PCB transfers in the EPA's TRI (see Table 10-5), that many owners of PCB electrical equipment have removed PCB-containing equipment to eliminate potential liability.

10.2.3.2. *Accidental Fires*

The available information is not adequate to support an estimate of potential annual releases of dioxin-like PCBs from accidental electrical equipment fires. For fires involving PCB transformers or capacitors, the amount of PCBs released is dependent on the extensiveness of the fire and the speed at which it is extinguished. A number of these fires are documented. A New York fire involving 200 gal of transformer fluid containing some 65% by weight PCBs resulted in a release of up to 1,300 lb of PCBs. A capacitor fire that burned uncontrolled for 2 hr in Sweden resulted in the destruction of 12 large utility capacitors containing an estimated 25 pounds each of PCBs, for a total potential release of 300 lb. However, data are incomplete on the exact amount of PCBs released as a result of these two fires.

EPA has imposed reporting requirements to ensure that the National Response Center is informed immediately of fires involving PCB transformers (40 CFR 761). The recordkeeping requirements are used to document the use, location, and condition of PCB equipment. Responses are mandatory, but the submitter may claim them to be confidential information. The number of PCB transformer fires is estimated to be approximately 20 per year; the number of PCB capacitor fires is unknown (U.S. EPA, 1987d). As these PCB-containing items reach the end of their useful lives and are retired, their susceptibility to fires will be eliminated, and the overall number of PCB transformer and capacitor fires will be reduced.

10.2.4. Municipal Wastewater Treatment

EPA conducted the National Sewage Sludge Survey in 1988 and 1989 to obtain national data on sewage sludge quality and management. As part of this survey, EPA tested for more than 400 analytes, including seven of the Aroclors, in sludges from 175 publicly owned treatment works (POTWs) that employed at least secondary wastewater treatment. Sludges from 19% of the POTWs had detectable levels of at least one of the following Aroclors: 1248, 1254, or 1260; none of the other Aroclors were detected in any sample (the detection limit [DL] was typically about 200 µg/kg dry weight) (U.S. EPA, 1996e). Analyses were not performed for dioxin-like PCB congeners. The Aroclor-specific results of the survey are presented in Table 10-7.

Gutenmann et al. (1994) reported similar results in a survey of sludges from 16 large U.S. cities for Aroclor 1260 content. At a DL of 250 µg/kg (dry weight), the investigators detected Aroclor 1260 (4,600 µg/kg) at only one facility. These results indicate that PCBs are not likely to be formed at POTWs, but rather are present because of disposal of PCB products or recirculation of previously disposed of PCBs.

Although PCBs, measured as Aroclors, were not commonly detected in sewage sludge at microgram-per-kilogram levels in studies by EPA (U.S. EPA, 1996e) and Gutenmann et al. (1994), the presence of dioxin-like PCB congeners at lower concentrations may be more common. Green et al. (1995) and Cramer et al. (1995) reported the results of analyses of 99 samples of sewage sludge for PCB congener numbers 77, 81, 126, and 169. The sludge samples were collected from 74 wastewater treatment plants across the United States during the summer

Table 10-7. Aroclor concentrations (ng/kg) measured in EPA's National Sewage Sludge Survey[a]

Aroclor	Percent detected	Maximum concentration	Median concentration	
			Nondetects set to detection limit	Nondetects set to zero
1016	0	--	--	0
1221	0	--	--	0
1232	0	--	--	0
1242	0	--	--	0
1248	9	5.2	0.209	0
1254	8	9.35	0.209	0
1260	10	4.01	0.209	0
Any Aroclor (total)	19	14.7	1.49	0

[a] For publicly owned treatment works with multiple samples, the pollutant concentrations were averaged before the summary statistics presented in the table were calculated.

-- = No information given

Source: U.S. EPA (1996e).

of 1994. These data are summarized in Table 10-8. Results from all samples collected from the same facility were averaged by Green et al. and Cramer et al. to ensure that results were not biased toward the concentrations found at facilities from which more than one sample was collected. If all nondetect values were assumed to be zero, then the POTW mean TEQ_P-WHO_{94} and TEQ_P-WHO_{98} concentrations were 25.1 and 24.2 ng TEQ/kg (dry-weight basis), respectively. If the nondetect values were set equal to the DLs, then the POTW mean TEQ_P-WHO_{94} and TEQ_P-WHO_{98} concentrations were 25.2 and 24.3 ng TEQ/kg, respectively.

In 1999, sewage sludge samples from a POTW in Ohio were collected and analyzed for PCBs (U.S. EPA, 2000b). The facility, which accepts both domestic and industrial wastewater, employs secondary wastewater technology. Assuming nondects were zero, the mean TEQ emission factor was 141 ng TEQ_P-WHO_{98}/kg. These results are presented in Table 10-9.

In 2000 and 2001, the Association of Metropolitan Sewage Agencies conducted a survey of dioxin-like PCB compounds in sewage sludge (Alvarado et al., 2001). A total of 200 sewage sludge samples were collected from 171 POTWs located in 31 states. Assuming nondetects were zero, the mean and median TEQ emission factors were reported as 8.3 and 3.37 ng TEQ_P-WHO_{98}/kg, respectively.

Table 10-8. Dioxin-like PCB concentrations measured in sludges collected from 74 U.S. publicly owned treatment works (POTWs) during 1994[a,b]

Congener	IUPAC number	Percent detected	Maximum concentration (ng/kg)	Median concentration (ng/kg)		Mean concentration (ng/kg)	
				Nondetect set to ½ detection limit	Nondetect set to zero	Nondetect set to ½ detection limit	Nondetect set to zero
3,3',4,4'-TCB	77	100	22,900	783	783	2,243	2,243
3,4,4',5-TCB	81	86	1,250	27.3	27	65.2	63.5
2,3,3',4,4'-PeCB	105						
2,3,4,4',5-PeCB	114						
2,3',4,4',5-PeCB	118						
2',3,4,4',5-PeCB	123						
3,3',4,4',5-PeCB	126	99	3,020	91.6	91.6	237	237
2,3,3',4,4',5-HxCB	156						
2,3,3',4,4',5'-HxCB	157						
2,3',4,4',5,5'-HxCB	167						
3,3',4,4',5,5'-HxCB	169	22	1,470	8.5	0	32.5	26.2
2,2',3,3',4,4',5-HpCB	170						
2,2',3,4,4',5,5'-HpCB	180						
2,3,3',4,4',5,5'-HpCB	189						
Total TEQ$_P$-WHO$_{98}$				9.3	9.2	24.3	24.2

[a] For POTWs with multiple samples, the sample concentrations were averaged by Cramer et al. (1995) to POTW averages before calculation of the total TEQ mean and median values presented in the table. The TEQ$_P$-WHO$_{94}$ and TEQ$_P$-WHO$_{98}$ values were calculated on a facility-level basis.

[b] Blank cells indicate that no measurements of these congeners were made.

Source: Green et al. (1995); Cramer et al. (1995).

Table 10-9. Dioxin-like PCB concentrations in sewage sludge collected from U.S. publicly owned treatment works during 1999

Congener	IUPAC number	Mean emission factor (ng/kg)	
		Nondetect set to ½ detection limit	Nondetect set to zero
3,3',4,4'-TCB	77	42,467	42,467
2,3,3',4,4'-PeCB	105	7,230	7,230
2,3,4,4',5-PeCB	114	701	701
2',3,4,4',5-PeCB	123	249	249
2,3',4,4',5-PeCB	118	12,867	12,867
3,3',4,4',5-PeCB	126	1,270	1,270
2,3,3',4,4',5-HxCB	156	1,843	1,843
2,3,3',4,4',5'-HxCB	157	524	524
2,3',4,4',5,5'-HxCB	167	935	935
3,3',4,4',5,5'-HxCB	169	570	570
2,2',3,3',4,4',5-HpCB	170	2,627	2,627
2,2',3,4,4',5,5'-HpCB	180	6,497	6,497
2,3,3',4,4',5,5'-HpCB	189	199	199
Total TEQ_P-WHO_{98}		141	141

Source: U.S. EPA (2000b).

For 2001, EPA conducted another National Sewage Sludge Survey to characterize the dioxin and dioxin-like equivalence levels in biosolids produced by the 6,857 POTWs operating in the United States in 2001 (U.S. EPA, 2002d). Sewage sludge samples were collected from 94 POTWs that used secondary or higher treatment practices. All the facilities had been sampled as part of the 1988/1989 National Sewage Sludge Survey. To determine the mean and median TEQ emission estimates of the dioxin-like PCBs, EPA weighted the values on the basis of wastewater flow rates of all POTWs in the United States (i.e., number of facilities with wastewater flow rate >100 mg/day, >10 but ≤100 mg/day, >1 but ≤10 mg/day, and ≤1 mg/day). The weighted mean and median TEQ_P-WHO_{98} concentrations of the dioxin-like PCB congeners were 5.22 and 2.05 ng/kg, respectively.

According to the results of its 1988/1989 National Sewage Sludge Survey, EPA estimated that approximately 5.4 million dry metric tons of sewage sludge were generated in 1989 (Federal Register, 1993a). EPA also used the results of the 1984 to 1996 Clean Water Needs Surveys to estimate that 6.3 million dry metric tons of sewage sludge were generated in 1998 and 6.6 million dry metric tons were generated in 2000 (U.S. EPA, 1999b). Because estimates for 1987 and 1995 are not available, the 1989 and 1998 activity level estimates are used for reference years 1987 and 1995, respectively. Tables 10-10, 10-11, and 10-12 list the volume, by use and disposal practices, of sludge disposed of annually for reference years 1989, 1995, and 2000.

Table 10-10. Quantity of sewage sludge disposed of annually in 1989 by primary, secondary, or advanced treatment publicly owned treatment works (POTWs) and potential dioxin-like PCB TEQ releases

Use/disposal practice	Volume disposed of (1,000 dry metric tons/yr)	Percent of total volume	Potential TEQ_P-WHO_{98} release[a] (g of TEQ/yr)	Potential TEQ_P-WHO_{94} release[a] (g of TEQ/yr)
Land application	1,714	32[b]	41.5	43
Distribution and marketing	71	1.3	1.7	1.8
Surface disposal site/other	396	7.4	9.6	9.9
Sewage sludge landfill	157	2.9	4.2	3.9
Co-disposal landfills[c]	1,819	33.9	44	45.6
Sludge incinerators and co-incinerators[d]	865	16.1	e	e
Ocean disposal[f]	336	6.3	0	0
TOTAL	5,358	100	101	104.2

[a] Potential TEQ release for nonincinerated sludges was estimated by multiplying the sludge volume generated (column 2) by the mean dioxin-like PCB TEQ concentration in 74 POTW sludges reported by Green et al. (1995) and Cramer et al. (1995) (i.e., 24.2 ng TEQ_P-WHO_{98}/kg and 25.1 ng TEQ_P-WHO_{94}/kg).
[b] Includes 21.9% applied to agricultural land, 2.8% applied as compost, 0.6% applied to forestry land, 3.1% applied to "public contact" land, 1.2% applied to reclamation sites, and 2.4% applied in undefined settings.
[c] Landfills used for disposal of sewage sludge and solid waste residuals.
[d] Co-incinerators treat sewage sludge in combination with other combustible waste materials.
[e] See Section 10.4.6 for a discussion of dioxin-like PCB releases to air from sewage sludge incinerators.
[f] The Ocean Dumping Ban Act of 1988 generally prohibited the dumping of sewage sludge into the ocean after December 31, 1991. Ocean dumping of sewage sludge ended in June 1992 (Federal Register, 1993a). The current method of disposal of the 336,000 metric tons of sewage sludge that were disposed of in the oceans in 1988 has not been determined.

Sources: Federal Register (1990, 1993a); Green et al. (1995); Cramer et al. (1995).

Table 10-11. Quantity of sewage sludge disposed of annually in 1995 by primary, secondary, or advanced treatment publicly owned treatment works (POTWs) and potential dioxin-like PCB TEQ releases

Use/disposal practice	Volume disposed of (1,000 dry metric tons/yr)	Percent of total volume	Potential dioxin release[a] (g TEQ/yr)	
			TEQ_P-WHO_{98}	TEQ_P-WHO_{94}
Land application[b]	2,500	39.7	60.5	62.8
Advanced treatment[c]	700	11.1	16.9	17.6
Other beneficial use[d]	500	7.9	12.1	12.6
Surface disposal/Landfill	1,100	17.5	26.6	27.6
Incineration	1,400	22.2	e	e
Other disposal method	100	1.6	2.4	2.5
TOTAL	6,300	100	118.5	123.1

[a] Potential TEQ release for nonincinerated sludges was estimated by multiplying the sludge volume generated (column 2) by the mean dioxin-like PCB TEQ concentration in 74 POTW sludges reported by Green et al. (1995) and Cramer et al. (1995) (i.e., 24.2 ng TEQ_P- WHO_{98}/kg and 25.1 ng TEQ_P-WHO_{94}/kg).

[b] Without further processing or stabilization, such as composting.

[c] Such as composting.

[d] EPA assumed that this category includes distribution and marketing (i.e., sale or give-away of sludge for use in home gardens). Based on the 1988 National Sewage Sludge Survey and 1988 Needs Survey, approximately 1.3% of the total volume of sewage disposed was distributed and marketed (Federal Register, 1993a). Therefore, it is estimated that 2 g (TEQ_P-WHO_{98} and TEQ_P-WHO_{94}) were released through distribution and marketing in 1995.

[e] See Section 3.5 for estimates of CDD/CDF releases to air from sewage sludge incinerators.

Sources: U.S. EPA (1999b); Green et al. (1995); Cramer et al. (1995).

These tables also list the estimated amount of dioxin-like PCB TEQs that may be present in sewage sludge and potentially released to the environment. For reference years 1987 and 1995, these values were estimated using the POTW mean TEQ_P-WHO_{98} concentration calculated from the results reported by Green et al. (1995) and Cramer et al. (1995). For reference year 2000, they were estimated using the POTW mean TEQ_P-WHO_{98} concentration reported by EPA (U.S. EPA, 2002d) as part of the 2001 National Sewage Sludge Survey. Multiplying these TEQ concentrations by the sludge volumes generated yields annual potential total releases of 101 g TEQ_P-WHO_{98} (104.2 g TEQ_P-WHO_{94}) in 1987, 118.5 g TEQ_P-WHO_{98} (123.1 g TEQ_P-WHO_{94}) in 1995, and 26.6 g TEQ_P-WHO_{98} in 2000 for nonincinerated sludges.

Table 10-12. Quantity of sewage sludge disposed of annually in 2000 by primary, secondary, or advanced treatment publicly owned treatment works (POTWs) and potential dioxin-like PCB TEQ releases

Use/disposal practice	Volume disposed of (1,000 dry metric tons/yr)	Percent of total volume	Potential TEQ_{DF}-WHO_{98} release[a] (g TEQ/yr)
Land application[b]	2,800	42.4	14.6
Advanced treatment[c]	800	12.1	4.2
Other beneficial use[d]	500	7.6	2.6
Surface disposal/landfill	900	13.6	4.7
Incineration	1,500	22.7	e
Other disposal method	100	1.5	0.5
TOTAL	6,600	100	26.6

[a] Potential dioxin TEQ release for nonincinerated sludges was estimated by multiplying the sludge volume generated (column 2) by the average of the mean TEQ_{DF}-WHO_{98} concentrations in sludge reported by U.S. EPA (2002c) (i.e., 5.22 ng TEQ_{DF}-WHO_{98}/kg).
[b] Without further processing or stabilization, such as composting.
[c] Such as composting.
[d] EPA assumed that this category includes distribution and marketing (i.e., sale or give-away of sludge for use in home gardens). Based on the 1988 National Sewage Sludge Survey and 1988 Needs Survey, approximately 1.3% of the total volume of sewage disposed of was distributed and marketed (Federal Register, 1993a). Therefore, it is estimated that 0.5 g TEQ_{DF}-WHO_{98} were released through distribution and marketing in 2000.
[e] See Section 3.5 for estimates of CDD/CDF releases to air from sewage sludge incinerators.

Sources: U.S. EPA (1999b, 2002d).

Of the 101 g TEQ_P-WHO_{98} released in 1987, 1.7 g entered commerce as a product for distribution and marketing and the remainder was applied to land (41.5 g to land application and 9.6 g to surface disposal sites) or landfilled (48.2 g). Of the 118.5 g TEQ_P-WHO_{98} released in 1995, 60.5 g were applied to land without further processing or stabilization, 16.9 g underwent advanced treatment such as composting, 26.6 g were disposed of on the surface or landfilled, and the remainder was either used or disposed of in other ways. Of the 26.6 g TEQ_P-WHO_{98} released in 2000, 14.6 g were applied to land without further processing or stabilization, 4.2 g underwent advanced treatment such as composting, 4.7 g were disposed of on the surface or landfilled, and the remainder was either used or disposed of in other ways. The PCBs in landfilled sludge were not considered releases to the environment under the definition established in this document. The other disposal practices were considered releases and were summed to get total land releases, as shown in Table 10-2 (above).

The 1987 and 1995 release estimates are assigned a confidence rating of B, indicating high confidence in the production estimate and medium confidence in the emission factor estimates. The medium rating was based on the judgment that, although the 74 facilities tested by Green et al. (1995) and Cramer et al. (1995) may be reasonably representative of the variability in POTW technologies and sewage characteristics nationwide, the sample size was still relatively small, and not all dioxin-like PCB congeners were monitored. The 2000 release estimates are assigned a confidence rating of A, indicating high confidence in both the production estimate and the emission factor estimates. High confidence was placed in the emission factors estimated because they were weighted on the basis of wastewater flow rates of all POTWs in the United States.

10.3. CHEMICAL MANUFACTURING AND PROCESSING SOURCES

In the early 1980s, EPA investigated the extent of inadvertent generation of PCBs during the manufacture of synthetic organic chemicals (Hammerstrom et al., 1985). For example, phthalocyanine dyes and diarylide pigments were reported to contain PCBs in the milligram-per-kilogram range. EPA subsequently issued regulations under TSCA (40 CFR 761.3) that ban the distribution in commerce of any products containing an annual average PCB concentration of 25 mg/kg (50 mg/kg maximum concentration at any time). In addition, EPA requires manufacturers with processes that inadvertently generate PCBs and importers of products that contain inadvertently generated PCBs to report to EPA any process or import for which the PCB concentration is greater than 2 mg/kg for any resolvable PCB gas chromatographic peak.

10.4. COMBUSTION SOURCES

10.4.1. Municipal Waste Combustors

Municipal waste combustors (MWCs) have long been identified as potential PCB air emission sources. Stack gas concentrations of PCBs for three MWCs were reported (U.S. EPA, 1987d); the average test results yielded an emission factor of 18 μg/kg refuse. Stack gas emissions of PCBs from the three MWCs were quantified without determining the MWCs' PCB destruction efficiency.

EPA also analyzed the PCB content of various consumer paper products (U.S. EPA, 1987d). The results indicated that paper products such as magazine covers and paper towels contained up to 139 μg/kg paper. These levels, which were reported in 1981, were attributed to the repeated recycling of waste paper containing PCBs. For example, carbonless copy paper manufactured prior to 1971 contained PCB levels as high as 7%. This copy paper then became a component of waste paper, which was recycled. The PCBs were inevitably introduced into other paper products, resulting in continued measurable levels in municipal refuse some four years after the PCB manufacturing ban was imposed. Refuse-derived fuel manufactured from these paper products had PCB levels of 8,500 μg/kg, indicating that this fuel could be a source of atmospheric PCBs. Therefore, it was assumed that municipal refuse does contain detectable levels of PCBs and that some of these PCBs may enter the atmosphere when the refuse is incinerated (U.S. EPA, 1987d).

Shane et al. (1990) analyzed fly ash from five MWCs for PCB congener group content. Total PCB levels ranged from 99 to 322 μg/kg in the ash, with the tri, tetra, and penta congener groups occurring in the highest concentrations. The investigators also analyzed seven bottom ash and eight bottom ash/fly ash mixtures for total PCB measured as Aroclor 1254. The DL for this Aroclor analysis was 5 μg/kg. Aroclor 1254 was detected in two of the seven bottom ash samples (26 and 8 μg/kg) and in five of the eight fly ash/bottom ash mixtures (range, 6 to 33 μg/kg).

Sakai et al. (2001) analyzed the PCB levels in fly ash and bottom ash from a newly constructed MWC in Japan. The I-TEQ values derived from the data give a total TEQ value of 31.6 ng/kg for fly ash and 0.85 ng/kg for bottom ash.

The development of more sensitive analytical methodologies has enabled researchers in recent years to detect dioxin-like PCB congeners in the stack gases and fly ash from full-scale and pilot-scale MWCs (Sakai et al., 1993a, b, 1994, 2001; Boers et al., 1993; Schoonenboom et al., 1993). Similarly, the advances in analytical techniques have enabled researchers to determine that dioxin-like PCBs can be formed during the oxidative solid combustion phase of incineration, presumably due to dimerization of chlorobenzenes. Laboratory-scale studies have also demonstrated that dioxin-like PCBs can be formed from heat treatment of fly ash in air (Schoonenboom et al., 1993; Sakai et al., 1994); however, the available data are not adequate to support development of a quantitative estimate of a dioxin-like PCB emission factor for this source category. MWCs are designated as a Category E source.

10.4.2. Industrial Wood Combustion

Emissions of PCB congener groups (but not individual congeners) were measured during stack testing at two industrial wood-burning facilities (CARB, 1990d, e). Table 10-13 presents the average of the congener group (monochlorobiphenyl [MCB] through decachlorobiphenyl [DCB]) emission factors for these two facilities. No tetra- or higher-chlorinated congeners (the congener groups containing the dioxin-like PCBs) were detected at either facility at DLs corresponding to emission factors in the low range of nanogram per kilogram of wood combusted.

Table 10-13. PCB congener group emission factors for industrial wood combustors[a]

Congener group	Number of detections	Maximum concentration detected (ng/kg wood)	Mean concentration (ng/kg)	
			Nondetect set to detection limit	Nondetect set to zero
Monochlorobiphenyls	1	32.1	39.4	16
Dichlorobiphenyls	1	23	50.9	11.5
Trichlorobiphenyls	1	19.7	42.3	9.8
Tetrachlorobiphenyls	0	--	22.7	--
Pentachlorobiphenyls	0	--	17.6	--
Hexachlorobiphenyls	0	--	17	--
Heptachlorobiphenyls	0	--	17.9	--
Octachlorobiphenyls	0	--	15.8	--
Nonachlorobiphenyls	0	--	25	--
Decachlorobiphenyls	0	--	36.3	--

[a] Two sites for each congener group.

-- = No information given

Source: CARB (1990d, e).

In CARB (1990d), PCBs were measured in the emissions from two spreader stoker wood-fired boilers operated in parallel by an electric utility for generating electricity. The exhaust gas stream from each boiler was passed through a dedicated electrostatic precipitator (ESP), after which the gas streams were combined and emitted to the atmosphere through a common stack. Stack tests were conducted both when the facility burned fuels allowed by existing permits and when the facility burned a mixture of permitted fuel supplemented by urban wood waste at a ratio of 70:30.

In CARB (1990e), PCBs were measured in the emissions from twin fluidized-bed combustors designed to burn wood chips to generate electricity. The air pollution control device (APCD) system consisted of ammonia injection for controlling nitrogen oxides and a multiclone and an ESP for controlling PM. During testing, the facility burned wood wastes and agricultural wastes allowed by existing permits. The available data are not adequate to support development of a quantitative estimate of dioxin-like PCB emissions from this source. Industrial wood combustion is designated as a Category E source.

10.4.3. Medical Waste Incineration

As discussed in Chapter 3, Section 3.3, EPA has issued nationally applicable emission standards and guidelines that address CDD/CDF emissions from medical waste incinerators (MWIs). Although PCBs are not addressed in these regulations, the database of stack test results at MWIs compiled for this rulemaking does contain limited data on PCB congener group emission factors. Data are available for two MWIs lacking add-on APCD equipment and for two MWIs with add-on APCD equipment in place. The average congener group emission factors derived from these test data are presented in Table 10-14. Because data are available for only 4 of the estimated 1,065 facilities that make up this industry, and because these data do not provide congener-specific emission factors, no national estimates of total PCB or dioxin-like PCB emissions are being made at this time. Medical waste incineration is designated as a Category E source.

Table 10-14. PCB congener group emission factors for medical waste incinerators (MWIs)[a]

Congener group	Mean emission factor (ng/kg) (2 MWIs without APCD)		Mean emission factor (ng/kg) (2 MWIs with APCD)	
	Nondetects set to detection limit	Nondetects set to zero	Nondetects set to detection limit	Nondetects set to zero
Monochlorobiphenyls	0.059	0.059	0.311	0
Dichlorobiphenyls	0.083	0.083	0.34	0
Trichlorobiphenyls	0.155	0.155	0.348	0
Tetrachlorobiphenyls	4.377	4.377	1.171	0
Pentachlorobiphenyls	2.938	2.938	17.096	9.996
Hexachlorobiphenyls	0.238	0.238	1.286	1.078
Heptachlorobiphenyls	0.155	0.155	0.902	0
Octachlorobiphenyls	0.238	0.238	0.205	0
Nonachlorobiphenyls	0.155	0.155	--	--
Decachlorobiphenyls	0.155	0.155	0.117	0

[a] See Section 3.3 for details on tested facilities.

APCD = Air pollution control device
-- = No information given

10.4.4. Tire Combustion

As discussed in Chapter 3, Section 3.6, tires are burned in a variety of facilities, including dedicated tire burners, cement kilns, industrial boilers, and pulp and paper combustion facilities. Emissions of PCB congener groups (but not individual congeners) were measured during stack testing of a tire incinerator (CARB, 1991). The facility consisted of two excess air furnaces equipped with steam boilers to recover the energy from the heat of combustion. Discarded whole tires were fed to the incineration units at rates ranging from 2,800 to 5,700 kg/hr during the three testing days. The furnaces were equipped to burn natural gas as auxiliary fuel. The steam produced from the boilers drove electrical turbine generators that produced 14.4 megawatts of electricity. The facility was equipped with a dry acid gas scrubber and a fabric filter for the control of emissions prior to exiting the stack. Table 10-15 presents the congener group (MCB through DCB) emission factors for this facility. The emission factor for the total of the tetra- through heptachlorinated congener groups was about 1.2 μg/kg tire processed. Because these data do not provide PCB congener-specific emission factors, no estimates of emissions of dioxin-like PCBs can be made. Tire combustion is designated as a Category E source.

Table 10-15. PCB congener group emission factors for a tire combustor[a]

Congener group	Number of detections	Maximum emission factor (ng/kg)	Mean emission factor (ng/kg)	
			Nondetect set to detection limit	Nondetect set to zero
Monochlorobiphenyls	0	--	0.04	--
Dichlorobiphenyls	1	34.8	11.7	11.6
Trichlorobiphenyls	1	29.5	11.8	9.8
Tetrachlorobiphenyls	0	--	10	--
Pentachlorobiphenyls	2	2,724	1,092	1,092
Hexachlorobiphenyls	1	106.5	55.9	35.5
Heptachlorobiphenyls	1	298.6	107.7	99.5
Octachlorobiphenyls	0	--	20.9	--
Nonachlorobiphenyls	0	--	17.7	--
Decachlorobiphenyls	0	--	41.9	--

[a]Three samples for each congener group.

-- = No information given

Source: CARB (1991).

10.4.5. Cigarette Smoking

Using high-resolution mass spectrometry, Matsueda et al. (1994) analyzed tobacco from 20 brands of commercially available cigarettes collected in 1992 from Japan, the United States, Taiwan, China, the United Kingdom, Germany, and Denmark for the PCB congeners 77, 126, and 169. Table 10-16 presents the results of the study. However, no studies examining tobacco smoke for the presence of these congeners have been reported. Thus, it is not known whether the PCBs present in the tobacco are destroyed or volatilized during combustion or whether PCBs are formed during combustion. At least 1,200 tobacco constituents (e.g., nicotine, n-paraffin, some terpenes) are transferred intact from the tobacco into the smoke stream by distillation in this area, and it is plausible that PCBs present in the unburned tobacco would be subject to similar distillation.

Cigarette consumption and the combustion processes operating during cigarette smoking are discussed in Chapter 5, Section 5.5.

A preliminary rough estimate of potential emissions of dioxin-like PCBs can be made using the following assumptions: (a) the average TEQ_P-WHO_{98} content of seven brands of U.S. cigarettes reported by Matsueda et al. (1994), 0.64 pg/pack (0.032 pg/cigarette), is representative of cigarettes smoked in the United States; (b) dioxin-like PCBs are neither formed nor destroyed, and the congener profile reported by Matsueda et al. (1994) is not altered during combustion of cigarettes; and (c) all dioxin-like PCBs contributing to the TEQ are released from the tobacco during smoking. On the basis of these assumptions, the calculated annual emissions would be 0.018 g TEQ_P-WHO_{98}, 0.016 g TEQ_P-WHO_{98}, and 0.014 g TEQ_P-WHO_{98} for reference years 1987, 1995, and 2000, respectively. These estimates are assigned a confidence rating of D because the emission factor is clearly not representative of cigarette smoke.

10.4.6. Sewage Sludge Incineration

EPA (U.S. EPA, 1996g) derived an emission factor of 5.4 μg PCBs/kg dry sewage sludge incinerated. This emission factor was based on measurements conducted at five multiple-hearth incinerators controlled with wet scrubbers. However, it is not known what fraction of the emissions was dioxin-like PCBs.

In 1999, stack tests were conducted at a multiple-hearth incinerator in Ohio equipped with a venturi scrubber and a three-tray impingement conditioning tower (U.S. EPA, 2000b). Of the four test runs conducted, the first test run was aborted and the results from the fourth test run were determined to be statistical outliers ($p>0.05$). The back-half CDD/CDF concentrations for test run 4 were 50 to 60% lower than back-half emission concentrations for test runs 2 and 3. Because of the problems associated with test run 4, the results were not used to calculate an emission factor for dioxin-like PCBs. The average TEQ emission factor (excluding test run 4)

Table 10-16. Dioxin-like PCB concentrations in cigarette tobacco in brands from various countries (pg/pack)[a]

Congener	IUPAC number	U.S. (avg. of 7 brands)	Japan (avg. of 6 brands)	United Kingdom (avg. of 3 brands)	Taiwan (1 brand)	China (1 brand)	Denmark (1 brand)	Germany (1 brand)
3,3',4,4'-TCB	77	105.7	70.2	53	133.9	12.6	21.7	39.3
3,4,4',5-TCB	81							
2,3,3',4,4'-PeCB	105							
2,3,4,4',5-PeCB	114							
2,3',4,4',5-PeCB	118							
2',3,4,4',5-PeCB	123							
3,3',4,4',5-PeCB	126	6.2	7.8	6.1	14.5	2.4	2.2	7.3
2,3,3',4,4',5-HxCB	156							
2,3,3',4,4',5'-HxCB	157							
2,3',4,4',5,5'-HxCB	167							
3,3',4,4',5,5'-HxCB	169	0.9	0.9	0.9	2.4	0.4	0.5	1.6
2,2',3,3',4,4',5-HpCB	170							
2,2',3,4,4',5,5'-HpCB	180							
2,3,3',4,4',5,5'-HpCB	189							
Total TEQ$_P$-WHO$_{98}$		0.64	0.8	0.62	1.49	0.24	0.23	0.75

[a] Blank cells indicate that no measurements of these congeners were made.

Source: Matsueda et al. (1994).

was 0.51 ng TEQ_P-WHO_{98}/kg (see Table 10-17). This emission factor was assigned a low confidence rating because it is based on limited surveys that are judged to be possibly nonrepresentative.

Table 10-17. Dioxin-like PCB concentrations in stack gas collected from a U.S. sewage sludge incinerator

Congener	IUPAC number	Mean emission factor (ng/kg)	
		Nondetect set to ½ detection limit	Nondetect set to zero
3,3',4,4'-TCB	77	92.37	92.37
2,3,3',4,4'-PeCB	105	18	18
2,3,4,4',5-PeCB	114	2.56	2.56
2',3,4,4',5-PeCB	123	0.82	0.82
2,3',4,4',5-PeCB	118	38.65	38.65
3,3',4,4',5-PeCB	126	4.51	4.51
2,3,3',4,4',5-HxCB	156	4.25	4.25
2,3,3',4,4',5'-HxCB	157	1.41	1.41
2,3',4,4',5,5'-HxCB	167	2.55	2.55
3,3',4,4',5,5'-HxCB	169	3.61	3.61
2,2',3,3',4,4',5-HpCB	170	7.19	7.19
2,2',3,4,4',5,5'-HpCB	180	17.79	17.79
2,3,3',4,4',5,5'-HpCB	189	0.6	0.6
Total TEQ_P-WHO_{98}		0.51	0.51

Source: U.S. EPA (2000b).

Approximately 0.865 million dry metric tons of sewage sludge were incinerated in 1988 (Federal Register, 1993a), approximately 2.11 million dry metric tons in 1995 (e-mail dated July 13, 1998, from K. Maw, Pacific Environmental Services, to G. Schweer, Versar, Inc.), and an estimated 1.42 million dry metric tons in 2000 (U.S. EPA, 1999b). Using the above estimated amounts of sewage sludge incinerated per year and the average TEQ emission factor of 0.51 ng TEQ_P-WHO_{98}/kg, the estimated annual releases of total PCBs to air were 0.44 g TEQ_P-WHO_{98} in 1987, 1.1 g TEQ_P-WHO_{98} in 1995, and 0.72 g TEQ_P-WHO_{98} in 2000. These emissions were assigned a low confidence rating (Category C) because the emission factor was given a low rating.

10.4.7. Backyard Barrel Burning

The low combustion temperatures and oxygen-starved conditions associated with backyard barrel burning may result in incomplete combustion and increased pollutant emissions (Lemieux, 1997). EPA's Control Technology Center, in cooperation with New York State's departments of health and environmental conservation, conducted a study to examine, characterize, and quantify emissions from the simulated open burning of household waste materials in barrels (Lemieux, 1997). A representative waste to be burned was prepared on the basis of the typical percentages of various waste materials disposed of by New York State residents (i.e., nonavid recyclers); hazardous wastes such as chemicals, paints, and oils were not included in the test waste. A variety of compounds, including dioxin-like PCBs, were measured in the emissions from the simulated open burning. The measured TEQ emission factors for waste that had not been separated for recycling purposes were 1.02×10^{-2} µg TEQ_P-WHO_{94}/kg and 5.26×10^{-3} µg TEQ_P-WHO_{98}/kg waste burned (see Table 10-18). These limited emissions data were judged to be inadequate for estimating national emissions (a Category E source). The activity level for backyard barrel burning is discussed in Section 6.5.2.

10.4.8. Petroleum Refining Catalyst Regeneration

As discussed in Section 5.4, regeneration of spent catalyst used in catalytic reforming to produce high-octane reformates is a potential source of CDD/CDF air emissions. In 1998, emissions from the caustic scrubber used to treat gases from the external catalyst regeneration unit of a refinery in California were tested for CDDs/CDFs as well as PCB congener groups (CARB, 1999) (see Chapter 5, Section 5.4 for details).

All PCB congener groups were detected in each of the three samples collected. The average congener group emission factors in units of nanograms per barrel of reformer feed are presented in Table 10-19. The total PCB emission factor was 118 ng/barrel. This emission factor assumes that emissions are proportional to reforming capacity; emission factors may be more related to the amount of coke burned, APCD equipment present, and/or other process parameters.

Because emissions data are available for only one U.S. petroleum refinery (which represents less than 1% of the catalytic reforming capacity at U.S. refineries), and because these data do not provide congener-specific emission factors, no national estimates of total PCB or dioxin-like PCB emissions are being made at this time. This is a Category E source.

Table 10-18. Dioxin-like PCB emission factors from backyard barrel burning[a]

Congener	IUPAC number	Emission factors (µg/kg)		
		Test 1	Test 2	Average
3,3',4,4'-TCB	77	9.3	15.2	12.3
3,4,4',5-TCB	81			
2,3,3',4,4'-PeCB	105	5.9	4.9	5.4
2,3,4,4',5-PeCB	114			
2,3',4,4',5-PeCB	118	8.3	14.3	11.3
2',3,4,4',5-PeCB	123	18.6	28.7	23.7
3,3',4,4',5-PeCB	126			
2,3,3',4,4',5-HxCB	156			
2,3,3',4,4',5'-HxCB	157			
2,3',4,4',5,5'-HxCB	167			
3,3',4,4',5,5'-HxCB	169			
2,2',3,3',4,4',5-HpCB	170			
2,2',3,4,4',5,5'-HpCB	180			
2,3,3',4,4',5,5'-HpCB	189			
Total TEQ_P-WHO_{98}		4.21e-03	6.31e-03	5.26e-03

[a]Blank cells indicate that the congener was not detected in either of the two duplicate samples.

Source: Lemieux (1997).

Table 10-19. PCB congener group emission factors for a petroleum catalytic reforming unit[a]

Congener group	Mean concentration (ng/dscm) (at 12% O_2)	Mean emission rate (lb/hr)	Mean emission factor (lb/1000 bbl)	Mean emission factor (ng/barrel)
Monochlorobiphenyls	166	5.51e-08	7.11e-09	3.23e+00
Dichlorobiphenyls	355	1.17e-07	1.52e-08	6.89e+00
Trichlorobiphenyls	743	2.45e-07	3.17e-08	1.44e+01
Tetrachlorobiphenyls	849	2.81e-07	3.62e-08	1.64e+01
Pentachlorobiphenyls	914	3.02e-07	3.88e-08	1.76e+01
Hexachlorobiphenyls	780	2.57e-07	3.30e-08	1.50e+01
Heptachlorobiphenyls	1,430	4.73e-07	6.01e-08	2.73e+01
Octachlorobiphenyls	698	2.32e-07	2.95e-08	1.34e+01
Nonachlorobiphenyls	179	5.99e-08	7.59e-09	3.44e+00
Decachlorobiphenyls	41.3	1.39e-08	1.76e-09	7.98e-01
Total PCBs	6,155.3	2.04e-06	2.61e-07	1.18e+02

[a]Three samples and three detections for each congener group.

Source: CARB (1999).

10.5. NATURAL SOURCES

This section discusses biotransformation and photochemical transformation of other PCBs. Although there is some evidence that these processes occur, the data were considered insufficient for developing release estimates.

10.5.1. Biotransformation of Other PCBs

Studies show that under anaerobic conditions, biologically mediated reductive dechlorination to lower-chlorinated congeners, followed by slow anaerobic and/or aerobic biodegradation, is a major pathway for destruction of PCBs in the environment. Research reported to date and summarized below indicates that biodegradation should result in a net decrease rather than a net increase in the environmental load of dioxin-like PCBs.

Laboratory studies (e.g., Bedard et al., 1986; Pardue et al., 1988; Larsson and Lemkemeier, 1989; Hickey, 1995; Schreiner et al., 1995) have revealed that more than two dozen strains of aerobic bacteria and fungi that are capable of degrading most PCB congeners with five or fewer chlorines are widely distributed in the environment. Many of these organisms are of the genus *Pseudomonas* or *Alcaligenes*. The major metabolic pathway involves addition of oxygen at the 2,3-position by a dioxygenase enzyme, with subsequent dehydrogenation to the catechol followed by ring cleavage. Several bacterial strains have been shown to possess a dioxygenase enzyme that attacks the 3,4-position.

Only a few strains have demonstrated the ability to degrade hexachlorobiphenyl (HxCB) and the higher-chlorinated biphenyls. The rate of aerobic biodegradation decreases with increasing chlorination. The half-lives for biodegradation of tetrachlorobiphenyls (TCBs) in fresh surface water and soil are 7 to 60+ days and 12 to 30 days, respectively. For pentachlorobiphenyls (PeCBs) and the higher-chlorinated PCBs, the half-lives in fresh surface water and soil are likely to exceed 1 year. PCBs with all or most chlorines on one ring and PCBs with fewer than two chlorines in the ortho position tend to degrade more rapidly. For example, Gan and Berthouex (1994) monitored over a 5-yr period the disappearance of PCB congeners applied to soil with sewage sludge. Three of the tetra- and pentachlorinated dioxin-like PCBs (IUPAC Nos. 77, 105, and 118) followed a first-order disappearance model, with half-lives ranging from 43 to 69 months. A hexa-substituted congener (IUPAC No. 167) and a hepta-substituted congener (IUPAC No. 180) showed no significant loss over the 5-yr period.

Prior to the early 1990s, little investigation focused on anaerobic microbial dechlorination or degradation of PCBs, even though most PCBs eventually accumulate in anaerobic sediments (Abramowicz, 1990; Risatti, 1992). Environmental dechlorination of PCBs via losses of meta and para chlorines has been reported in field studies for freshwater, estuarine, and marine anaerobic sediments, including those from the Acushnet Estuary, the Hudson River, the

Sheboygan River, New Bedford Harbor, Escambia Bay, Waukegan Harbor, the Housatonic River, and Woods Pond (Brown et al., 1987; Rhee et al., 1989; Van Dort and Bedard, 1991; Abramowicz, 1990; Bedard et al., 1995; Bedard and May, 1996). The altered PCB congener distribution patterns found in these sediments (i.e., different patterns with increasing depth or distance from known sources of PCBs) have been interpreted as evidence that bacteria may dechlorinate PCBs in anaerobic sediment.

Reported results of laboratory studies confirm anaerobic degradation of PCBs. Chen et al. (1988) found that "PCB-degrading" bacteria from the Hudson River could significantly degrade the MCB, dichlorobipheyl (DiCB), and trichlorobiphenyl (TrCB) components of a 20 ppm Aroclor 1221 solution within 105 days. These congener groups make up 95% of Aroclor 1221. No degradation of higher-chlorinated congeners (present at 30 ppb or less) was observed, and a separate 40-day experiment with TCB also showed no degradation.

Rhee et al. (1989) reported degradation of mono- to penta-substituted PCBs in contaminated Hudson River sediments held under anaerobic conditions in the laboratory (N_2 atmosphere) for 6 months at 25°C. Amendment of the test samples with biphenyl resulted in greater loss of PCBs. No significant decreases in the concentrations of the higher-chlorinated congeners (more than five chlorines) were observed. No evidence of degradation was observed in samples incubated in CO_2/H_2 atmospheres. Abramowicz (1990) hypothesized that this result could be an indication that, in the absence of CO_2, a selection is imposed favoring organisms capable of degrading PCBs to obtain CO_2 and/or low-molecular-weight metabolites as electron receptors.

Risatti (1992) examined the degradation of PCBs at varying concentrations (10,000 ppm, 1,500 ppm, and 500 ppm) in the laboratory with "PCB-degrading" bacteria from Waukegan Harbor. After nine months of incubation at 22°C, the 500 ppm and 1,500 ppm samples showed no change in PCB congener distributions or concentrations, thus indicating a lack of degradation. Significant degradation was observed in the 10,000 ppm sediment, with at least 20 congeners ranging from the TrCBs through the PeCBs showing decreases.

Quensen et al. (1988) also demonstrated that microorganisms from PCB-contaminated sediments (Hudson River) dechlorinated most TrCBs through HxCBs in Aroclor 1242 under anaerobic laboratory conditions. The Aroclor 1242 used to spike the sediment contained predominantly TrCBs and TCBs (85 mol percent). Three concentrations of the Aroclor, corresponding to 14, 140, and 700 ppm on a sediment dry-weight basis, were used. Dechlorination was most extensive at the 700 ppm test concentration: 53% of the total chlorine was removed in 16 weeks, and the proportion of TCBs through HxCBs decreased from 42 to 4%. Much less degradation was observed in the 140 ppm sediment, and no observable degradation was found in the 14ppm sediment. These results and those of Risatti (1992) suggest that the organism(s) responsible for this dechlorination may require relatively high levels of PCBs as a terminal electron acceptor to maintain a growing population.

Quensen et al. (1990) reported that dechlorination of 500 ppm spike concentrations of Aroclor 1242, 1248, 1254, and 1260 by microorganisms from PCB-contaminated sediments in the Hudson River and Silver Lake occurred primarily at the meta and para positions; ortho-substituted MCBs and DiCBs increased in concentration. Significant decreases over the incubation period (up to 50 weeks) were reported for dioxin-like PCBs 156, 167, 170, 180, and 189. Of the four dioxin-like TCBs and PeCBs detected in the Aroclor spikes (IUPAC Nos. 77, 105, 114, and 118), all decreased significantly in concentration, with the possible exception of PeCB 114 in the Aroclor 1260-spiked sediment.

Nies and Vogel (1990) reported similar results with Hudson River sediments incubated anaerobically and enriched with acetone, methanol, or glucose. Approximately 300 ppm of Aroclor 1242 (31 mol percent TCBs, 7 mol percent PeCBs, and 1 mol percent HxCBs) were added to the sediments prior to incubation for 22 weeks under an N_2 atmosphere. Significant dechlorination was observed, primarily at the meta and para positions on the higher-chlorinated congeners (TCBs, PeCBs, and HxCBs), resulting in the accumulation of lower-chlorinated, primarily ortho-substituted mono- through tri-substituted congeners. No significant dechlorination was observed in the control samples (samples containing no added organic chemical substrate and samples that were autoclaved).

Bedard and May (1996) also reported similar findings in the sediments of Woods Pond, which was believed to be contaminated with Aroclor 1260. Significant decreases in the sediment concentrations of PCBs 118, 156, 170, and 180 (relative to their concentrations in Aroclor 1260) were observed. No increases or decreases were reported for the other dioxin-like PCBs.

Bedard et al. (1995) demonstrated that it is possible to stimulate substantial microbial dechlorination of the highly chlorinated PCB mixture Aroclor 1260 in situ with a single addition of 2,6-dibromobiphenyl. The investigators added 365 g of 2,6-dibromobiphenyl to 6-ft-diameter submerged caissons containing 400 kg sediment (dry weight) and monitored the change in PCB congener concentrations for a period of one year. At the end of the observation period, the MCBs through HxCBs decreased by 74% in the top of the sediment and by 69% in the bottom. The average number of chlorines per molecule dropped 21%, from 5.83 to 4.61, with the largest reduction observed in meta chlorines (54% reduction) followed by para chlorines (6%). The dechlorination stimulated by 2,6-dibromobiphenyl selectively removed meta-chlorines positioned next to other chlorines.

The findings of these latter studies are significant, because removal of meta and para chlorines from the dioxin-like PCBs should reduce their toxicity and bioaccumulative potential and also lead to the formation of lower-chlorinated congeners that are more amenable to aerobic biodegradation.

Van Dort and Bedard (1991) reported the first experimental demonstration of biologically mediated ortho-dechlorination of a PCB and stoichiometric conversion of that PCB congener (2,3,5,6-TCB) to lower-chlorinated forms. In that study, 2,3,5,6-TCB was incubated under anaerobic conditions with unacclimated methanogenic pond sediment for 37 weeks, with reported dechlorination to 2,5-DiCB (21%); 2,6-DiCB (63%); and 2,3,6-TrCB (16%).

10.5.2. Photochemical Transformation of Other PCBs

Photolysis and photo-oxidation may be major pathways for destruction of PCBs in the environment. Research reported to date and summarized below indicates that ortho-substituted chlorines are more susceptible to photolysis than are meta- and para-substituted congeners; thus, photolytic formation of more toxic dioxin-like PCBs may occur. Oxidation by hydroxyl radicals, however, apparently occurs preferentially at the meta and para positions, resulting in a net decrease rather than a net increase in the environmental load of dioxin-like PCBs.

On the basis of the data available in 1983, Leifer et al. (1983) concluded that all PCBs, especially the higher-chlorinated congeners and those that contain two or more chlorines in the ortho position, photodechlorinate. In general, as the chlorine content increases, the photolysis rate increases. More recently, Lepine et al. (1992) exposed dilute solutions (4 ppm) of Aroclor 1254 in cyclohexane to sunlight for 55 days in December and January. Congener-specific analysis indicated that the amounts of many higher-chlorinated congeners, particularly mono-ortho-substituted congeners, decreased, whereas those of some lower-chlorinated congeners increased. The results for the dioxin-like PCBs indicated a 43.5% decrease in the amount of PeCB 114, a 73.5% decrease in the amount of HxCB 156, and a 24.4% decrease in the amount of HxCB 157. However, TCB 77 and PeCB 126 (the most toxic of the dioxin-like PCB congeners), which were not detected in unirradiated Aroclor 1254, represented 2.5% and 0.43%, respectively, of the irradiated mixture.

With regard to photo-oxidation, Atkinson (1987) and Leifer et al. (1983), using assumed steady-state atmospheric OH concentrations and measured oxidation rate constants for biphenyl and MCB, estimated atmospheric decay rates and half-lives for gas-phase PCBs. Atmospheric transformation was estimated to proceed most rapidly for those PCB congeners containing either a small number of chlorines or those containing all or most of the chlorines on one ring. Kwok et al. (1995) extended the work of Atkinson (1987) by measuring the OH radical reaction rate constants for 2,2'-, 3,3'-, and 3,5-DiCB. These reaction rate constants, when taken together with Atkinson's measurements for biphenyl and MCB and the estimation method described in Atkinson (1991), were used to generate more reliable estimates of the gas-phase OH radical reaction rate constants for the dioxin-like PCBs. The persistence of the PCB congeners increased with increasing degree of chlorination. Table 10-20 presents these estimated rate constants and the corresponding tropospheric lifetimes and half-lives.

Table 10-20. Estimated tropospheric half-lives of dioxin-like PCBs with respect to gas-phase reaction with the OH radical

Congener group	Dioxin-like congener	Estimated OH reaction rate constant (10^{-12} cm^3/ molecule-sec)	Estimated tropospheric lifetime (days)[a]	Estimated tropospheric half-life (days)[a]
Tetrachlorobiphenyls	3,3',4,4'-TCB	0.583	20	14
	3,4,4',5-TCB	0.71	17	12
Pentachlorophenyls	2,3,3',4,4'-PeCB	0.299	40	28
	2,3,4,4',5-PeCB	0.383	31	22
	2,3',4,4',5-PeCB	0.299	40	28
	2',3,4,4',5-PeCB	0.482	25	17
	3,3',4,4',5-PeCB	0.395	30	21
Hexachlorobiphenyls	2,3,3',4,4',5-HxCB	0.183	65	45
	2,3,3',4,4',5'-HxCB	0.214	56	39
	2,3',4,4',5,5'-HxCB	0.214	56	39
	3,3',4,4',5,5'-HxCB	0.266	45	31
Heptachlorobiphenyls	2,2',3,3',4,4',5-HpCB	0.099	121	84
	2,2',3,4,4',5,5'-HpCB	0.099	121	84
	2,3,3',4,4',5,5'-HpCB	0.125	95	66

[a] Calculated using a 24-hr, seasonal, annual, and global tropospheric average OH radical concentration of 9.7×10^5 molecule/cm^3 (Prinn et al., 1995).

Source: Telephone conversation on November 16, 1995, between Roger Atkinson, Air Pollution Research Center, University of California, and Greg Schweer, Versar, Inc. (based on Atkinson, 1991, and Kwok et al., 1995).

Sedlak and Andren (1991) demonstrated in laboratory studies that OH radicals generated with Fenton's reagent rapidly oxidized PCBs (2-MCB and the DiCBs through PeCBs present in Aroclor 1242) in aqueous solutions. The results indicated that the reaction occurs via addition of a hydroxyl group to one nonhalogenated site; reaction rates are inversely related to the degree of chlorination of the biphenyl. The results also indicated that meta and para sites are more reactive than ortho sites due to stearic hindrance effects. On the basis of their kinetic measurements and reported steady-state aqueous system OH concentrations or estimates of OH radical production rates, the authors estimated environmental half-lives for dissolved PCBs (MCB through octachlorobiphenyl) in fresh surface water and in cloud water to be 4 to 11 days and 0.1 to 10 days, respectively.

10.6. PAST USE OF COMMERCIAL PCBs

An estimated total of 1.5 million metric tons of PCBs were produced worldwide (DeVoogt and Brinkman, 1989). Slightly more than one-third of these PCBs (568,000 metric tons) were used in the United States (Versar, Inc., 1976). Although the focus of this section is on past uses of PCBs within the United States, it is necessary to note that the use and disposal of PCBs in many countries, coupled with the persistent nature of PCBs, have resulted in their movement and presence throughout the global environment. The ultimate sink of most PCBs released to the environment is aquatic sediments. Currently, however, large quantities of PCBs are estimated to be circulating between the air and water environments or are present in landfills and dumps, some of which may offer the potential for re-release of PCBs into the air. Tanabe (1988) presented a global mass balance for PCBs that indicated that as of 1985, 20% of the total PCBs produced were present in seawater, whereas only 11% were present in sediments (see Table 10-21). Nearly two-thirds of total global PCB production was estimated by Tanabe to still be in use in electrical equipment or to be present in landfills and dumps.

As discussed in Section 10.2, an estimated 568,000 metric tons of PCBs were sold in the United States between 1930 and 1975 (Versar, Inc., 1976). Table 10-22 presents annual estimates of domestic sales by year for each Aroclor from 1957 to 1974. Estimates of PCB usage in the United States by usage category from 1930 to 1975 are presented in Table 10-23. Prior to voluntary restrictions by Monsanto Corporation in 1972 on sales for uses other than "closed electrical systems," approximately 13% of the PCBs were used in "semi-closed applications," and 26% were used in "open-end applications." Most of the usage for semi-closed and open-end applications occurred between 1960 and 1972 (Versar, Inc., 1976).

Table 10-24 presents estimates of the amounts of individual Aroclors that were directly released to the environment (water, air, or soil) between 1930 and 1974. Because detailed usage data were not available for the period 1930 to 1957, Versar, Inc. (1976) assumed that the usage pattern for this period followed the average pattern for the period of 1957 to 1959. The basic assumption used by Versar in deriving these estimates was that PCBs were released on the order of 5% of those used in closed electrical systems, 60% of those used in semi-closed applications, and 25% of those used for plasticizers and that 90% of PCBs used for miscellaneous industrial uses had escaped. The reliability of these release estimates was assumed to be ±30%.

Versar, Inc. (1976) also estimated that 132,000 metric tons of PCBs were landfilled. This total comprised 50,000 metric tons from capacitor and transformer production wastes, 36,000 metric tons from disposal of obsolete electrical equipment, and 46,000 metric tons from disposal

Table 10-21. Estimated PCB loads in the global environment as of 1985

Environment	PCB load (metric tons)	Percentage of PCB load	Percentage of world production
Terrestrial and coastal			
Air	500	0.13	
River and lake water	3,500	0.94	
Seawater	2,400	0.64	
Soil	2,400	0.64	
Sediment	130,000	35	
Biota	4,300	1.1	
Total	143,100	39	
Open ocean			
Air	790	0.21	
Seawater	230,000	61	
Sediment	110	0.03	
Biota	270	0.07	
Total	231,170	61	
Total load in environment	374,000	100	31
Degraded and incinerated	43,000		4
Land-stocked[a]	783,000		65
World production	1,200,000[b]		100

[a] Still in use in electrical equipment and other products, and deposited in landfills and dumps.

[b] This value is from Tanabe (1988). DeVoogt and Brinkman (1989) estimated worldwide production to have been 1,500,000 metric tons.

Source: Tanabe (1988).

of material from open-end applications. An estimated additional 14,000 metric tons of PCBs, although still "in service" in various semi-closed and open-end applications in 1976, were ultimately destined for disposal in landfills.

An estimated 3,702 kg of TEQ_P-WHO_{98} were released directly to the U.S. environment between 1930 and 1977 (see Table 10-25). These estimates are based on the Aroclor release estimates presented in Table 10-22 and the mean TEQ_P-WHO_{98} concentrations in Aroclors presented in Table 10-3.

Table 10-22. Estimated domestic sales of aroclors and releases of PCBs, 1957–1974 (metric tons)

Year	Estimated domestic sales									Total PCB releases
	Aroclor 1016	Aroclor 1221	Aroclor 1232	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260	Aroclor 1262	Aroclor 1268	
1957	0	10	89	8,265	807	2,023	3,441	14	0	14,649
1958	0	7	51	4,737	1,161	3,035	2,713	83	33	11,820
1959	0	115	109	6,168	1,535	3,064	3,002	163	46	14,202
1960	0	47	70	8,254	1,282	2,761	3,325	148	86	15,973
1961	0	43	109	8,993	1,825	2,855	2,966	164	72	17,027
1962	0	64	102	9,368	1,571	2,869	2,991	196	95	17,256
1963	0	164	6	8,396	2,274	2,681	3,459	188	129	17,297
1964	0	270	6	10,692	2,376	2,849	3,871	202	86	20,352
1965	0	167	3	14,303	2,524	3,509	2,645	253	89	23,493
1966	0	239	7	17,943	2,275	3,191	2,665	348	129	26,797
1967	0	200	11	19,529	2,134	3,037	2,911	381	130	28,333
1968	0	62	41	20,345	2,220	4,033	2,382	327	127	29,537
1969	0	230	124	20,634	2,563	4,455	2,013	323	136	30,478
1970	0	670	118	22,039	1,847	5,634	2,218	464	150	33,140
1971	1,512	1,005	78	9,970	97	2,114	782	0	0	15,558
1972	9,481	78	0	330	366	1,585	138	0	0	11,978
1973	10,673	16	0	2,812	0	3,618	0	0	0	17,119
1974	9,959	26	0	2,815	0	2,805	0	0	0	15,605
TOTAL	31,625	3,413	924	195,593	26,857	56,118	41,522	3,254	1,308	360,614
% of Total	8.8	0.9	0.3	54.2	7.4	15.6	11.5	0.9	0.4	100

Source: Versar, Inc. (1976).

Table 10-23. Estimated U.S. usage of PCBs by use category, 1930–1975

Use class	Use category	Amount used (1,000 metric tons)	Percent of total usage	Reliability of estimate (%)
Closed electrical systems	Capacitors	286	50.3	±20
	Transformers	152	26.8	±20
Semi-closed applications	Heat transfer fluids	9	1.6	±10
	Hydraulics and lubricants	36	6.3	±10
Open-end applications	Plasticizer uses	52	9.2	±15
	Carbonless copy paper	20	3.5	±5
	Misc. industrial	12	2.1	±15
	Petroleum additives	1	<1	±50
TOTAL		568	100	

Source: Versar, Inc. (1976).

Table 10-24. Estimated direct releases of Aroclors to the U.S. environment, 1930–1974[a] (metric tons)

Year	Estimated environmental releases					Total PCB releases
	Aroclor 1016	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260	
1930–56	0	8,486	2,447	2,269	1,614	14,816
1957	0	903	319	307	423	1,952
1958	0	649	483	416	355	1,903
1959	0	1,042	724	518	507	2,791
1960	0	1,340	556	449	540	2,885
1961	0	1,852	792	587	611	3,842
1962	0	1,811	659	554	571	3,595
1963	0	1,655	935	529	682	3,801
1964	0	2,085	980	555	755	4,375
1965	0	2,689	1,025	660	497	4,871
1966	0	3,180	876	566	472	5,094
1967	0	3,376	814	525	504	5,219
1968	0	3,533	853	733	433	5,552
1969	0	4,165	993	985	452	6,595
1970	0	4,569	697	1,168	474	6,908
1971	76	1,466	51	325	121	2,039
1972	474	22	0	104	9	609
1973	534	141	0	181	0	856
1974	498	141	0	140	0	779
TOTAL	1,582	43,105	13,204	11,571	9,020	78,482
% of Total	2.0	54.9	16.8	14.7	11.5	100

[a] Does not include an additional 132,000 metric tons estimated to have been landfilled during this period.

Source: Versar, Inc. (1976).

Table 10-25. Estimated releases of dioxin-like PCB TEQs to the U.S. environment, 1930–1977

Aroclor	Percent of U.S. sales[a] (1957–1974)	Estimated PCB releases (1930–1974)[b] (metric tons)	Estimated mean TEQ_P-WHO_{98} concentration[c] (mg/kg)	Estimated total TEQ_P-WHO_{98} released (kg)
1016	12.88	1,582	d	d
1221	0.96	--	0.328	--
1232	0.24	--	--	--
1242	51.76	43,103	7.47	322
1248	6.76	13,205	16.87	223
1254	15.73	11,572	125.94	1,457
1260	10.61	9,019	188.45	1,700
1262	0.83	--	--	--
1268	0.33	--	--	--
TOTAL				3,702

[a] Sales during the period 1957–1974 constituted 63% of all PCB sales during 1930–1977. Sales data for individual Aroclors are not available for years prior to 1957; however, sales of Aroclors 1221, 1232, 1262, and 1268 were minor even prior to 1957.

[b] From Table 10-24.

[c] From Table 10-3 (assumes nondetect values are zero).

[d] Data are available for only a few samples of Aroclor 1016 where only two dioxin-like PCB congeners were detected. The total TEQ_P-WHO_{98} released is less than 0.01 kg.

-- = Indicates that release estimates were not made because of relatively low usage amounts

Source: Versar, Inc. (1976).

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FINAL REPORT FOR PHASE II
ENVIRONMENTAL INVESTIGATION SERVICES
PCB INVESTIGATION
SAN DIEGO GAS & ELECTRIC FACILITIES

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FINAL REPORT FOR PHASE II
ENVIRONMENTAL INVESTIGATION SERVICES
PCB INVESTIGATION
SAN DIEGO GAS & ELECTRIC FACILITIES

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LIST OF APPENDICES

1.0 INTRODUCTION

EnecoTech Southwest, Inc. (EnecoTech) has prepared this report detailing the Polychlorinated Biphenyls (PCB) sampling activities performed on October 29, 30, 31, and November 7, 1996. This report was requested by San Diego Gas & Electric (SDG&E) for submittal to the Department of Toxic Substances Control (DTSC) as specified in the EnecoTech proposal dated September 11, 1996. This report has been written to comply with the requirements of the Health and Safety Code, Division 20, Section 25200.14(d), and the County of San Diego, Site Assessment and Mitigation Division (SA/M), guidelines.

2.0 BACKGROUND

In response to findings of a Tiered Permitting Phase I Environmental Assessment performed by SDG&E for DTSC, EnecoTech conducted an investigation to assess stains and discoloration of soil and concrete structures adjacent to oil-containing transformers and circuit breakers for the presence of PCBs. The subject area was comprised of four sites: Silvergate Power Plant (1348 Sampson Street, San Diego, CA), [redacted] As required for PCB management under the Toxic Substances Control Act (TSCA), release of material may require compliance with spill response and agency reporting requirements. The permissible limit for PCBs in soil is 25 mg/kg. Soil may contain up to 50 mg/kg if the area is marked with a label or notice indicating the possible levels of PCB exposure. Surfaces were sampled to assess PCB levels relative to the 100 μg/100 square centimeter (cm^2) limit for low-contact, outdoor surfaces. Permissible limits are found in <u>EPA Regulations for PCB Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions</u>, Subpart G, Section 761.125. TSCA required the US EPA to develop rules controlling the manufacturing, processing, distribution in commerce, use, handling, storage, and disposal of PCBs. These regulations can be found in 40 CFR (Code of Federal Regulations), Part 761. Subpart G, Section 761.125, states the requirements for PCB spill cleanup.

3.0 FIELD ACTIVITIES AND ANALYTICAL RESULTS

3.1 Field Procedures

Surface wipe sampling was performed on oily-stained areas on concrete bases of Oil Circuit Breakers (OCB), Circuit Breakers (CIR), and Transformers (labeled as "Bank" or "Unit" followed by a number and a direction, for example - "Bank 4E"). Wipe samples were taken utilizing a 100 cm^2 square template which was placed flush on the object surface. A clean absorbent towel soaked in liquid hexane was then used to wipe off surface material.

Soil sampling was performed on areas where the stain extended beyond equipment's concrete bases or where a drip/leak directly impacted the soil. Stains were primarily caused by a combination of leaking drain valves and leaking transformer cooling fin assemblies. Soil samples were collected no deeper than one foot below ground surface at each stained area. In areas where the soil was overlain by a crushed rock or gravel soil covering, this material was moved aside to obtain the soil sample. Details of EnecoTech sampling procedures are included in Appendix B.

3.2 Site Safety and Waste Disposal

As specified in the PCB sampling procedures found in Appendix B, personal protective equipment was utilized in all four sites. A Photo-Ionization Detector was utilized to measure part per million (ppm) exposure to the sampling solvent (hexane) to determine the need for respiratory protection. Readings of 125 ppm eposure to the solvent during PCB wipe sampling established the need for respiratory protection. An organic vapor chemical cartridge was worn in conjunction with a HEPA particulate filter to prevent exposure to hexane and to eliminate the possibility of PCB-containing dust particulate from entering the respiratory tract. Polycoated tyvek suits, tyvek booties, and nitrile gloves prevented contact with possible PCB containing materials.

Rinsate from cleaning soil scoops and other tools was placed in 5-gallon Department of Transportation (DOT)-approved buckets and stored on site for future sampling and disposal by SDG&E personnel. All solid waste (tyvek suits and booties, 100 cm^2 templates for wipe samples, and nitrile gloves) were double-bagged, labeled, and stored on site for SDG&E personnel to dispose of in accordance with routine laboratory waste disposal practices.

3.3 Individual Site Summaries

The following sections provide a summary of PCB sampling activities for each of the four sites. All samples were analyzed for PCBs by EPA Method 8080. EnecoTech's standard sampling procedures for PCBs are included as Appendix B. Site location maps and referenced figures highlighting sample locations and delineating stained or impacted areas are included in Appendix C. Laboratory analytical reports and chain of custody records are included in Appendix D.

Silvergate Power Plant (Sampson Substation)
On October 29, 1996, 23 PCB wipe samples (including two field blanks and one duplicate) were collected from oily stains on equipment concrete bases in the transformer and circuit breaker equipment area. Thirty-two soil samples were collected on October 29 and 30, 1996. Soil samples were collected from areas of surface discoloration, due to leaking valves on oil circuit breakers and transformers and/or leaking transformer cooling fins.

The site location and all sample locations are indicated on Figures 1 through 4, Appendix C. Table 1, Appendix A summarizes PCB wipe sample analytical results, and Table 2, Appendix A summarizes PCB soil sample analytical results.

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4.0 RESULTS

The 100 $\mu g/100\ cm^2$ limit for low-contact surfaces was not exceeded in any samples. The

Soil sample results ranged from <0.25 mg/kg to 3.70 mg/kg, well below the 25 mg/kg action level under TSCA (see Section 2.0 Background).

The majority of the samples with detectable concentrations of PCB were identified as containing Archlor 1260. The following samples at the respective sites were identified as containing Archlor 1254:

Silvergate PCB Wipe Samples	Table 1	Sample 7 CIR 131 North
Silvergate PCB Soil Samples	Table 2	Sample 5B 4S South (stained soil)
		Sample 12 Valves by 3N (oily surface)

Redacted

4.1 Quality Assurance/Quality Control Procedures and Evaluations

Field blanks were collected at each PCB wipe sampling site. Blanks consisted of soaking an absorbent towel in hexane and placing it in a sample jar. Clean nitrile gloves were used to collect each field blank wipe sample. These samples were labeled with date, time, location, and placed on ice with other samples taken. All field blank analytical results exhibited no detectable levels within the limits of the laboratory analysis.

One duplicate sample was taken at Silvergate Power Plant. The duplicate was retrieved using a clean pair of gloves, clean 100 cm^2 template, and clean sample jar. The stain in question was big enough to allow two samples to be taken within one foot of one another. The first sample Bank 4B north contained 7.7 $\mu g/100\ cm^2$ of PCBs. The duplicate sample Bank 4B north contained 5.3 $\mu g/100\ cm^2$ of PCBs.

The highest soil sample results were found at Silvergate Power Plant: 3.70 mg/kg for Bank 1S East; 2.0 mg/kg for Bank 2S South; and, 1.1 mg/kg for Bank 4S South (stained soil).

Approximately 31% of the samples analyzed exhibited no detectable levels, indicating that there was no carryover of contaminants between sample sites. For example, in a hypothetical situation, Sample #10 contains PCBs, Sample #11 has no detectable levels, and Sample #12 again shows PCB contamination. If contaminant carryover between sample sites was occurring, it would not be possible to have a non-detectable sample between two areas of contamination.

5.0 CONCLUSIONS

As detailed in Tables 1 through 7, Appendix A, no soil sample results were greater than 25 mg/kg PCBs, and all wipe samples were below the 100 $\mu g/100\ cm^2$ "Low Contact" report and remediation threshold as requied for PCBmanagement under TSCA. Based on the sample results, these sites will not require any further action to comply with spill response and agency reporting requirements.

The results were in accordance with stickers or placards found on many of the transformers or circuit breakers. The stickers indicated that oil tested "Non-PCB Containing". Some placards indicated a PCB content of less than 50 ppm, while others stated that the contents were "Non-PCB Containing".

6.0 QUALIFICATIONS AND LIMITATIONS

EnecoTech is pleased to have performed environmental assessment services at the subject sites in San Diego, California. These services have been performed in accordance with and are limited by the scope of work stated in our proposal number 26-0089, dated September 11, 1996, for investigative services. EnecoTech assumes no responsibility for detection or assessment of any conditions affecting the property which were outside the scope of work requested by San Diego Gas & Electric.

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EnecoTech has strived to conduct the tasks outlined in proposal 26-0089 consistent with that level of care ordinarily exercised by members of the profession currently practicing under similar conditions. In performing these tasks, EnecoTech has relied on documents, oral statements, and other information from public officials and third parties outside EnecoTech's control. EnecoTech cannot and does not warrant the accuracy of this information.

No environmental assessment is infallible. Some uncertainty will always exist concerning the presence or absence of potentially adverse conditions at any particular property, irrespective of the rigor of the investigation. Accordingly, EnecoTech offers no warranty that adverse environmental conditions other than those identified in this report do not exist at the four subject sites in San Diego, California, or may not exist there in the future.

APPENDIX A

Tables 1 Through 7

TABLE 1: PCB Wipe Samples for Silvergate Power Plant

Sample Number	Sample Location and Equipment Designation	Sample Date	PCB Concentration ($\mu g/100\ cm^2$)
0	OCB 3101 (Blank)	10/29/96	<0.25
1	OCB 3101	10/29/92	1.40
2	OCB 3102	10/29/96	<0.25
3	CIR 130	10/29/96	0.78
4	CIR 130 GT22001	10/29/96	0.72
5	CIR 370	10/29/96	0.49
6	CIR 133	10/29/96	<0.25
7	CIR 131 North	10/29/96	1.00
8	CIR 131 South	10/29/96	0.90
9	Bank 2N South	10/29/96	2.90
10	Bank 2N North	10/29/96	4.00
11	Bank 3S	10/29/96	1.20
12	Bank 3N East	10/29/96	0.86
13	Bank 3N West	10/29/96	0.56
14	Bank 4B South	10/29/96	3.60
15A	Bank 4B North	10/29/96	7.70
15B	Bank 4B North (Duplicate)	10/29/96	5.30
16	Bank 4G	10/29/96	1.80
17	BK 4W LTG	10/29/96	5.60
18	BK 4W PWR	10/29/96	8.60
19	Bank 1G	10/29/96	4.00
20	Bank 1B	10/29/96	8.40
21	Blank B	10/29/96	<0.25

TABLE 2: PCB Soil Samples for Silvergate Power Plant

Sample Number	Sample Location and Equipment Designation	Sample Date	PCB Concentration (mg/kg)
1	Bank 4N East (8" deep)	10/29/96	<0.02
2	Bank 4N East (surface)	10/29/92	0.50
3	Bank 4N South	10/29/96	<0.02
4	Bank 4N West	10/29/96	<0.02
5A	Bank 4S South (clay bottom)	10/29/96	<0.02
5B	Bank 4S South (stained soil)	10/29/96	1.10
6	Bank 4S East	10/29/96	0.45
7	Bank 4S West	10/29/96	0.43
8	Bank 4S North	10/29/96	0.95
9	BK 4W PWR	10/29/96	<0.02
10	OCB 3404	10/29/96	<0.02
11	Valves by 3N (6" deep)	10/29/96	<0.02
12	Valves by 3N (oily surface)	10/29/96	0.98
13	Bank 3N East	10/29/96	0.83
14	Bank 3N South	10/29/96	0.32
15	Bank 3N West	10/29/96	0.50
16	Bank 3S East	10/29/96	0.51
17	Bank 3S West	10/29/96	0.37
18	Bank 3S North	10/29/96	0.87
19	Bank 3S South	10/29/96	0.77
20	Bank 2G	10/29/96	0.03
21	Valves Near 2N	10/29/96	<0.02
22	Bank 2N North	10/30/96	0.46
23	Bank 2N East	10/30/96	0.72
24	Bank 2N South	10/30/96	0.59

TABLE 2: PCB Soil Samples for Silvergate Power Plant (Continued)

Sample Number	Sample Location and Equipment Designation	Sample Date	PCB Concentration (mg/kg)
25	Bank 2S North	10/30/96	0.95
26	Bank 2S South	10/30/96	2.00
27	OCB 3101	10/30/96	0.36
28	Bank 1N South	10/30/92	0.81
29	Bank 1S East	10/30/96	3.70
30	Bank 1G	10/30/96	0.36
31	Bank 1B	10/30/96	<0.02

Redacted

Redacted

Redacted

Redacted

Redacted

APPENDIX B

Field Procedures for PCB Sampling

FIELD PROCEDURES FOR PCB SAMPLING

Wipe samples were collected at test locations of stained concrete, per the sampling methods from A Compendium of Superfund Field Operations Methods, EPA 540 P-B7, December 1987. EnecoTech personnel utilized clean, disposable, nitrile gloves at each sample location while collecting and/or handling samples. A 100 cm^2 stencil was utilized at each sample station to identify the sample surface area. A clean absorbent towel was then moistened with laboratory-grade hexane solvent and used to thoroughly wipe the 100 cm^2 area. Without allowing the absorbent towel to contact any other surface, it was then folded with the exposed side in, then folded again to form a small square. The absorbent towel was then placed into a clean, four ounce glass jar, which was then sealed with a teflon-lined lid.

Soil samples in areas identified by surface staining were collected using a soil scoop. Samples were transferred from the scoop to clean 9 ounce glass jars with teflon-lined lids. EnecoTech personnel utilized clean, disposable, nitrile gloves while collecting and/or handling samples. In areas where the soil was overlain by a crushed rock or gravel soil covering, that material was moved aside to obtain samples. The soil scoop was cleaned by washing in an Alconox solution and double-rinsing with clean water prior to use at each sample collection. Soil and soil coverings disturbed during sampling were placed back into their original positions as closely as possible.

Each sample container submitted for analyses had a label affixed with a unique sample name correlating to the SDG&E designation on the adjacent equipment, job name, sampler's signature, date sampled, and time of collection. EnecoTech personnel utilized clean, disposable, nitrile gloves when collecting or otherwise handling samples and at all times when the potential for contact with PCB contaminants existed. Samples were placed into an ice chest or refrigerated at 4° Celsius until received at a state-certified laboratory. A chain of custody form was used to document sample possession from the time of collection to the time of delivery to the laboratory. When possession of the samples was transferred, the persons relinquishing and receiving possession signed and dated the chain of custody form. The sample control officer at the laboratory verified sample integrity and confirmed that the sample is of sufficient quantity for the requested analyses.

Liquid waste (cleaning rinsate) and solid waste (disposable tyvek suits and booties, nitrile gloves, and stencils) are contained in labeled, 5-gallon DOT-approved drums or double-bagged. All waste will be left on site until the nature of the waste has been determined, based on the results of chemical analysis. Disposal is carried out following California and Federal guidelines.

APPENDIX C

Figures 1 Through 15

"Reproduced with permission granted by THOMAS BROS. MAPS. This map is copyrighted by THOMAS BROS. MAPS. It is unlawful to copy or reproduce all or any part thereof, whether for personal use or resale, without permission"

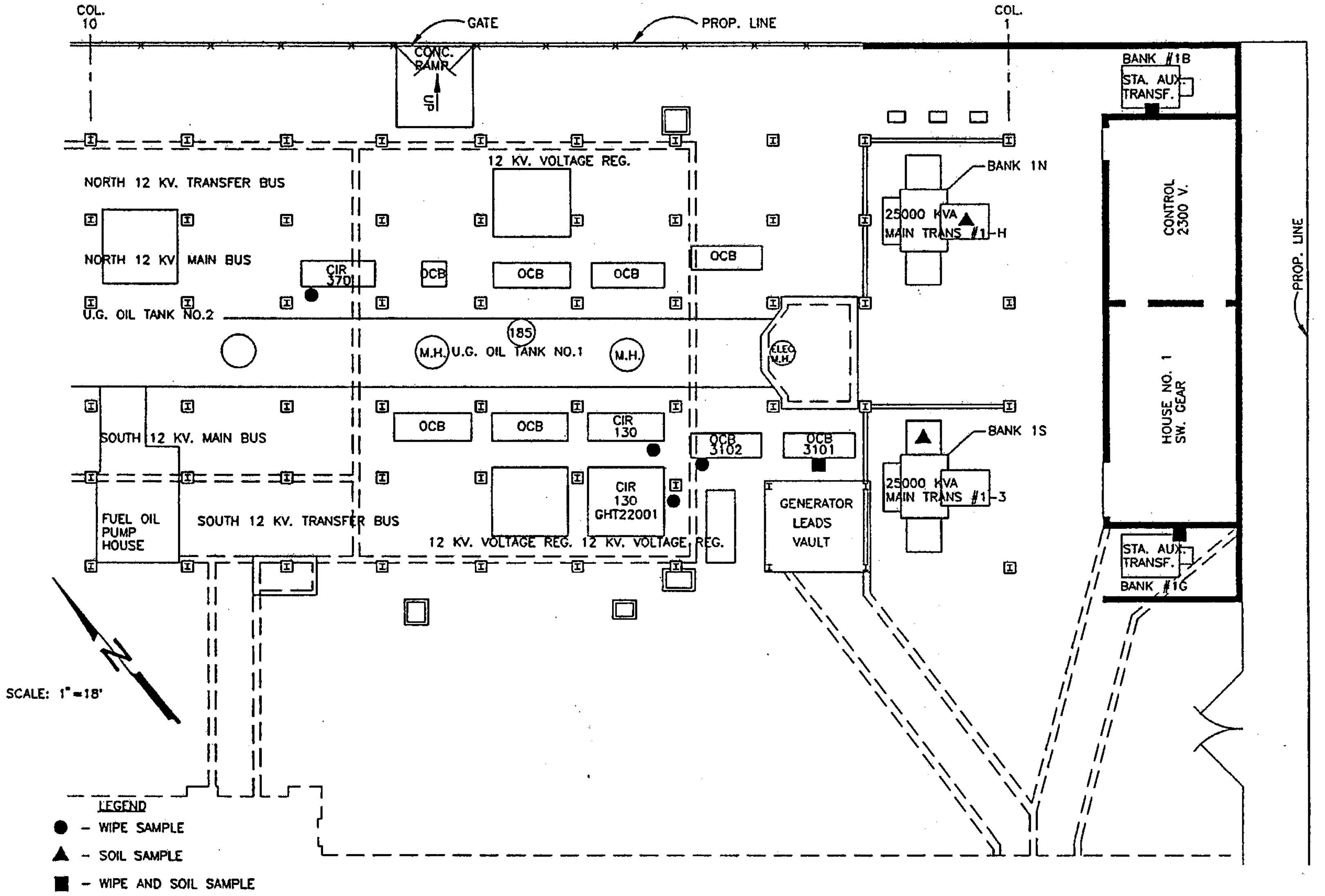
EnecoTech
ENVIRONMENTAL CONSULTANTS

Project: SDG&E PHASE II ENVIRONMENTAL INVESTIGATION

1348 SAMPSON STREET
SAN DIEGO, CALIFORNIA

SITE LOCATION MAP
SILVERGATE POWER PLANT

File No.: 02-01298-001	ACAD File No.: 1298SD1	Date: 10/96	REV.:
Drawn By:	Design By:	Checked By:	Approved By:
			Figure No.: 1



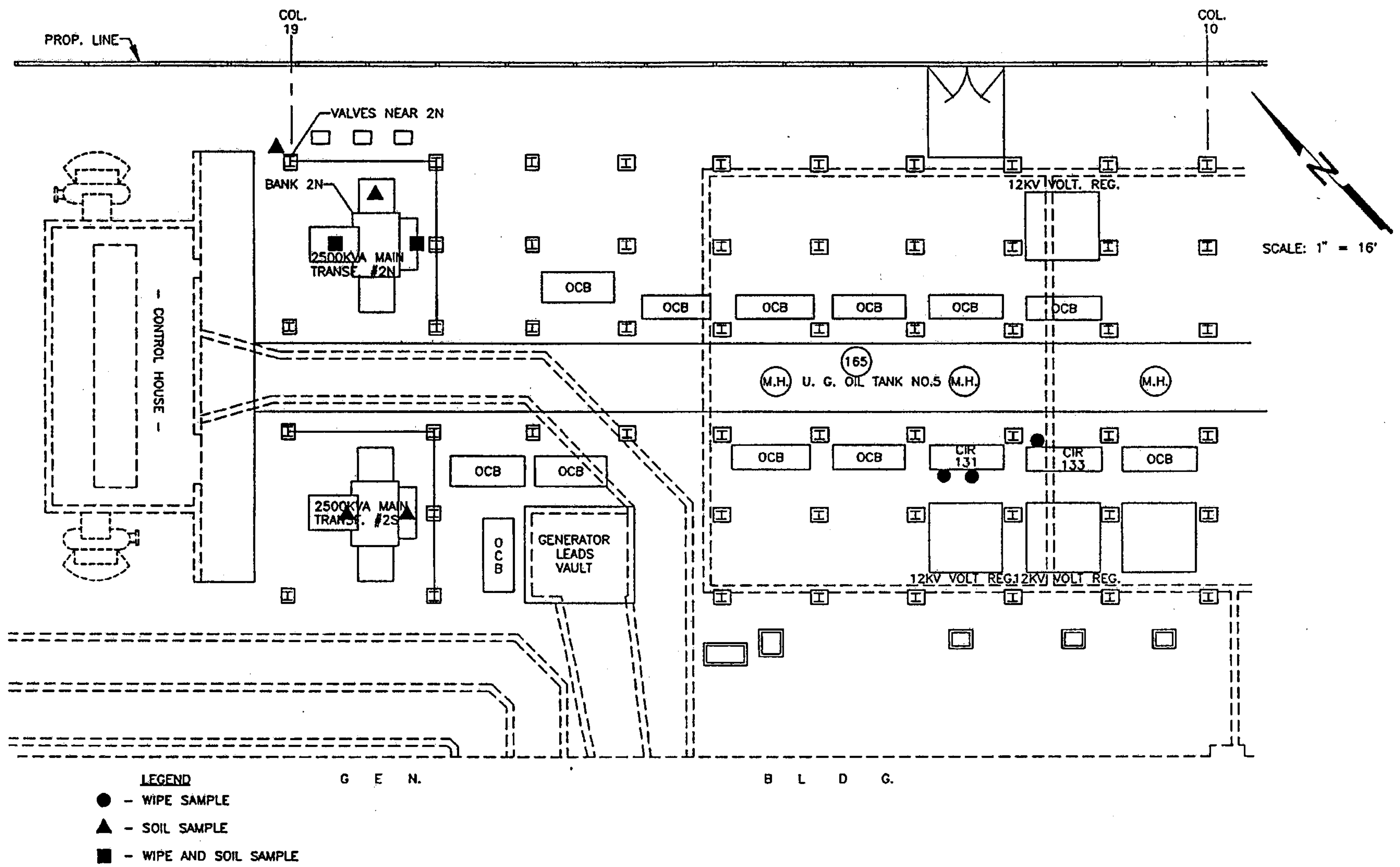
EnecoTech®
ENVIRONMENTAL CONSULTANTS

Project: SDG&E PHASE II ENVIRONMENTAL INVESTIGATION

1348 SAMPSON STREET
SAN DIEGO, CALIFORNIA

SILVERGATE POWER PLANT
PCB SAMPLING

File No.:	ACAD No.:	Drawn:	Designed:	Checked:	Approved:	Date:	Rev.:	Figure No.:
02-01298-001	P2-5				MJG	11/96		2



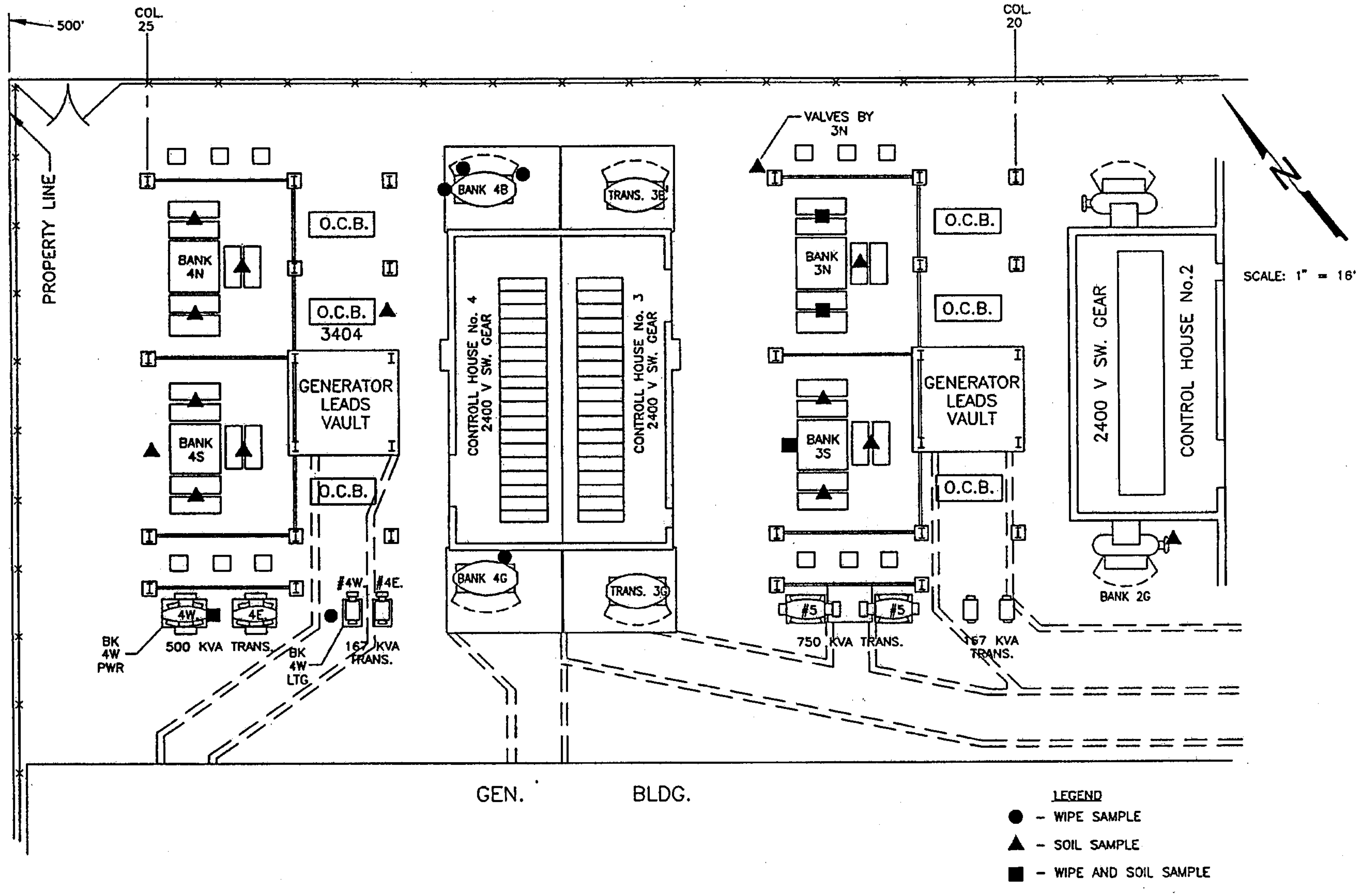
EnecoTech®
ENVIRONMENTAL CONSULTANTS

Project: SDG&E PHASE II ENVIRONMENTAL INVESTIGATION

1348 SAMPSON STREET
SAN DIEGO, CALIFORNIA

SILVERGATE POWER PLANT
PCB SAMPLING

File No.:	ACAD No.:	Drawn:	Designed:	Checked:	Approved:	Date:	Rev.:	Figure No.:
02-01298-001	P2-6				MJG	11/96		3



EnecoTech®
ENVIRONMENTAL CONSULTANTS

Project: SDG&E PHASE II ENVIRONMENTAL INVESTIGATION

1348 SAMPSON STREET
SAN DIEGO, CALIFORNIA

SILVERGATE POWER PLANT
PCB SAMPLING

File No.:	ACAD No.:	Drawn:	Designed:	Checked:	Approved:	Date:	Rev.:	Figure No.:
02-01298-001	P2-7				MJG	11/96		4

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APPENDIX D

Laboratory Analytical Reports and Chain of Custody Forms

ENVIRONMENTAL ANALYSIS LABORATORY
SDGE

1298-001

114 10th Avenue, Room 410
San Diego, CA 92101
ELAP Certificate No. 1289
Attn: John Capito, Supervisor
Phone: 619/696-2552

ENECOTECH SOUTHWEST, INC.
2535 CAMINO DEL RIO SOUTH
SUITE 250
SAN DIEGO, CA 92108
Attn: MIKE GIBBS - ENECOTECH

Order #: 96-10-139
Date: 11/06/96 12:21
Work ID: SILVERGATE PCB WIPES
Date Received: 10/30/96
Date Completed: 11/06/96

Purchase Order: PCB DIST.
Invoice Number:

Client Code: ENECOTECH

EnecoTech Project No. 02-01298-001/HT203
Please refer to the Report Comments for a list of the archlors identified.
cc: Jerry Brull/SDG&E - EB 6

SAMPLE IDENTIFICATION

Sample Number	Sample Description	Sample Number	Sample Description
01	(0) OCB 3101 (BLANK)	13	(12) BANK 3N EAST
02	(1) DCB 3101	14	(13) BANK 3N WEST
03	(2) DCB 3102	15	(14) BANK 4B SOUTH
04	(3) CIR 130	16	(16) BANK 4G
05	(4) CIR 130 GT 22001	17	(17) BANK 4W LTG
06	(5) CIR 370	18	(18) BANK 4W PWR
07	(6) CIR 133	19	(19) BANK 1G
08	(7) CIR 131 NORTH	20	(20) BANK 1B
09	(8) CIR 131 SOUTH	21	(21)BLANK B
10	(9) BANK 2N SOUTH	22	(15A) BANK 4B NORTH
11	(10) BANK 2N NORTH	23	(15B) BANK 4B NORTH DUPE
12	(11) BANK 35		

Results reported as "nd" are less than the detection limit for that test. Detection limits are listed either as "Limit" or "Minimum".

11/6/96
Certified By
Senior Chemist

RECEIVED
NOV 1[illegible] 1996

REGULAR TEST RESULTS BY TEST

PCB ANALYSIS, WIPE **Minimum:** **Maximum:**
Method: EPA 8080

Samp	Sample Description	Result	Units	Limit	Prepared	Analyzed	By
01A	(0) OCB 3101 (BLANK)	nd	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
02A	(1) DCB 3101	1.4	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
03A	(2) DCB 3102	nd	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
04A	(3) CIR 130	0.78	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
05A	(4) CIR 130 GT 22001	0.72	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
06A	(5) CIR 370	0.49	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
07A	(6) CIR 133	nd	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
08A	(7) CIR 131 NORTH	1.0	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
09A	(8) CIR 131 SOUTH	0.90	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
10A	(9) BANK 2N SOUTH	2.9	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
11A	(10) BANK 2N NORTH	4.0	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
12A	(11) BANK 35	1.2	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
13A	(12) BANK 3N EAST	0.86	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
14A	(13) BANK 3N WEST	0.56	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
15A	(14) BANK 4B SOUTH	3.6	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
16A	(16) BANK 4G	1.8	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
17A	(17) BANK 4W LTG	5.6	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
18A	(18) BANK 4W PWR	8.6	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
19A	(19) BANK 1G	4.0	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
20A	(20) BANK 1B	8.4	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
21A	(21)BLANK B	nd	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
22A	(15A) BANK 4B NORTH	7.7	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC
23A	(15B) BANK 4B NORTH DUPE	5.3	ug/100 cm. sq.	0.25	10/31/96	11/02/96	JIC

TEST METHODOLOGIES

PCB'S ANALYSIS, WIPE:	EPA 8080 Organochlorine Pesticides & PCB's.

REPORT COMMENTS

1. The following archlors were identified for the samples reported above the detection limit.

Sample	Archlor
02A	1260
04A	1260
05A	1260
06A	1260
08A	1254
09A	1260
10A	1260
11A	1260
12A	1260
13A	1260
14A	1260
15A	1260
16A	1260
17A	1260
18A	1260
19A	1260
20A	1260
22A	1260
23A	1260

SDGE Environmental Analysis Laboratory
Method 8080 - PCBs
% Recovery QC Sheet
Matrix: Wipe

Extraction Date: 10/31/96
Batch: WP1031A #1
Analyst(s): OBR
Aroclor: 1260

Method Blank: 0 mg/kg

	LCS/LCSD Recoveries	MS/MSD Recoveries	MS/MSD Recoveries
Sample ID:	NA	0	0
Sample Concentration mg/kg	0.00	0.00	0.00
Spike Added mg/kg	50.00	#DIV/0!	#DIV/0!
Concentration mg/kg	50.43	0.00	0.00
	LCS QC Limits	MS QC Limits	MS QC Limits
% Recovery	100.67 61 - 131 OK	#DIV/0! 64 - 125 ##	#DIV/0! 64 - 125 ##
Spike Added mg/kg	50.00	#DIV/0!	#DIV/0!
Concentration mg/kg	50.37	0.00	0.00
	LCSD QC Limits	MSD QC Limits	MSD QC Limits
% Recovery	100.75 61 - 131 OK	#DIV/0! 64 - 125 ##	#DIV/0! 64 - 125 ##
% RPD	0.12 16 OK	#DIV/0! 14 ##	#DIV/0! 14 ##

*** outside limits**

Comments:

Analyst: JC Date: 11·05·96

Reviewed: Date: 11/6/96

File: WP1029A.XLS
Sheet: QC Report
11/5/96; 12:36 PM

SDGE Environmental Analysis Laboratory
Method 8080 - PCBs
% Recovery QC Sheet
Matrix: Wipe

Extraction Date:	10/31/96
Batch:	WP1031A #2
Analyst(s):	OBR
Aroclor:	1260

Method Blank: 0 mg/kg

	LCS/LCSD Recoveries	MS/MSD Recoveries	MS/MSD Recoveries
Sample ID:	NA	0	0
Sample Concentration mg/kg	0.00	0.00	0.00
Spike Added mg/kg	50.00	#DIV/0!	#DIV/0!
Concentration mg/kg	51.82	0.00	0.00
	LCS QC Limits	MS QC Limits	MS QC Limits
% Recovery	103.64 61 - 131 OK	#DIV/0! 64 - 125 ##	#DIV/0! 64 - 125 ##
Spike Added mg/kg	50.00	#DIV/0!	#DIV/0!
Concentration mg/kg	51.01	0.00	0.00
	LCSD QC Limits	MSD QC Limits	MSD QC Limits
% Recovery	102.02 61 - 131 OK	#DIV/0! 64 - 125 ##	#DIV/0! 64 - 125 ##
% RPD	1.57 16 OK	#DIV/0! 14 ##	#DIV/0! 14 ##

*** outside limits**

Comments:

Analyst: ____________ Date: 11/5/96

Reviewed: ____________ Date: 11/6/96

SDGE Environmental Analysis Laboratory
Method 8080 - PCBs
% Recovery QC Sheet
Matrix: Wipe

Extraction Date:	10/31/96	
Batch:	wp1031b #1	Method Blank: 0 mg/kg
Analyst(s):	OBR	
Aroclor:	1260	

	LCS/LCSD Recoveries	MS/MSD Recoveries	MS/MSD Recoveries
Sample ID:	NA	0	0
Sample Concentration mg/kg	0.00	0.00	0.00
Spike Added mg/kg	50.00	#DIV/0!	#DIV/0!
Concentration mg/kg	51.77	0.00	0.00
% Recovery	LCS QC Limits 103.54 61 - 131 OK	MS QC Limits #DIV/0! 64 - 125 ##	MS QC Limits #DIV/0! 64 - 125 ##
Spike Added mg/kg	50.00	#DIV/0!	#DIV/0!
Concentration mg/kg	51.65	0.00	0.00
% Recovery	LCSD QC Limits 103.29 61 - 131 OK	MSD QC Limits #DIV/0! 64 - 125 ##	MSD QC Limits #DIV/0! 64 - 125 ##
% RPD	0.24 16 OK	#DIV/0! 14 ##	#DIV/0! 14 ##

*** outside limits**

Comments:

Analyst: JC Date: 11/5/96

Reviewed: Date: 11/6/96

File: WP1031B.XLS
Sheet: QC Report
11/5/96; 12:39 PM

EnecoTech
ENVIRONMENTAL CONSULTANTS

CHAIN OF CUSTODY RECORD

7425 Mission Valley Road • Suite 201 • San Diego, CA 92108

COC CA# 2616

ROJ. NO. -01298-1/HT20

PROJECT NAME: Silvergate / SDG+E

MPLERS: (Signature) Jennifer Noble

Jennifer Noble
John Royal

Ship To:

EnecoTech contact: Mike Gibbs

AT. NO.	DATE	TIME	COMP.	GRAB	STATION LOCATION	NO. OF CON-TAINERS 4oz jar	EPA 8080 (PCB)							Remarks/Bottle No.
0	10/29/96	9:46		1	OCB 3101 [Blank]	1								PCB wipe 100cm² samples
1		9:48		1	OCB 3101	1								using hexane solvent with
2		9:57		1	OCB 3102	1								absorbent towel
3		10:05		1	CIR 130	1								
4		10:12		1	CIR 130 GT 22.001	1								
5		10:18		1	CIR 370	1								
6		10:24		1	CIR 133	1								
7		10:29		1	CIR 131 North	1								
8		10:31		1	CIR 131 South	1								
9		10:45		1	Bank 2N South	1								
10		10:55		1	Bank 2N North	1								
11		11:00		1	Bank 3S	1								
12		11:08		1	Bank 3N East	1								
13		11:14		1	Bank 3N West	1								
14	↓	11:23		1	Bank 4B South	1								

linquished by: (Signature) John Royal	Date/Time 10/30/96 851	Received by: (Signature) H. E. Allred	Relinquished by: (Signature) H. E. Allred	Date/Time 10/30/96 0922	Received by: (Signature)
linquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
linquished by: (Signature)	Date/Time	Received for Laboratory by: (Signature)	Date/Time	Remarks	

Distribution: Original Accompanies Shipment; First Copy to Coordinator Field Files; Second Copy to Representative of Inspected Facility

Split Samples: ☐ Accepted ☐ Declined ______ Signature

EnecoTech
ENVIRONMENTAL CONSULTANTS

CHAIN OF CUSTODY RECORD

~~7425 Mission Valley Road • Suite 201 •~~ San Diego, CA 92108

COC.CA# 2617

ROJ. NO. 01296-/HT203

PROJECT NAME Silvergate - SDG+E

MPLERS: (Signature) Jennifer Noble, John Royd

Ship To:

EnecoTech contact : Mike Gibbs

T. NO.	DATE	TIME	COMP.	GRAB	STATION LOCATION	NO. OF CON-TAINERS 4 oz. jars	EPA 8080 (PCB)							Remarks/Bottle No.
6	10/29	11:44		1	Bank 4G	1	1							PCB Wipe, 100 cm^2 Samples
7		11:52		1	Bkn 4W LTG	1	1							using hexane solvent with
8		11:58		1	Bk 4W PWR	1	1							absorbent wipes.
9		12:19		1	Bank 1G	1	1							
0		12:31		1	Bank 1B	1	1							
21		12:40		1	Blank B	1	1							
5A		11:31		1	Bank 4B North	1								
B	↓	11:36		1	Bank 4B North Duplicate	1								

inquished by: (Signature)	Date/Time 10/30/96 851	Received by: (Signature) H. E. Allred	Relinquished by: (Signature) H. E. Allred	Date/Time 10/31/ 0823	Received by: (Signature)
inquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
inquished by: (Signature)	Date/Time	Received for Laboratory by: (Signature)	Date/Time	Remarks	

Distribution: Original Accompanies Shipment, First Copy to Coordinator Field Files; Second Copy to Representative of Inspected Facility

Split Samples: ☐ Accepted ☐ Declined _______________ Signature

ENVIRONMENTAL ANALYSIS LABORATORY SDGE

114 10th Avenue, Room 410
San Diego, CA 92101
ELAP Certificate No. 1289
Attn: John Capito, Supervisor
Phone: 619/696-2552

RECEIVED
NOV 13 1996

ENECOTECH SOUTHWEST, INC.
2535 CAMINO DEL RIO SOUTH
SUITE 250
SAN DIEGO, CA 92108
Attn: MIKE GIBBS - ENECOTECH

Order #: 96-10-140
Date: 11/07/96 13:02
Work ID: SILVERGATE PCB SOIL SAMPLES
Date Received: 10/30/96
Date Completed: 11/07/96

Purchase Order: PCB DIST.
Invoice Number:

Client Code: ENECOTECH

cc: Jerry Brull - EB 6

SAMPLE IDENTIFICATION

Sample Number	Sample Description	Sample Number	Sample Description
01	(1) 4N EAST (8" DEEP)	12	(11) VALVES BY 3N-6" DEEP
02	(2) 4N EAST (SURFACE)	13	(12) VALVES BY 3N OILY SUR
03	(3) 4N SOUTH	14	(13) 3N EAST
04	(4) 4N WEST	15	(14) 3N SOUTH
05	(5A)4S SOUTH (CLAY BOTTOM)	16	(15) 3N WEST
06	(6) 4S EAST	17	(16) 3S EAST
07	(7) 4S WEST	18	(17) 3S WEST
08	(8) 4S NORTH	19	(18) 3S NORTH
09	(9) BK 4W PWR	20	(19) 3S SOUTH
10	(5B) 4S SO (STRAINED SOIL)	21	(20) BANK 2G
11	(10) OCB 3404	22	(21) VALVES NEAR 25

Results reported as "nd" are less than the detection limit for that test. Detection limits are listed either as "Limit" or "Minimum".

2/7/96
Certified By
Senior Chemist

REGULAR TEST RESULTS BY TEST

PCB ANALYSIS, SOLID Minimum: Maximum:
Method: EPA 8080

Samp	Sample Description	Result	Units	Limit	Prepared	Analyzed	By
01A	(1) 4N EAST (8" DEEP)	nd	ppm	0.02	10/31/96	11/05/96	JIC
02A	(2) 4N EAST (SURFACE)	0.50	ppm 1260	0.02	10/31/96	11/05/96	JIC
03A	(3) 4N SOUTH	nd	ppm	0.02	10/31/96	11/05/96	JIC
04A	(4) 4N WEST	nd	ppm	0.02	10/31/96	11/05/96	JIC
05A	(5A)4S SOUTH (CLAY BOTTOM)	nd	ppm	0.02	10/31/96	11/06/96	JIC
06A	(6) 4S EAST	0.45	ppm 1260	0.02	10/31/96	11/06/96	JIC
07A	(7) 4S WEST	0.43	ppm 1260	0.02	10/31/96	11/06/96	JIC
08A	(8) 4S NORTH	0.95	ppm 1260	0.02	10/31/96	11/06/96	JIC
09A	(9) BK 4W PWR	nd	ppm	0.02	10/31/96	11/06/96	JIC
10A	(5B) 4S SO (STRAINED SOIL)	1.1	ppm 1254	0.02	10/31/96	11/06/96	JIC
11A	(10) OCB 3404	nd	ppm	0.02	10/31/96	11/06/96	JIC
12A	(11) VALVES BY 3N-6" DEEP	nd	ppm	0.02	10/31/96	11/06/96	JIC
13A	(12) VALVES BY 3N OILY SUR	0.98	ppm 1254	0.02	10/31/96	11/06/96	JIC
14A	(13) 3N EAST	0.83	ppm 1260	0.02	10/31/96	11/06/96	JIC
15A	(14) 3N SOUTH	0.32	ppm 1260	0.02	10/31/96	11/06/96	JIC
16A	(15) 3N WEST	0.50	ppm 1260	0.02	10/31/96	11/06/96	JIC
17A	(16) 3S EAST	0.51	ppm 1260	0.02	10/31/96	11/06/96	JIC
18A	(17) 3S WEST	0.37	ppm 1260	0.02	10/31/96	11/06/96	JIC
19A	(18) 3S NORTH	0.87	ppm 1260	0.02	10/31/96	11/06/96	JIC
20A	(19) 3S SOUTH	0.77	ppm 1260	0.02	10/31/96	11/06/96	JIC
21A	(20) BANK 2G	0.03	ppm 1260	0.02	10/31/96	11/06/96	JIC
22A	(21) VALVES NEAR 25	nd	ppm	0.02	10/31/96	11/06/96	JIC

TEST METHODOLOGIES

PCB'S ANALYSIS, SOLID:	EPA 8080 Organochlorine Pesticides & PCB's.

SDGE Environmental Analysis Laboratory
Method 8080 - PCBs
% Recovery QC Sheet
Matrix: Solid

Extraction Date:	10/31/96
Batch:	SO1031B
Analyst(s):	BMM
Aroclor:	1260

Method Blank: 0 mg/kg

	#2 LCS/LCSD Recoveries	MS/MSD Recoveries	MS/MSD Recoveries
Sample ID:	NA	LCS #3	9610140-22A ✓
Sample Concentration mg/kg	0.00	0.00	0.00
Spike Added mg/kg	0.83	0.83	0.83
Concentration mg/kg	0.85	0.88	0.83
	LCS QC Limits	MS QC Limits	MS QC Limits
% Recovery	102.42 58 - 125 OK	106.01 32 - 147 OK	100.16 32 - 147 OK
Spike Added mg/kg	0.83	0.83	0.83
Concentration mg/kg	0.87	0.89	0.87
	LCSD QC Limits	MSD QC Limits	MSD QC Limits
% Recovery	104.66 58 - 125 OK	106.82 32 - 147 OK	104.34 32 - 147 OK
% RPD	2.17 25 OK	0.77 67 OK	4.08 67 OK

*** outside limits**

Comments:

Analyst: Jc Date: 11/7/96

Reviewed: mc Date: 11/7/96

File: SO1031B.XLS
Sheet: QC Report
11/7/96; 10:08 AM

SDGE Environmental Analysis Laboratory
Method 8080 - PCBs
%.Recovery QC Sheet
Matrix: Solid

Extraction Date: 10/31/96
Batch: SO1031A
Analyst(s): BMM
Aroclor: 1260

Method Blank: 0 mg/kg

	LCS/LCSD Recoveries LCS#1	MS/MSD Recoveries	MS/MSD Recoveries
Sample ID:	NA	9610140-09A	9610140-21A
Sample Concentration mg/kg	0.00	0.00	0.03
Spike Added mg/kg	0.83	0.83	0.83
Concentration mg/kg	0.86	0.80	0.88
	LCS QC Limits	MS QC Limits	MS QC Limits
% Recovery	103.03 58 - 125 OK	96.23 32 - 147 OK	102.17 32 - 147 OK
Spike Added mg/kg	0.83	0.83	0.83
Concentration mg/kg	0.87	0.90	0.90
	LCSD QC Limits	MSD QC Limits	MSD QC Limits
% Recovery	104.54 58 - 125 OK	108.41 32 - 147 OK	105.26 32 - 147 OK
% RPD	1.46 25 OK	11.90 67 OK	2.99 67 OK

*** outside limits**

Comments:

Analyst: ______________ Date: 11/7/96

Reviewed: ______________ Date: 11/7/96

File: SO1031A.XLS
Sheet: QC Report
11/7/96; 10:04 AM

EnecoTech
ENVIRONMENTAL CONSULTANTS

CHAIN OF CUSTODY RECORD

[illegible]

~~7425 Mission Valley Road - Suite 201~~ • San Diego, CA 92108

COC CA# 2619

Ship To:

EnecoTech contact: Mike Gilles

PROJ. NO.: 2-01298-01/AT203

PROJECT NAME: Silvergate SDGE

SAMPLERS: (Signature) Jennifer Noble, John Royal — Jennifer Noble, John Royal

STAT. NO.	DATE	TIME	COMP.	GRAB	STATION LOCATION	NO. OF CONTAINERS 9 oz Jar	PCB EPA 8080							Remarks/Bottle No.
1	10/29	2:06		1	4N east (6" deep)	1								soil sample: pulled rocks/
2		2:08		1	4N East (surface)	1								gravel away with hoe or
3		2:17		1	4N South	1								shovel, then used cleaned
4		2:26		1	4N West	1								trowel, or gloved hands
5A		3:06		1	4S South (clay bottom)	1								to collect sample
6		3:01		1	4S East	1								
7		3:23		1	4S West	1								
8		3:25		1	4S North	1								
9		3:42		1	OH 4W PWR	1								
5B		3:08		1	4S South (stained soil)	1								
10		3:23		1	OCB 3404	1								
11		3:57		1	Valves by 3N (6" deep)	1								
12		4:00		1	Valves by 3n oily surface	1								
13		4:21		1	3N East	1								
14		4:22		1	3N South	1								

Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
John Royal	10/30/96 851	H. E. Allred	H. E. Allred	10/30/96 0924	
Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
Relinquished by: (Signature)	Date/Time	Received for Laboratory by: (Signature)	Date/Time	Remarks	

Distribution: Original Accompanies Shipment, First Copy to Coordinator Field Files; Second Copy to Representative of Inspected Facility

Split Samples: ☐ Accepted ☐ Declined _______ Signature

EnecoTech
ENVIRONMENTAL CONSULTANTS

CHAIN OF CUSTODY RECORD

~~7425 Mission Valley Road • Suite 201~~ • San Diego, CA 92108

COC CA# 2618

PROJ. NO. 2-01298-01/HT203

PROJECT NAME Silvergate - SDG+E

SAMPLERS: (Signature) Jennifer Noble John Royal — Jennifer Noble / John Royal

Ship To:

EnecoTech contact : Mike Gibbs

STAT. NO.	DATE	TIME	COMP.	GRAB	STATION LOCATION	NO. OF CONTAINERS 9oz Jar	PCB EPA 8080	Remarks/Bottle No.
15	10/29	4:33		1	3N West	1		Soil sample: pulled rocks/
16		4:50		1	3S East	1		gravel away with hoe or
17		4:51		1	3S West	1		shovel, then used clean
18		4:48		1	3S North	1		trowel or gloved hands
19		4:49		1	3S South	1		to collect sample.
20		5:00		1	Bank 2G	1		
21	↓	5:20		1	Valves near 25	1		

Relinquished by: (Signature) John Royal	Date/Time 10/30/90 851	Received by: (Signature) H.E. Allred	Relinquished by: (Signature) H.E. Allred	Date/Time 10/30/96 0824	Received by: (Signature)
Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
Relinquished by: (Signature)	Date/Time	Received for Laboratory by: (Signature)	Date/Time	Remarks	

Distribution. Original Accompanies Shipment; First Copy to Coordinator Field Files; Second Copy to Representative of Inspected Facility

Split Samples: ☐ Accepted ☐ Declined ______ Signature

ENVIRONMENTAL ANALYSIS LABORATORY

SDG&E

114 10th Avenue, Room 410
San Diego, CA 92101
ELAP Certificate No. 1289
Attn: John Capito, Supervisor
Phone: 619/696-2552

RECEIVED
NOV 14 1996

ENECOTECH SOUTHWEST, INC.
2535 CAMINO DEL RIO SOUTH
SUITE 250
SAN DIEGO, CA 92108
Attn: MIKE GIBBS - ENECOTECH

Order #: 96-11-004
Date: 11/12/96 12:44
Work ID: SILVERGATE SOIL SAMPLES
Date Received: 11/01/96
Date Completed: 11/12/96

Purchase Order: PCB DIST.
Invoice Number:

Client Code: ENECOTECH

cc: Jerry Brull - EB 6

SAMPLE IDENTIFICATION

Sample Number	Sample Description	Sample Number	Sample Description
01	(22) 2N NORTH	06	(27) OCB 3101
02	(23) 2N EAST	07	(28) BANK IN SOUTH
03	(24) 2N SOUTH	08	(29) BANK 1S EAST
04	(25) 2S NORTH	09	(30) BANK 1G
05	(26) 2S SOUTH	10	(31) BANK 1B

Results reported as "nd" are less than the detection limit for that test. Detection limits are listed either as "Limit" or "Minimum".

11/12/96
Certified By
Senior Chemist

PCB ANALYSIS, SOLID **Minimum:** **Maximum:**
Method: EPA 8080

Samp	Sample Description	Result	Units	Limit	Prepared	Analyzed	By
01A	(22) 2N NORTH	0.46	ppm 1260	0.02	11/06/96	11/09/96	JIC
02A	(23) 2N EAST	0.72	ppm 1260	0.02	11/06/96	11/09/96	JIC
03A	(24) 2N SOUTH	0.59	ppm 1260	0.02	11/06/96	11/09/96	JIC
04A	(25) 2S NORTH	0.95	ppm 1260	0.02	11/06/96	11/09/96	JIC
05A	(26) 2S SOUTH	2.0	ppm 1260	0.02	11/06/96	11/09/96	JIC
06A	(27) OCB 3101	0.36	ppm 1260	0.02	11/06/96	11/09/96	JIC
07A	(28) BANK 1N SOUTH	0.81	ppm 1260	0.02	11/06/96	11/09/96	JIC
08A	(29) BANK 1S EAST	3.7	ppm 1260	0.02	11/06/96	11/09/96	JIC
09A	(30) BANK 1G	0.36	ppm 1260	0.02	11/06/96	11/09/96	JIC
10A	(31) BANK 1B	nd	ppm	0.02	11/06/96	11/09/96	JIC

TEST METHODOLOGIES

PCB'S ANALYSIS, SOLID: EPA 8080 Organochlorine Pesticides & PCB's.

SDGE Environmental Analysis Laboratory
Method 8080 - PCBs
% Recovery QC Sheet
Matrix: Solid

Extraction Date: 11/6/96
Batch: SO1106A
Analyst(s): BMM
Aroclor: 1260

Method Blank: 0 mg/kg

	LCS/LCSD Recoveries	MS/MSD Recoveries	MS/MSD Recoveries
Sample ID:	NA (MB#1)	MB#2	9611003-10A
Sample Concentration mg/kg	0.00	0.00	0.06
Spike Added mg/kg	0.83	0.83	0.83
Concentration mg/kg	0.97	1.03	0.73
	LCS QC Limits	MS QC Limits	MS QC Limits
% Recovery	116.46 58 - 125 OK /	123.92 32 - 147 OK /	80.09 32 - 147 OK
Spike Added mg/kg	0.83	0.83	0.83
Concentration mg/kg	0.92	0.98	0.82
	LCSD QC Limits	MSD QC Limits	MSD QC Limits
% Recovery	109.90 58 - 125 OK /	118.00 32 - 147 OK /	91.13 32 - 147 OK
% RPD	5.80 25 OK	4.42 67 OK	12.90 67 OK

*** outside limits**

Comments:

Analyst: ________ Date: 11·12·96

Reviewed: ________ Date: 11/12/96

File: SO1106A.XLS
Sheet: QC Report
11/12/96; 11:11 AM

SDGE Environmental Analysis Laboratory
Method 8080 - PCBs
% Recovery QC Sheet
Matrix: Solid

Extraction Date:	11/6/96	
Batch:	SO1106A1	Method Blank: 0 mg/kg
Analyst(s):	BMM	
Aroclor:	1260	

	LCS/LCSD Recoveries	MS/MSD Recoveries	MS/MSD Recoveries
Sample ID:	NA	9611003-19A	0
Sample Concentration mg/kg	0.00	0.00	0.00
Spike Added mg/kg	#DIV/0!	0.83	#DIV/0!
Concentration mg/kg	0.00	0.90	0.00
	LCS QC Limits	MS QC Limits	MS QC Limits
% Recovery	#DIV/0! 58 - 125 OK	107.51 32 - 147 OK	#DIV/0! 32 - 147 ##
Spike Added mg/kg	#DIV/0!	0.83	#DIV/0!
Concentration mg/kg	0.00	0.87	0.00
	LCSD QC Limits	MSD QC Limits	MSD QC Limits
% Recovery	#DIV/0! 58 - 125 OK	103.37 32 - 147 OK	#DIV/0! 32 - 147 ##
% RPD	#DIV/0! 25 OK	3.44 67 OK	#DIV/0! 67 ##

*** outside limits**

Comments:

Analyst: ______________ Date: 11/12/96

Reviewed: ______________ Date: 11/12/96

File: SO1106A1.XLS
Sheet: QC Report
11/12/96; 11:09 AM

SDGE Environmental Analysis Laboratory
Method 8080 - PCBs
% Recovery QC Sheet
Matrix: Solid

Extraction Date:	11/6/96	Method Blank: 0 mg/kg
Batch:	so1106b	
Analyst(s):	BMM	
Aroclor:	1260	

	LCS/LCSD Recoveries	MS/MSD Recoveries	MS/MSD Recoveries
Sample ID:	NA [MB#3]	9611004-02A	0
Sample Concentration mg/kg	0.00	0.72 ▲	0.00
Spike Added mg/kg	0.83	0.83	#DIV/0!
Concentration mg/kg	0.97	3.05	0.00
% Recovery	LCS QC Limits 116.46 58 - 125 OK	MS QC Limits ▲279.44 32 - 147 *	MS QC Limits #DIV/0! 32 - 147 ##
Spike Added mg/kg	0.83	0.83	#DIV/0!
Concentration mg/kg	0.92	3.11	0.00
% Recovery	LCSD QC Limits 109.90 58 - 125 OK	MSD QC Limits ▲287.06 32 - 147 *	MSD QC Limits #DIV/0! 32 - 147 ##
% RPD	5.80 25 OK	2.69 67 OK	#DIV/0! 67 ##

*** outside limits**

Comments: ▲ Sample concentration was high + required dilution. Sample spikes were not diluted. JI-C 11/12/96.

Analyst JI-C Date: 11/12/96

Reviewed: RL Date: 11/12/96

File: SO1106B.XLS
Sheet: QC Report
11/12/96; 11:18 AM

EnecoTech
ENVIRONMENTAL CONSULTANTS

CHAIN OF CUSTODY RECORD

7425 Mission Valley Road • ~~Suite 201~~ • San Diego, CA 92108

COC CA# 2621

PROJ. NO. 2-01278-001
PROJECT NAME Silvergate

MPLERS: (Signature) Jenny Noble Jenny Noble
& John Royal John Royal

Ship To:

EnecoTech contact : Mike Gibbs

AT. NO.	DATE	TIME	COMP.	GRAB	STATION LOCATION	NO. OF CONTAINERS	PCB EPA 8080	Remarks/Bottle No.
						4oz. jar		
22	10/30	8:20		1	2N North	1		Soil Sample: pulled rocks/
23		8:25		1	2N East	1		gravel aside with hoe or
24		8:30		1	2N South	1		shovel, then used clean
25		8:33		1	2S North	1		trowel or gloved hands
26		8:37		1	2S South	1		to collect Sample.
27		8:57		1	OCB 3101	1		
28		9:15		1	Bank 1N South	1		
29		9:40		1	Bank 1S East	2 4oz.		
30		9:35		1	Bank 1G	2 4oz.		
31		9:20		1	Bank 1B	1		

elinquished by: (Signature) John Royal	Date/Time 11/1/96 1337	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
elinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
elinquished by: (Signature)	Date/Time	Received for Laboratory by: (Signature)	Date/Time 11/1/96 13:37	Remarks	

Distribution: Original Accompanies Shipment, First Copy to Coordinator Field Files, Second Copy to Representative of Inspected Facility

Split Samples: ☐ Accepted ☐ Declined ______ Signature

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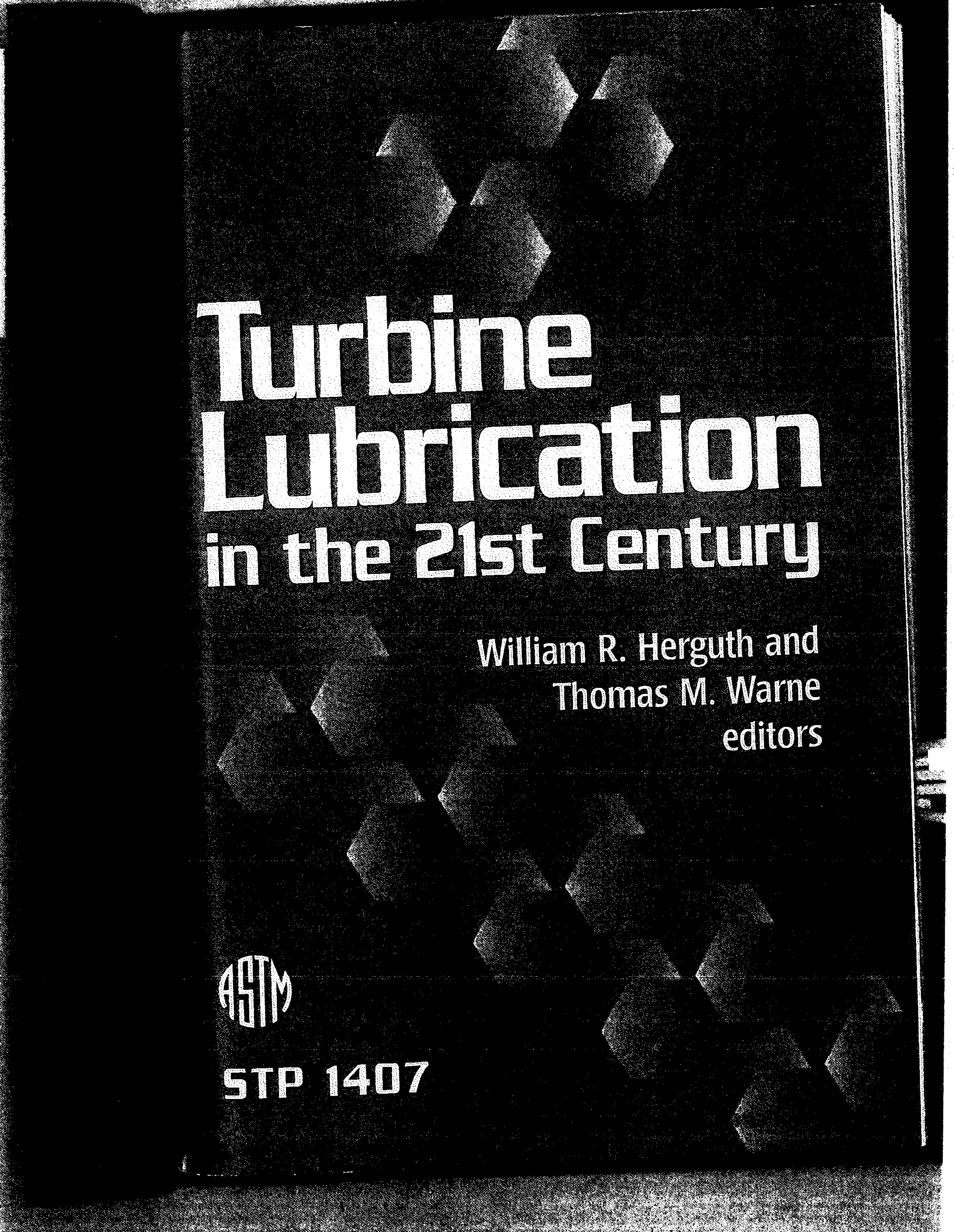

Turbine Lubrication in the 21st Century

William R. Herguth and
Thomas M. Warne
editors

ASTM

STP 1407

STP 1407

Turbine Lubrication in the 21st Century

William R. Herguth and Thomas M. Warne, editors

ASTM Stock Number: STP1407

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Printed in Baltimore, MD
January 2001

nd Thomas M. Warne, editors.

Vash.

m R., 1950- II. Warne,
; 1407.

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Foreword

This publication, *Turbine Lubrication in the 21st Century,* contains papers presented at the symposium of the same name held in Seattle, Washington, on June 26, 2000. The symposium was sponsored by ASTM Committee D-2 on Petroleum Products and Lubricants and its Subcommittee D02.C0 on Turbine Oils. The symposium chairman was William R. Herguth, Herguth Laboratories, Inc., Vallejo, California. The symposium co-chairman was Thomas M. Warne, Chevron Global Lubricants, Richmond, California.

Overview

This publication summarizes the presentations delivered at the "Symposium on Turbine Lubrication in the 21st Century," held in Seattle, Washington on June 26, 2000. The symposium was sponsored by ASTM Committee D-2 on Petroleum Products and Lubricants and its Subcommittee D02.C0 on Turbine Oils.

In the final years of the 20th Century, the lubrication requirements of turbines used for power generation increased significantly. In response, two trends emerged. One was the production of more stable lubricants; the second was the development of improved techniques for monitoring the condition and suitability for use of turbine lubricants.

For some applications, users have turned to synthetic, non-hydrocarbon fluids, such as polycarboxylic acid esters and phosphate esters. Two of the presentations describe current and future directions for some of these fluids. Phillips describes current and future applications of Fire-Resistant Turbine Lubricants, with particular emphasis on European actions to improve the safety of turbine operation. Gschwender, Snyder, Nelson, Carswell, Fultz and Saba address the special case of aircraft turbine engine lubrication and the evolution of new military specifications for Advanced High-Temperature Turbine Engine Oils.

Conventional mineral oil lubricants, produced by solvent extraction and dewaxing of heavy petroleum fractions, still constitute the largest volume of turbine lubricants. However, as we enter the 21st century, petroleum refiners have developed new processing methods; these lead to more stable hydrocarbon fluids which show great promise for the production of more stable turbine oils. One route to these hydrocarbon base fluids is through the oligomerization of olefins; the second involves the catalytic hydrocracking and isomerization of petroleum fractions. Kramer summarizes the history and current state of the Evolution of Base Oil Technology.

The use of such highly paraffinic, low heterocycle hydrocarbon base stocks can lead to steam and gas turbine lubricants with significantly improved oxidation resistance and better thermal stability. Three papers from different lubricant suppliers address some of these performance advantages these formulators have discovered using new technology base oil. Irvine discusses the Performance Advantages of Turbine Oils Formulated with Group II and Group III Basestocks; Schwager and Hardy address the Improved Response of Turbine Oils Based on Group II Hydrocracked Base Oils, while Okazaki covers the Performance Advantages of Turbine Oils Formulated with Group II Base Oils.

Regardless of the stability of lubricating fluids, successful use requires that the lubricant be regularly monitored to ensure continued suitability for use. Swift, Butler, and Dewald present new information on Turbine Oil Quality and Field Application Requirements. Kauffman and Ameye describe the use of a new instrument for oil analysis, in Antioxidant Analysis for Monitoring the Remaining Useful Life of Turbine Fluids.

This publication would not have been possible without the contributions of time, knowledge, and enthusiasm from our authors; the willingness of their employers to support this effort; the reviewers who read the papers and offered suggestions for improvement; and the ASTM personnel who provided editorial assistance and a firm hand to keep us on schedule. The co-Chairs wish to thank all who made this Symposium a success.

William R. Herguth
Herguth Laboratories, Inc.
Vallejo, California, USA;
symposium chairman and STP editor

Thomas M. Warne
Chevron Global Lubricants
Richmond, California, USA;
symposium co-chairman and STP editor

W. David Phillips[1]

The Use of a Fire-Resistant Turbine Lubricant: Europe Looks to the Future

Reference: Phillips, W. D., "**The Use of a Fire-Resistant Turbine Lubricant: Europe Looks to the Future,**" *Turbine Lubrication in the 21st Century, ASTM STP 1407*, W. R. Herguth and T. M. Warne, Eds., American Society for Testing and Materials, West Conshohocken, PA, 2001.

Abstract: Turbine oil fires continue to cause concern. Although not frequent occurrences, a serious fire can have an enormous financial impact. To reduce the risk of hydraulic oil fires in steam turbines, phosphate esters are now widely used, but large volumes of inflammable mineral oil remain in the lubrication system. In order to decrease the fire risk still further, phosphates have also been used in both steam and gas turbines as fire-resistant lubricants. This paper reviews the need for these products and the experience in both trials and commercial operation. It examines the reasons for their slow adoption by industry but also why current market pressures, particularly in Europe, are likely to accelerate their use.

Keywords: safety, fire-resistant turbine lubricants, turbine fires, fire protection, phosphate esters, steam turbines, gas turbines, fluid conditioning, life-cycle costs

Introduction

In 1944, at a meeting of the Machines Technical Committee of the German Power Station Association, a report was made on the operation of a 6 MW steam turbine with a new fire-resistant lubricant based on tricresyl phosphate. After 6000 hours the experience was regarded as totally satisfactory [*1*]. This is the first known use of a phosphate ester-based turbine lubricant. The objective then, as it remains today, was to find a way of overcoming the main disadvantage associated with mineral turbine oils, namely their inflammability, and to avoid the occurrence of turbine oil fires with their impact on operator safety; the often huge cost of repairs and reduced availability of equipment.

In the intervening period much work has taken place to demonstrate the technical feasibility of using fire-resistant turbine lubricants based on aryl phosphate ester fluids as

---

[1] Global Market Leader, Performance Additives and Fluids, Great Lakes Chemical Corporation, Tenax Road, Trafford Park, Manchester, M17 1WT, United Kingdom.

alternatives to mineral oils. Not only have trials in both steam and gas turbines taken place but substantial commercial use has arisen in certain market segments. Their favorable impact on safety has also been confirmed during this period following widespread use as turbine control fluids-particularly in large steam turbines of 250-1500 MW where steam temperatures have risen close to 600 °C.

This paper summarizes the latest position with regard to the remaining "trials" on these fluids; their current commercial use and, particularly in Germany, the factors which are resulting in their promotion by some large utilities, their trade association and by the insurance industry.

Turbine Fires

To many people in the power generation industry, the idea that turbo-generator fires are a concern comes as a surprise! Some utilities, in fact, would go as far as to suggest that fires are unknown in their stations. It is true that large fires are not a frequent occurrence. On closer investigation, however, the situation may be somewhat different as fires can go unreported if they are quickly extinguished and cause neither an unscheduled outage nor casualties. Obviously a severe fire is not good publicity and can shake shareholder confidence but even small fires are important as they can be symptomatic of a greater problem which could eventually lead to a more serious incident. In examining the limited statistics available we should therefore be aware that they may not truly represent the extent of the problem.

Unfortunately few detailed investigations into the origins and frequency of turbine fires have been undertaken. The most rigorous was published in 1983 as an Electric Power Research Institute (EPRI) report entitled "Turbine Generator Fire Protection by Sprinkler System" [*2*]. This was based on 151 responses of 210 U.S. utilities and related to 1181 turbines (principally steam turbines) of >60 MW output. Between 1930 and 1983 some 175 fires were reported of which 121 involved oil either as a primary or secondary source of ignition. Six of these fires involved nuclear units. The study also revealed that in the early 1980s only 285 turbines (24%) of those surveyed had any form of fire protection around the bearings while 350 (30%) had some form of protection on the oil piping. Recent discussions with the author of this report and other authorities in the USA suggest that, while fire protection has improved, there are still many units which are unprotected.

The frequency of turbine fires in the EPRI report appeared to increase from about 1 in 200 unit years in the 1950s through 1 in 145 unit years in the 1960s to about 1 in 100 unit years in the 1970s. (These are probably conservative estimates.) The increase in frequency is thought to be due mainly to better reporting but could also be the result of, for example, higher steam temperatures. These figures are also to be considered against the increasing use of fire-resistant control fluids which were introduced in the mid-1950s. Unfortunately there does not appear to be any published data for the 80s and 90s which would confirm, or otherwise, this trend.

Apart from the above study little detailed data on turbine fires appears publicly available. Some reports are published by the insurance industry, for example the brokers Marsh and McLennan have issued periodic reports [*3*]. While the utility industry normally avoids publicizing information on fires, in Europe the large German-based utility

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association (the Technische Vereinigung der Grosskraftwerksbetreiber-VGB) maintains a list of major fires. This currently identifies 78 that have taken place, mainly in the USA and Europe, since 1972 [*4*]. In the former Soviet Union about 140 incidents took place between 1980 and 1986 [*5*] and this was after many units had already converted to fire-resistant control fluids!

The costs of turbine fires can, in severe cases, be enormous. One publication [*6*] reported on the costs of twenty large fires occurring between 1982 and 1991 where the total property damage was $417 million–an average of $22.7 million per incident. These figures did not take outage costs into consideration which could be up to double the repair costs. The average outage period in the cases cited was 200 days. Although these figures are for the worst incidents, a risk-benefit analysis undertaken for the EPRI report [*4*] indicated that in 1983 dollars the potential cost to the utility of operating a turbo-generator unit without fire protection for 30 years would be $1.62 million and $0.87 million for a 600 MW and 900 MW turbo-generator respectively. Today these figures would be closer to $6 million and $3 million (or $200 000 and $100 000/year). In the UK, two 500 MW sets have been extensively damaged as a result of turbine oil fires in the last four years.

While repair costs can normally be covered by insurance, outage or business interruption costs, particularly during the commissioning of new equipment when the fire risk is probably at its highest, may not necessarily be insured. Large utilities also tend to carry their own insurance and to be able to rely on excess capacity in times of need, a situation that is changing with privatisation. Even when insurance is available, one of the results of a fire can be a substantial increase in premiums as the insurance companies attempt to recover their losses. Significant inconvenience in the post-fire period can also be expected as alternative power supplies are sourced and the site is cleared.

Clearly, in view of the danger to life and the high financial cost, adequate fire protection should be a priority for the utility and for many years sprinkler systems have been used with steam turbines and gas inerting systems with combustion turbines. These are both forms of “active” fire protection where the fire is extinguished after ignition and can be expensive to install and maintain. The cost of mechanical fire protection for a large steam turbine, for example, would be in the region of $40 000-100 000.

Although they are effective when correctly installed and maintained there are occasions when availability can be impaired e.g. as a result of incomplete maintenance [*7*]. The possibility of false alarms may be low but they are reported [*8*]. Lightening, for example, is known to have activated detection systems and resulted in the unscheduled shutdown of gas turbines with considerable damage to the bearings. As a result there may be a reluctance to operate these systems automatically; indeed in some stations a visual observation of a fire is relied on more than automatic means. Even the best “active” systems are, however, of little use in the event of a catastrophic failure of the turbine with the expulsion of blades through the turbine casing when both oil and water lines in the vicinity of the turbine can be destroyed.

Fire protection techniques that eliminate the possibility of fire are clearly to be preferred. An example of a “passive” protection measure would be the use of guarded piping but this is expensive.

Fire-Resistant Lubricants

An alternative approach has been to consider the use of fire-resistant lubricants. Such products offer:

- built-in protection
- protection throughout the whole of the lubrication system
- protection which is available 100% of the time the fluid is in the system and which does not deteriorate with time.

Several types of synthetic turbine oil have been considered in the past. Due to the necessity for operation at high temperatures and high bearing loads the focus has been on non-aqueous fluids. Initially polychlorinated biphenyls were evaluated but, while they possessed excellent fire resistance, lubrication problems were found when used alone [9]. To overcome this deficit they were blended with triaryl phosphates and successfully tested. However, when pcbs were banned in the 1970s for toxicity and environmental reasons, the subsequent development concentrated on phosphate esters. The fact that they were already widely used in turbine control systems was an obvious advantage as it meant that the same fluid could possibly be used for both systems.

Synthetic carboxylate esters from trimethylolpropane or pentaerythritol and short chain acids (C_{5-9}) are used as low viscosity base-stocks for aviation gas turbine oils, while higher viscosity esters from trimethylolpropane and C_{18} unsaturated acids are occasionally used in turbine control systems. However, this type of product does not possess the same level of fire resistance as the phosphate esters (see Table 1) and where it has been used in the hydraulic systems of large steam turbines, fires have resulted. Consequently, to date, this type of fluid has not been considered as a fire-resistant turbine lubricant.

The main advantage of triaryl phosphate esters is undoubtedly their fire-resistance. For example they have autoignition temperatures in the region of 550-590 °C and possess inherent self-extinguishing properties. This means that if, under severe conditions, they do ignite the flame does not propagate once the fluid has moved away from the source of ignition. Additionally these fluids possess excellent lubricating characteristics, demonstrated by their wide use as anti-wear additives for improving the lubricating properties of both mineral and synthetic oils. A summary of their fire resistance properties in comparison with mineral oils and carboxylate esters is given in Table 1.

Although the phosphate esters have some characteristics in common with mineral oils (see Table 2), there are aspects of their performance that are quite different. These include:

- viscosity/temperature characteristics where phosphates normally have much lower viscosity indices. This difference requires that tank heating be available in order to ensure that the viscosity is low enough for pumping on start-up. This aspect of design is, however, fairly common in conventional systems.
- density. Phosphates have values ~30% higher than mineral oil possibly necessitating more powerful pumps and a higher static head to avoid cavitation.
- hydrolysis of the phosphate. This is a chemical reaction of water with the phosphate which results in the production of acidic degradation products. If not controlled this reaction can have an adverse impact on fluid life as the acid produced has an auto-catalytic effect on fluid breakdown as well as promoting corrosion at high levels. In

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order to overcome this disadvantage the fluid is normally conditioned by circulating through an adsorbent media on a by-pass system (see below)

Table 1-*A Comparison of the Fire-Resistance Properties of an ISO VG 46 Mineral Turbine Oil and Triaryl Phosphate Ester and an ISO VG 68 Carboxylate Ester*

Property	Test Method	Mineral Oil	Polyol Ester	Phosphate Ester
Flash point-Open Cup (°C)	ISO 2592	220	266	270
Fire point (°C)	ISO 2592	245	313	365
Auto-ignition temperature (°C)	ASTM D2155	340	430	575
Hot manifold ignition (°C)	AMS 3150C	350	395	>800
Wick ignition	ISO 14935	Fail	Fail	Pass
Factory Mutual Spray test	FM Std. 6930			
-Persistence of burning		Fail	Pass	Pass
-Spray Flammability Parameter		Group 3	Group 2	Group 1
Persistence of burning	ISO 15029-1	Fail	Pass	Pass
Ignitability Index	ISO 15029-2	Group H (worst)	Group G	Group D
Compression ignition test	MIL-PERF-19457D			
-ignition ratio		10	18	>42

- incompatibility with conventional paints and seals. Fortunately a range of suitable seals are now available, in particular fluorocarbon elastomers which are increasingly used in turbine applications. The interior surfaces of systems for use with phosphates are preferably left unpainted as rusting is not normally a problem. However, the industry trend is towards the use of stainless steel which would obviate the need for coatings.

In the same way that mineral oils can vary in their chemical composition and performance, so phosphate esters can also vary depending on the raw materials from which they are produced. There are three basic types of product used in turbine applications, trixylyl phosphate, isopropylatedphenyl phosphate and tertiarybutylphenyl phosphate ester. A comparison of the main properties which are structurally influenced is given in Table 3 and the stability properties are seen to vary significantly. As a result TXP-based products are preferred for applications where water contamination is likely to be a concern, while for applications where high temperature stress is unavoidable, for example in gas turbines, the tertiarybutylphenyl phosphates may be preferred

The differences in properties in comparison with mineral oils require that systems be designed for use with phosphates. It is unfortunately not normally possible to convert a system from mineral oil to phosphate by draining the oil and refilling with the new fluid, due mainly to compatibility aspects, and system modifications may also be needed e.g. to the pump train as a result of the higher fluid density. Contact with the turbine builder is necessary to determine what equipment modifications are required.

Table 2-*A Comparison of Some Typical Properties of an ISO VG 46 Mineral Turbine Oil and Phosphate Ester*

Property	Mineral Oil	Triaryl Phosphate
Viscosity at 100 °C (cSt)	6.7	5.0
at 40 °C	46	43
at 0 °C	450	1700
Pour Point (°C)	-9	-20
Acid number (mgKOH/g)	0.15	0.05
Specific Gravity at 20 °C	0.870	1.135
Air release (min)	3	1
Foaming tendency /stability-24 °C (ml)	250/0	30/0
Water content (%)	0.001	0.06
Rust prevention (distilled water)	Pass	Fail
Specific heat at 20 °C (J/gK)	1.76	1.69
Thermal conductivity (W/mK)	0.134	0.132

Fire-Resistant Turbine Control Fluids

Following a number of turbine fires in the early 1950s, the concept of a split hydraulic and lubricating oil system with the use of a fire-resistant hydraulic fluid in the control system, was introduced. This move was based on the assumption, since shown to be erroneous, that the great majority of turbine fires originate from the hydraulic system as a consequence of the high hydraulic pressures and the proximity of high temperature steam pipes. In fact the statistics show that there is little difference between the hydraulic and lube oil systems as sources of fires-at least in steam turbines [*4,10*].

The earliest fluids used were blends of polychlorinated biphenyls (pcbs) and phosphates. The latter were added to reduce the viscosity and density of the pcbs without significantly adversely affecting their fire resistance. The use of pcbs was, however, quickly discontinued in view of valve erosion problems as well as toxicity and environmental concerns. Since the early 1970s, phosphate esters have been the only fire-resistant fluids approved by the turbine builders for this application although small amounts of more flammable carboxylate or synthetic esters have been used in refurbished systems. It is thought that there are over 1000 large steam turbines (>250 MW output) currently in operation worldwide with fire-resistant hydraulic fluids based on phosphate esters and the use of these fluids has largely eliminated the risk of fire arising from ignition of the hydraulic fluid.

Experience with Fire-Resistant Lubricants

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As suggested earlier, while the use of a fire-resistant hydraulic fluid is effective in reducing the fire hazard associated with the control system, the risk of fire associated with the mineral turbine oil remains. Large volumes of oil, possibly up to 100 m^3 in the very largest sets, remain in the bearing lubrication system. Of particular concern in this respect is the common use of shaft-driven oil pumps which can continue to feed a fire with oil as long as the shaft is turning. A leak of fire-resistant lubricant obviously does not pose the same threat.

Table 3-*The Effect of Chemical Type on the Performance of Phosphate Esters*

Chemical Type	Autoignition Temperature (°C)	Air Release (mins)	Hydrolytic Stability	Oxidative Stability
Isopropylphenyl	540	5	Moderate	Moderate
Tertbutylphenyl	580	5	Poor-Moderate	Excellent
Xylyl	570-590	1	Good-Very good	Good

The very earliest use of a fire-resistant lubricant appears to have occurred during the 1930s when pcbs were investigated [9] as a result of a series of fires. Although some satisfactory operating experience was obtained, interest lapsed and nothing further was done until the 1950s when a further series of fires "sparked" a revival of interest. The topic was then taken up by some U.S. utilities and also in the late 1960s by General Electric who converted a 12.5 MW set at their Medium Steam Turbine Division. Over a decade of valuable operating experience was obtained with phosphate esters in this industrial set which, after initial teething problems ran very successfully [11]. Subsequently, in Western Europe, several trials were also carried out in the UK, Germany and France [12]. In the earliest of these dating from 1974, the Technical University of Munich began to test a phosphate ester in a small steam turbine of 1.5 MW and this was followed in 1979 by the conversion of another unit of 5.5 MW [13]. The larger of these units is still in operation today and has operated on two charges of fluid in this time period.

In 1982 in Basel, a 10 MW back-pressure turbine was converted from mineral oil to phosphate after experiencing foaming and deposition problems. In this unit the new fluid was used not only for the turbine control and lubrication systems but also for the gears, the jacking system, and the air-cooled generator. Today, after about 60 000 hours of operation involving frequent starts which place increased stress on the fluid, the turbine continues to operate on the same fluid charge filled into the unit in 1982. The quality of the fluid is still as good as new and it is only necessary to replace the conditioning medium used to remove fluid degradation products, annually. Table 4 shows some of the analytical data obtained over the period of service to date. Examinations of bearings and reduction gear have not revealed any significant wear and the occasional severe water contamination has not caused any unscheduled shutdown or significant change to the fluid properties. More details on this experience are available in the relevant references [*12,14*].

A very serious incident during operation was avoided as a result of using the fire-resistant lubricant. A boiler failure occurred which led to a loss of steam pressure. Unfortunately, the circuit breaker which should have automatically isolated the generator, failed to trip. The generator therefore now operated as an "engine", motoring the turbine. It was not immediately possible to switch-off the power remotely because of the impact this would have on the rest of the manufacturing site. This resulted in the turbine overheating and the heat generated at the blade tips began to produce local welding with subsequent jamming of the blades in the housing. At this stage the generator was consuming about 3 MW of power! Eventually it was possible to open the switch but the damage cost about 1 million SFr to repair. Outage costs were about 0.5million SFr and the equipment was out of operation for about 1 year. Although fluid escaped from the lubricant system there was no fire and when the unit was eventually returned to use, the same fluid charge was re-installed.

Table 4-*Analytical Data on a Phosphate Ester Used for the Lubrication of a 10MW Steam Turbine*

Property	Units	0 hrs 4/83	3000 hrs	14000 hrs	26000 hrs	40000 hrs	55000 hrs 5/99
Viscosity	cSt	42.7	42.7	41.6	42.4	43.5	43.4
Acid Number	mgKOH/g	0.02	0.05	0.02	0.02	0.01	0.03
Water Content	%	0.05	0.08	0.16	0.11	0.05	0.07
Air release Value	min	2	1	1	1	1	1
Foaming	ml	190/0	240/0	280/0	210/0	370/0	400/0
Cleanliness	SAE Class	4	0	1	0	0	1

While the tests in Europe and the USA focussed on small industrial sets it was in the FSU that the most significant developments took place. Following trials in a 16.5 MW industrial unit in 1959, a 300 MW set (including the generator) belonging to the All Russia Thermal Engineering Institute in Moscow was converted to use phosphate ester and a trial started in the early 1970s [*15*]. The operating experience obtained led directly to the first commercial use of phosphate esters in large steam turbines with the conversion of a 220 MW nuclear unit at Kolskaya in 1982.

Today, the same operating charge is still in use and the turbine continues to function satisfactorily. This has been achieved without any off-line conditioning which is common in Western control and lubrication system design when using phosphate esters. This is a result of the improved hydrolytic stability of the phosphate developed by the All Russia Thermal Engineering Institute [*5*]. Since 1982 other large steam turbines of up to 1000 MW have been converted or operated from new [*16*]. Table 5 indicates those units currently in operation. Although it was originally planned to convert all the existing 220/800 MW sets to phosphate, capital limitations have forced the postponement of this

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Outside the FSU, interest in the lubrication of large steam turbines was limited to detailed studies by EPRI in 1983 of the feasibility of adapting a large steam turbine [*17*]. It was concluded that such a conversion was possible and that phosphate esters would be suitable but that the modifications would be expensive. A further review of the existing experience with fire-resistant lubricants by EPRI some six years later [*18*] also concluded that phosphate esters could safely be used to lubricate small–medium sized units with the knowledge then available.

Table 5-*Use of a Fire-Resistant Lubricant in Turbines of the CIS*

Power Station	Type	Output (MW)	Date Installed	Conversion to Phosphate	Operating hours on Phosphate
Kola Unit 1	Nuclear	220	1982	1983	110000
Zaporojie Unit 6	Thermal	800	1977	1985	77500
Zaporojie Unit 5	Thermal	800	1975	1992	61000
Perm Unit 1	Thermal	800	1986	1986	95200
Perm Unit 2	Thermal	800	1987	1987	86350
Perm Unit 3	Thermal	800	1990	1990	68200
Perm Unit 4	Thermal	800	1994	1994	42500
Rovny Unit 5	Nuclear	1000	1986	1986	95100
Khmelnitsk Unit 1	Nuclear	1000	1987	1987	86450
Yuzhno-Ukraine Unit 3	Nuclear	1000	1989	1909	70500

b) Gas Turbines

Although the experience in steam turbines with fire-resistant lubricants is probably better known, there is far greater experience in gas turbines. The earliest known operation with fire-resistant lubricants in this application commenced in 1958 when Texas Eastern Corporation decided to test phosphate esters in [*19*]. The trials were successful and Texas Eastern then planned the conversion of the remainder of their turbines. In Canada, the new pipelines that sprang up for gas transmission in the 1960s also decided to use fire-resistant lubricants and companies such as TransCanada Pipelines. Great Lakes Gas, Alberta Gas (subsequently the Nova Corporation), West Coast Transmission, Dome Petroleum etc. introduced these fluids into their equipment where possible–many from their initial installation. If industrial turbines were installed, the phosphates lubricated both the turbine and the associated compressor but if an aero-derivative unit was the prime mover, then the phosphate ester, if used, was only for lubrication of the compressor.

In the area of power generation, phosphates were used by General Electric (GE) as the combined hydraulic fluid and lubricant in some Frame 7 units produced in the 1970s. For a period there was a hot middle bearing which resulted in fires with mineral oil. Before the problem was "designed out," phosphate esters were used as lubricants and about ten units still run on these fluids today with some turbines approaching 100000 hours operation.

The number of gas turbines/ compressors currently operating on phosphates in North America is about 150 and includes equipment from G.E., Canadian Westinghouse, Nuovo Pignone and Solar. The introduction of dry gas seals in the 1990s encouraged some users in Canada to return from phosphates to mineral oils but a series of fires with these units resulted in government pressure to move all possible equipment to phosphates-including those units that had been supplied with mineral oil.

In Europe, by comparison, the experience in gas turbines is very limited. A 5 MW Sulzer Type 3 unit was installed by Ciba-Geigy in Basel in 1986, in the same power station as the steam turbine. The turbine, reduction gears and generator have operated successfully on the same fluid charge since commissioning. Table 6 shows the results of analyses on fluid samples taken from the turbine over this period.

Two incidents have occurred during operation with the fire-resistant lubricant which, had mineral oil been used, would have resulted in fires. The first involved a screw coupling failure on the line from the high pressure lifting pump which resulted in fluid being sprayed over the hot end of the turbine. Because no fire occurred it was possible to follow normal shutdown procedures. The second was a leakage from the power turbine shaft seal and oil escaped onto the hot housing. Instead of having to shut the unit down to replace the seal, operation continued with the fluid being collected until a convenient shutdown occasion occurred, thus avoiding an unwanted outage [14].

Fluid Maintenance

As with existing turbine oils it is necessary to adequately maintain phosphates in order to ensure efficient operation of the system and an acceptable fluid life. The parameters that are of most concern are the increase in acidity, water content and particulate contamination level. When triaryl phosphates degrade the most common result is an increase in acidity with little effect on viscosity change. Consequently this latter property is not one that requires regular attention. Water and acidity, however, need monitoring. To date there are no specifications for used fire-resistant turbine lubricants but there is a tendency to adopt the limits already in existence for phosphate esters when used as turbine control fluids i.e. a maximum acidity of 0.2-0.3 mgKOH/g.

While the presence of some dissolved water can be tolerated if the acidity is low, free water is to be avoided in view of the potential adverse effect on rusting, emulsification etc. As the solubility of water in phosphates is very much higher than in oil (reaching about 2500ppm at 25 °C) this is not usually a problem and the level of fluid acidity will normally determine the suitability of the fluid for continued use.

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Table 6-*Analytical Data of a Triaryl Phosphate Ester Used for the Lubrication of a 5 MW Industrial Gas Turbine*

Property	Units	Jan '86 0 hrs	'88	'90	'92	'94 42000 hrs	'96	'98	12/99 82000 hrs
Viscosity at 40 °C	cSt	45.2	46.3	46.4	46.0	46.0	45.8	45.0	45.4
Acid Number	mgKOH/g	0.07	0.08	0.01	0.01	0.01	0.04	0.04	0.08
Water Content	%	0.03	0.03	0.03	0.06	0.06	0.08	0.06	0.07
Air release Value	min	1	2	2.5	2	2	3	2	2

The key to the cost-effective use of phosphate esters is the use of conditioning media to remove acid degradation products. Initially, fullers earth and activated alumina were used for this purpose, but experience with these adsorbents has been unsatisfactory in systems where the acidity was allowed to rise too high. Deposits occurred and the air release/foaming properties deteriorated. The reason for this behavior was that the filter media, for example fullers earth, contained calcium and magnesium carbonates. These components reacted with the acidic decomposition products from the phosphate to produce soluble, and eventually insoluble, metal phosphate salts [*20*] which had an adverse effect on the surface-active properties of the fluid.

These treatment methods could substantially increase the life of the fluid where the system was well maintained and a low fluid acidity level was achieved. However, in cases where the fluid was severely stressed and it was impossible to maintain a low level of acidity this would eventually lead to an early fluid replacement and possibly the necessity of physically removing the deposits from internal surfaces by flushing and manual cleaning. Fortunately this problem is now solved. With the introduction of new adsorbents based on ion-exchange resins [*21*], it is now possible to keep the fluid in the system for many years. TransCanada Pipelines for example have reported units accumulating over 200 000 hours (25 years) on the same fluid charge. In 1998 they had over 14 million operating hours on these fluids [*22*]. With this length of fluid life, the life-cycle costs become very favorable and concerns regarding the disposal of the fluid are minimized. The resins used are however, wet and it is necessary to use a vacuum dehydration unit downstream to remove the displaced water. This equipment replaces the centrifuge used to remove water from wet turbine oil.

Fire-Resistant Fluids and Lubricants–Features and Benefits

As a result of the operating experience to date the principal features and benefits associated with phosphate ester fire-resistant fluids and lubricants are summarized in Table 7.

Table 7-*The Principal Features and Benefits of a Phosphate Ester Turbine Lubricant*

Feature	Principal Benefit
Fire resistance	• Improved safety/worker protection • Avoidance of fires leading to reduced downtime/ increased availability • Elimination of mechanical fire protection around the turbine with space saving and no maintenance requirements • Avoidance of shutdowns due to spurious alarms • Reduction in insurance premiums • Simpler building construction e.g. removing the need to isolate the reservoir • Greater shareholder confidence
Very long life when used with state of the art fluid conditioning	• Favorable life-cycle costs • Reduced downtime for replacement and (in most applications) lower maintenance requirements • Minimizes fluid disposal costs.
System modifications possible with favourable cost impact	• Single hydraulic and lube oil system • Reduction in tank capacity of up to 25% with certain fluid types • Possibility of higher bulk fluid temperatures • Simpler line construction leading to improved accessibility for repair etc.

Obstacles to Progress with Fire-Resistant Lubricants

With such a large amount of satisfactory operating experience it is perhaps surprising that industry has not adopted these fluids more widely. There are several reasons for this as follows:

1) The power generation industry is extremely conservative.
2) As suggested earlier there is no wide acceptance that turbine fires are a continuing problem. The builders argue, as a result, that there is no pressure from the market. In fact there have been a number of enquiries in recent years in which the builders have, at least initially, shown little interest.
3) Although the capital cost of the equipment when using a fire-resistant lubricant is not significantly different from when mineral oil is used, the turbine builder is understandably

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reluctant to introduce "design specials". Moving to a new fluid can result in considerable effort in modifying drawings, seeking alternative components, logistics problems with carrying different spares etc. At a time when competition is fierce such changes are unwelcome to the manufacturers, particularly if they have no spare capacity for their standard designs.

4) If the builders are involved in maintenance contracts, they are insisting that these contracts will be invalidated if phosphates are used and problems occur!

5) A fire-resistant lubricant is significantly more expensive than one based on mineral oil. However, the cost savings associated with the elimination of fire-protection around the turbine, favorable life-cycle costs and the safety benefits associated with the new fluids are not necessarily understood or taken into consideration when deciding what lubricant shall be used.

6) There is a perception that phosphate esters are noxious and require special precautions for handling. This is not the case. Extensive toxicity and ecotoxicity data are now available on these fluids [*23*] which have failed to reveal a significant risk and the handling precautions are the same as are recommended for mineral oil.

7) With the emphasis today on the high availability of equipment, users are not prepared to compromise that availability. If therefore the builder shows a reluctance to offer phosphates and to guarantee equipment availability with these fluids, the user will naturally think twice about their adoption.

Technical and Commercial Drivers Towards Fire-Resistant Lubricants

In spite of the reluctance of some turbine builders to introduce fire-resistant lubricant technology there are a number of factors, particularly in Europe, which are steadily influencing the market in this direction. For example, in the search for higher equipment efficiency, operating temperatures, and therefore also the fire risk, are continuing to increase. Gas turbine inlet temperatures have increased from 700 °C in 1950s to 1500 °C today [*24*] while steam temperatures are now at about 600 °C with the intention to increase still further to 650 °C when the metallurgy permits. In an attempt to reduce generating costs, the number of operatives in the utilities has decreased dramatically–by up to half in some cases. Consequently there are now fewer people 'walking the lines' and looking for leaks and signs of other potential problems. Less time is available for training and maintenance programmes are now targeting specific pieces of equipment rather than a 'holistic' approach to the system.

With the drive to increased margins there is a tendency to keep existing plant in economical operation for as long as possible. In the USA for example ~70% of fossil units are currently more than 30 years old. With age comes a greater chance of metal fatigue and an escape of oil. The current trend of refurbishing old units may also result in extending the life of existing pipework with the same effect.

In Europe, because of a number of fires, the German utility association (VGB) is now promoting the use of fire-resistant lubricants in both gas and steam turbines following advice from their technical committees [*25*]. Also in Europe a series of Commission Directives aimed at improving worker protection have been published. In the UK, for example, the Supply of Machinery (Safety) Regulations arising from the Machinery Safety

Directive state "*Machinery must be designed and constructed to avoid all risk of fire posed by the machinery itself or by gases, liquids etc. produced or used by the machinery*". A similar statement appears in the legislation of all EC member states. The legislation also contains provisions for the imposition of penalties in the event of a fire arising as a result of a lack of implementation.

The insurance industry in Europe is very supportive of the use of the new fluids. Allianz Insurance, for example, is offering substantial discounts on insurance premiums and also technical support to the customer in the event that they use fire-resistant lubricants [*26*]. In the USA, the NFPA (National Fire Protection Association) and Factory Mutual already recommend fire-resistant lubricants for use in gas turbines as an alternative to mineral oil and mechanical protection [*27,28*] and the scope of the latter's standard for "Less Flammable Hydraulic Fluids" is being extended to include turbine lubricating oils.

In order to examine the likely cost-effectiveness of phosphate esters, a committee was set up in Germany in 1998 under the chairmanship of Allianz GmbH and consisted of members of some of the German utilities, European turbine builders and fluid suppliers. It concluded that "the use of a fire-resistant fluid in the control and lubrication system of a 500 MW steam turbine offers a cost advantage against mineral oil and is at least cost neutral in combined cycle equipment" [*29*]. The author's experience in industrial gas turbines would support this conclusion.

The Future

There is no doubt that the industrial trends indicated above, particularly the regulatory aspects, will encourage the wider use of fire-resistant lubricants. Utilities will also see their application as a means of avoiding fires and maintaining safe working conditions under strong competitive pressures. In fact there is already a move in this direction from some of the larger utilities in Europe particularly when considering investment in new plant. New industrial steam and gas turbines are also expected to be in operation in the next twelve to eighteen months and, as the advantages become clearer and more quantifiable, the momentum is expected to gather pace.

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TRIBOLOGY GROUP

FIRE-RESISTANT FLUIDS FOR GENERAL HYDRAULIC AND STEAM TURBINE SYSTEMS

By A. C. M. Wilson*

Major items of C.E.G.B. power plant are now being designed to operate at high steam temperatures and hydraulic pressures. In consequence, the risk of fires due to leaking petroleum lubricants is increasing. Suitable fire-resistant (f.r.) fluids are therefore desirable. Some of these have, however, given rise to difficulties in service due to changes in their physical and chemical properties.

The physical properties of non-aqueous synthetic f.r. fluids (i.e. phosphate esters and chlorinated diphenyls) have been surveyed, and their chemical stability and anti-corrosion properties determined.

Whilst the physical properties of the phosphate esters are better than those of the chlorinated diphenyls the chemical stability and corrosion properties are much worse.

INTRODUCTION

The leakage of petroleum lubricants on to steam pipes at temperatures approaching 600°C and into lagging creates a fire hazard and a number of C.E.G.B. generating stations have experienced fires caused by the ignition of oil which has leaked from turbine hydraulic and lubrication systems. The higher hydraulic pressures proposed in future steam turbine designs will make the situation more serious as leaking fluid may be projected over long distances, and an atomized spray of oil may be formed, which, once ignited, may be difficult to extinguish. Similarly, high-pressure hydraulic boiler controls also present a fire hazard.

The U.S. Navy (1)† and Texas Eastern Transmission Corporation (2) were among the first to appreciate the fire risks involved with high-temperature and/or high pressure equipment and they now use fire-resistant (f.r.) fluids in such equipment. A number of steam turbines have also been designed to operate with f.r. fluid in the control mechanism, and mineral oil in the turbine and generator bearings. Three such machines are installed at the C.E.G.B. Generating Station at Richborough. A number of small steam turbines have been experimentally lubricated with f.r. fluids, and unattended gas turbine compressor units (2) are regularly lubricated with such fluids. Trials using f.r. fluid as a turbine bearing lubricant are in progress within the C.E.G.B. and boiler control equipment is being converted and designed to operate on these fluids.

Where f.r. fluids have been used, however, their performance has generally been unsatisfactory. There have been cases of large viscosity changes, severe corrosion, rapid acidity rises, and refusal of equipment to operate at low temperatures. The extent of the troubles encountered can be judged from the fact that in approximately 40 000 operating hours with the three machines at Richborough, nine charges of fluid have been used. Of the six charges removed, one was contaminated with mineral oil; two had increased in acidity to 0·5 mg KOH/g; a fourth charge, which was also acid at about 0·5 mg KOH/g, was contaminated with water which resulted in severe corrosion of the system; a fifth formed a gummy deposit and was also acid; and the sixth developed a fine suspended sludge which was accompanied by severe foaming. Three of these charges of fluid also suffered an approximate 40 per cent decrease in viscosity. The shortest fluid life has been 24 hours whilst the longest has been over 8000 hours. Whilst some users of f.r. fluids report successful and trouble free operation (3), others have experienced similar problems.

The information reported here is intended to form a more sound basis for selecting f.r. fluids, and so eliminate,

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† *References are given in Appendix 3.*

or at least reduce, the problems encountered. The fluids chosen would be required to serve as a hydraulic medium for boiler and turbine control systems, and possibly as a lubricant for steam turbine and generator bearings and will therefore be subjected to water contamination as well as high hot spot temperatures.

TYPES AND PROPERTIES OF FLUIDS EXAMINED

Types of fluid

Only non-aqueous synthetic fluids, Table 1, based on one of the following materials, have been examined:

1. phosphate esters,
2. chlorinated diphenyls.

Properties of fluids

Where f.r. fluids are used their properties should be as near as possible to those of the mineral oil they are to replace. In a number of important properties, however, f.r. fluids differ significantly from mineral oils resulting, generally, in an unsatisfactory performance. These properties, plus the fire-resistant properties, are listed and discussed below:

1. fire-resistant properties,
2. viscosity characteristics,
3. shear stability,
4. chemical stability,
5. anti-rust and corrosion properties,
6. other important properties.

Fire-resistant properties

The fire-resistant properties of liquids are assessed by four tests each of which gives information specific to particular conditions. These are: (1) flash point, (2) fire point, (3) auto-ignition temperature, and (4) flame propagation properties.

Typical figures for mineral oil and synthetic fire-resistant fluids are given in Table 2.

Fluid leaking on to a hot surface will be ignited when auto-ignition conditions exist. Although f.r. fluids have measurable auto-ignition temperatures, unlike mineral oils they will not support combustion or propagate fires, although some of the thermal decomposition products may continue to burn slowly.

Fire propagation is therefore the most important combustion parameter and a number of tests, ranging from simple fluid-soaked wick tests to high-pressure spray tests, are available to measure this feature (4).

Viscosity characteristics

Both phosphate esters and chlorinated diphenyls can be manufactured in a number of viscosity grades, so a material may be chosen with a viscosity suitable for the operating temperature of the equipment. The change of viscosity with temperature is, however, greater than it is with mineral oil, and this results in a high viscosity at low temperatures. Because of this, cold-start troubles have been experienced in cold weather. Viscosity index (v.i.) improvers, which are polymeric materials having the function of improving the viscosity–temperature characteristics, can be added to suitable base materials to obviate this difficulty.

Table 1. Fluids examined

Fluid	Description	Additives
Mineral turbine oil	B.S. 489 light and medium viscosity grades	Anti-oxidant, anti-rust, anti-foam
Mineral hydraulic oil	Low viscosity oil	Anti-oxidant, anti-rust, anti-foam, anti-wear
1	Chlorinated diphenyl-based	Corrosion inhibitor
2 (a and b)	Chlorinated diphenyl-based	Anti-rust* viscosity index improver
3	Chlorinated diphenyl-based	Anti-oxidant, anti-rust, anti-foam, viscosity index improver, corrosion inhibitor
4	Chlorinated diphenyl–phosphate ester blend	Viscosity index improver
5	Phosphate ester–chlorinated diphenyl blend	None
6	Phosphate ester–chlorinated diphenyl blend	Viscosity index improver
7	Chlorinated diphenyl–phosphate ester–petroleum hydrocarbon blend	Anti-rust, anti-foam, viscosity index improver
8	Phosphate ester	Anti-rust, viscosity index improver, corrosion inhibitor
9	Phosphate ester	Anti-rust, viscosity index improver
10	Phosphate ester	None
11	Phosphate ester	None
12	Phosphate ester	None
13	Phosphate ester	None

* 2a contains no anti-rust additive.

Table 3 gives typical kinematic viscosity figures for a number of commercially available and experimental f.r. fluids, and because of the importance of absolute viscosity in certain applications, this is also given. Figures for the pour point, viscosity index and minimum pumping

Table 2. Fire-resistant properties of fluids

Type of fluid	Flash point, °C ASTM. D92-57	Fire point, °C ASTM. D92-57	Auto-ignition temperature, °C ASTM. D286-58 (mod.)	Flame propagation tendency
Mineral oil	220	245	390	Propagates
Phosphate esters	260	370	640	No propagation
Chlorinated diphenyls	215	345	650	No propagation

Table 3. Physical characteristics of fluids

Fluid	Specific gravity 15·5/15·5 °C	Viscosity (cS) (cP in brackets)			Viscosity index (I.P. 73/53)	Pour point, °C (I.P. 15/65)	Minimum pumping temperature*, °C	
		37·8°C	60°C	98·9°C			Extrapolated	Actual
Mineral oil	0·870	29–60 (25–52)	12·5–22 (11–19·5)	4·7–7·0 (4·1–6·1)	75 min	−7 max	−11 to 2	
Mineral oil	0·870	23·5 (20·5)	10·7 (9·3)	4·1 (3·6)	72	−29	−4	
1	1·42	30 (42·5)	8·2 (12·2)	2·3 (3·3)	<0	−9	5	
2	1·34	22·5 (30)	8·5 (11·5)	2·8 (3·8)	<0	−18	−5	2
3	1·36	45 (61)	17 (24)	5·7 (7·8)	65	−9	−3	7
4	1·36	71·5 (98)	26 (36)	8 (10·8)	82	−15	3	12
5	1·27	32 (40·7)	9·7 (12·5)	2·8 (3·6)	<0	−12	5	
6	1·13	30·5 (34·5)	17 (19·5)	7·8 (8·8)	>150	−48	−31	−19
7	1·20	28 (33·6)	11·5 (13·8)	4·3 (5·2)	31	−24	−12	−5
8	1·17	47 (56)	18 (21·5)	5·8 (6·9)	60	−28	−2	
9	1·16	55·5 (64)	20 (23·2)	6·1 (7·1)	41	−12	3	
10	1·17	47 (56)	14 (16·5)	3·9 (4·5)	<0	−18	7	
11	1·14	48 (54)	16 (18·5)	4·8 (5·5)	<0	−18	3	
12	1·17	30 (33)	12·5 (13·8)	4·3 (4·7)	12	−26	−8	−1
13	1·15	43 (49·5)	16·3 (18·7)	5·2 (6·0)	25	−21	−5	5·5

* Temperature at which the fluid has a viscosity of 800 cS.

temperature are also quoted, the last being defined as that temperature at which the fluid has a kinematic viscosity of 800 cS. Whilst viscosity index indicates the rate of change of viscosity with temperature, the pour point and minimum pumping temperature give an indication of the performance of the fluid at low temperatures. The minimum pumping temperature is often quoted at 20 deg above the pour point and the extrapolated figures given in Table 3 agree reasonably well with this. The extrapolation of viscosities of f.r. fluids is, however, unreliable as these fluids increase more rapidly in viscosity, with decrease in temperature, below about 50°F. The few actual minimum pumping temperatures quoted in Table 3 suggest that the extrapolated figures are about 10 deg low.

Table 3 shows that fluids are available which have viscosity and low-temperature characteristics close to those of B.S. 489 light and medium turbine oils, and to a typical low-viscosity hydraulic oil.

Shear stability

One widely used fire-resistant fluid shows an approximate forty per cent decrease in viscosity in service due to shearing of the fluid. As the sensitivity of the controls is dependent upon viscosity, any substantial viscosity change at operating temperature is undesirable. Both phosphate esters and chlorinated diphenyls are claimed to be shear stable, and in fact all large viscosity changes experienced have occurred with fluids containing v.i. improvers.

The change in viscosity due to shear is given in Table 4 for seven fluids and a mineral oil as assessed by two laboratory tests (details appear in Appendix 1). The change in viscosity during service is also given although full results are not available for all fluids.

The fluids containing a v.i. improver are in general less shear stable than the mineral oil and base f.r. fluids. Stable v.i. improvers are, however, available as evidenced by fluid 3.

*Table 4. Change in viscosity with shear**
(Percentage viscosity drop at 37·8 and 98·9°C.)

Fluid	Service performance	Pump and injector test (210 cycles)	Raytheon sonic oscillator test
Mineral oil	2·5	—	0
1	5	—	—
3	—	—	0
4	—	—	31
6	38	44	41
8	18	15	11
9	12	6·2	5·5
11	—	—	0

* Test details are given in Appendix 1.

Chemical stability

The chemical stability of a lubricant is a determining factor of its useful life. High-grade mineral turbine and hydraulic oils in well maintained systems have a long life of the order of 10 to 20 years. The cost of the synthetic f.r. fluids is six to 10 times that of mineral oil, so that even with the same fluid life, lubrication costs will be much higher.

Whilst mineral oils rarely increase in acidity in under 10 years in steam turbine systems, three different branded f.r. fluids (6, 8 and 9, Table 1), based on phosphate esters, have shown a steady rise in acidity of the order of 0·05–0·20 mg KOH/g/1000 h, and a fair proportion of this acidity is strong acids of pH $< 4·0$. Corrosion of metals in systems will be experienced under these conditions particularly in the presence of moisture.

The degradation of mineral oils is almost wholly due to oxidation, but phosphate esters can be expected to degrade by hydrolytic and thermal reactions. The chlorinated diphenyls should have a good hydrolytic stability, but some oxidation and thermal degradation at high temperatures may occur.

The oxidation, thermal and hydrolytic stability of a number of f.r. fluids has been investigated, over the temperature range 60–190°C and with moisture contents ranging up to 100 per cent. Traces of moisture of the order of 0·1 per cent above saturation were shown to have a marked effect on the rate of degradation of the fluids. From these results a sequence of tests has been designed to check fluids for chemical stability and corrosion resistance (Appendix 2). Table 5 gives results using this test sequence together with results on a mineral turbine oil for comparison. From these it is obvious that only chlorinated diphenyl-based materials, i.e. fluids 2, 3 and 5, approach the stability of the mineral oil. The phosphate ester-based materials are much better under dry conditions, but they are still much inferior to the chlorinated diphenyls. Lower acid values are obtained in wet tests with phosphate esters when iron and copper are present, but the loss in weight of the metal specimens (Table 6) suggests that these are due to neutralization of the acidic hydrolysis products by attack on the metals.

*Table 5. Chemical stability of f.r. fluids**

Fluid	Acid value, mg KOH/g of fluid			
	Initial	Test 1 (dry)	Test 2 (wet)	Test 3 (wet + catalysts)
Mineral oil	0·15	0·15	0·20	0·20
1	1·10	0·85	1·5	1·1
2a	0·05	0·05	0·05	0·10
2b	0·10	0·10	0·30	0·35
3	0·20	0·15	0·40	0·10
4	0·15	0·05	0·70	0·15
5	0·05	0·05	0·15	0·10
6	0·15	2·0	2·6	0·20
7	0·10	0·15	0·35	0·35
8a	0·15	0·30	35·8	1·5
8b	0·15	0·25	27·0	1·1
9a	0·20	0·20	23·5	3·9
9b	0·20	0·15	12·2	3·5
10	0·05	0·35	0·50	0·55
11a	0·10	0·85	15·2	0·35
11b	0·05	1·0	0·40	0·20
12	0·05	0·20	19·0	0·60
13a	0·05	0·45	3·2	1·3
13b	0·05	Nil	0·40	0·10

* Test details are given in Appendix 2.

*Table 6. Corrosivity of f.r. fluids to metals**

Fluid	Metal			
	Copper		Iron	
	Weight loss, mg	Description	Weight loss, mg	Description
Mineral oil	0·2	Clean	0·4	Clean
1	1·0	Heavy stain	0·6	Heavy etching
2a	0·2	Slight stain	0·3	Rust spots
2b	0·2	Clean	Nil	Clean
3	0·2	Slight stain	0·2	Clean
4	0·3	Etched	1·2	Etched
5	0·5	Clean	0·6	Slight etching and rust
6	0·8	Stained	1·5	Etched and rusty
7	0·6	Clean	0·4	Slight matt surface
8b	0·5	Etched	0·3	Rust spots
9a	0·2	Etched plus deposit	7·5	Heavy etching plus deposit
10	0·3	Stained	1·2	Etched and rusty
11a	8·7	Heavy etching	3·4	Heavy etching plus copper film
11b	0·4	Stained	2·2	Rusty
12	0·4	Stained	1·3	Etched and rusty

* Test conditions as given in Appendix 2, Test 3.

Phosphate esters with an improved hydrolytic stability have been prepared experimentally (fluids 11b and 13b, Table 5), and the results obtained on fluid 13b in particular suggest that phosphate esters can be produced which will have a much better service life than the materials currently available. Unfortunately this fluid is a non-additive material and is poor in other respects, e.g. anti-rust properties. The addition of additives to make these properties acceptable will be expected to worsen the chemical, and particularly the hydrolytic, stability.

The tests so far discussed have not differentiated between thermal and oxidative degradation of the fluids. If the fluids were thermally very stable, and degradation was occurring principally by oxidation reactions, then the sealing of systems with an inert gas such as nitrogen might be economically beneficial. Tests were therefore carried out on a number of fluids using the C.E.R.L. turbine oil oxidation test (5) modified so that tests using oxygen could be compared with tests using nitrogen as the bubbling gas. The results (Table 7) show that the degradation is sometimes due wholly to thermal instability and those fluids based on phosphate esters are much less stable than those based on chlorinated diphenyls. As the hydrolytic stability of the phosphate esters is also much worse than that of the

Table 7. Thermal and oxidation stability of f.r. fluids

Fluid	(1) Oxidation and thermal stability acidity change, mg KOH/g	(2) Thermal stability acidity change, mg KOH/g
Mineral oil	Nil	Nil
1	−0·20	−0·10
2a	Nil	0·05
3	Nil	−0·05
4	0·10	0·35
5	0·10	0·10
6	7·85	1·25
8a	0·95	0·10
9a	0·30	0·15
10	0·60	Nil
11a	0·60	0·90
12	0·80	0·65

Test conditions:	(1)	(2)
Temperature, °C.	120	120
Catalyst, cm^2/g of oil	Nil	Nil
Duration, h . .	168	168
Gas flow . .	1·0 l/h oxygen	1·0 l/h nitrogen

chlorinated diphenyls and much worse than the oxidative and thermal stability, the use of nitrogen sealing would appear to be less conducive to an acceptable fluid life than either the maintenance of dry systems or the use of the more stable chlorinated diphenyl-based materials.

Anti-rust and corrosion properties

There is always a possibility of moisture entering lubrication systems whether it enters as condensed steam through the leaking glands of a steam turbine or as moisture breathed into a system. Whilst permanent protection in vapour spaces is not possible by additive treatment of the lubricant, protection of fluid-bathed surfaces is possible, and a limited protection can also be given to fluid-splashed surfaces and to surfaces subjected to settled water.

The anti-rust properties of a number of fluids have been determined using the ASTM.D665 (I.P. 135/64) 'Steam turbine rusting characteristics test'. Both salt and distilled water tests were carried out, and the results (Table 8) show the ability of the fluid to give protection only under fluid-flow conditions.

The chlorinated diphenyl-based materials (fluids 2 and 4) have better natural anti-rust properties than phosphate esters (fluids 10, 11, 12 and 13) but the addition of anti-rust additives improve both types of material (fluids 2b and 3, and 8b and 9a, respectively). A comparison of these results with the corrosion results given in Table 6 shows that those fluids with good anti-rust properties are generally very much less corrosive.

Other important properties

Density, solvent power, demulsification and anti-foam properties are also of importance in choosing a suitable fluid or in designing equipment. They are particularly important when converting equipment designed to operate on mineral oil.

Table 8. Anti-rust properties of fluids

Fluid	I.P. 135/64 test, salt water	I.P. 135/64 test, distilled water
Mineral oil	Rusting absent	Rusting absent
1	Rusting absent	Rusting absent
2a	Moderate rust	Light rust
2b	Rusting absent	Rusting absent
3	Rusting absent	Rusting absent
4	Light rust	Light rust
5	Heavy rust	Light rust
6	Heavy rust	Heavy rust
7	Rusting absent	Rusting absent
8b	Light rust	Light rust
9a	Rusting absent	Rusting absent
10	Heavy rust	Heavy rust
11b	Heavy rust	Moderate rust
12	Heavy rust	Moderate rust
13a	Heavy rust	Moderate rust

Both density and solvent power increase in these fluids in the order: mineral oil, phosphate ester, chlorinated hydrocarbon.

The densities are of the order 0·9, 1·2 and 1·4 and this means that water will separate at, and have to be removed from, the surface of synthetic fluids, and fine solid particles will have a greater tendency to remain suspended in the fluid and make air and water separation more difficult. More attention will therefore need to be paid to fluid filtration.

The greater solvent power of the f.r. fluids requires careful selection of surface coating and seal materials. Conversion of existing systems will pose the greatest problem as, although seals can be readily changed, surface coatings have to be removed, otherwise they will be softened and removed by the fluid and result in blocked orifices and jammed pistons. Suitable seal and surface coating materials can now be recommended by fluid suppliers.

The above two properties cannot be altered in a fluid but if considered at the design stage of equipment they should cause no trouble. Demulsibility and anti-foam properties can, however, be regulated to a certain extent by correct choice of additives, although neither should cause any concern in correctly designed and maintained systems. Nevertheless, it is desirable that f.r. fluids initially should have demulsification and anti-foam properties comparable to those of mineral oils used in steam turbine and hydraulic systems, although in service these properties may be harder to maintain due to the higher density of the fluids promoting retention of small particle size corrosion and wear products.

Fire-resistant fluids when tested according to I.P. 19 'Demulsification number of lubricating oil' and I.P. 146 (ASTM.D892) 'Foaming characteristics of lubricating oils', generally give results comparable to petroleum steam turbine oils, but some fluids have shown excessive foaming and poor demulsibility in these tests.

MAINTENANCE OF FIRE-RESISTANT FLUIDS

Whether a phosphate ester or chlorinated diphenyl-based material is chosen efficient filtering and drying systems should be installed.

Because of the poor hydrolytic stability of the phosphate esters, and the effect of traces of moisture on this type of fluid it is essential to maintain them in a very dry condition. This is difficult to achieve in hydraulic systems owing to them often breathing moisture-laden air, and is not possible to achieve in steam turbine lubrication systems. Because hydrolysis and thermal degradation do occur fuller's earth adsorption filters are normally incorporated either on a continuous bypass system or a periodic full-flow system, to remove the acidic products of degradation (3). Unfortunately additives may also be removed by these filters and corrosion of the system by acids, prior to their adsorption, will still occur. Paper edge filtration and vacuum drying should be advantageous for this type of fluid and is now incorporated at Richborough. Whilst these fluids, if properly chosen, treated and maintained could give a reasonable life in dry hydraulic systems, particularly low-temperature systems, they will be unsatisfactory in the wetter, and hotter steam turbine lubrication systems.

The more stable chlorinated diphenyl-based fluids should not require so much attention for acid or moisture removal, and paper edge vacuum filtration should be sufficient to ensure a clean and dry fluid. The better stability and anti-corrosion properties of these fluids should result in a much longer life and a cleaner, corrosion free, system.

CONCLUSIONS

Chlorinated diphenyl-based fire-resistant fluids have a much better chemical stability and corrosion resistance than fluids based on phosphate esters. Although their basic physical properties are less satisfactory than those of the phosphate esters, they can be modified to have acceptable properties. The physical and chemical properties, and changes occurring in these during service must be considered when equipment is designed.

Where phosphate ester-based materials are used particular attention must be given to keeping equipment, and fluid, dry and to limiting hot spot and fluid temperatures.

ACKNOWLEDGEMENTS

The author acknowledges the help given by Esso and Castrol Research Laboratories who carried out the shear stability tests recorded in Table 4. The experimental work was carried out at the Central Electricity Research Laboratories, and the service performance data quoted was obtained principally at Richborough Generating Station. The paper is published by permission of the Central Electricity Generating Board.

APPENDIX 1

SHEAR STABILITY TESTS FOR FIRE-RESISTANT FLUIDS

Sonic oscillator test

Equipment

Raytheon 200 W 10 kc magnetostrictive oscillator, Model DF-101.

Method

The fluid under test is vibrated at a frequency of approximately 10 kc/s.

The conditions of the test, 25 minutes at 1 amp, was chosen as that required to reduce the viscosity of fluid 6 by the maximum amount it was reduced in service. Fluid 6 was chosen because of its very high viscosity change.

In evaluating a fluid, however, the viscosity should preferably be plotted against vibration time until no further change in viscosity occurs.

Pump and injector test

Equipment

The equipment was a simplified version of that described in the American Specification Mil-H-19457 A (Ships) 30.8.61.

Method

Fluid was circulated round a system and forced under pressure through a diesel engine fuel injector. The viscosity of the fluid was determined after 210 cycles.

As with the sonic oscillator test, the viscosity of the fluid should preferably be determined and plotted against the number of times the fluid is pumped round the system until a constant viscosity is obtained.

APPENDIX 2

CHEMICAL STABILITY TEST FOR FIRE-RESISTANT FLUIDS

Scope

The chemical stability test for f.r. fluids was designed to show: (1) the relative stability of fluids towards oxidation, thermal and hydrolysis conditions, and (2) the corrosivity of the materials and their degradation products.

Summary of method

Tests are carried out on three combinations of fluid, water and metal specimens as follows:

(1) 5 g of fluid.
(2) 5 g of fluid plus 5 g of distilled water.
(3) 5 g of fluid plus 5 g of distilled water plus 2·5 cm^2 surface area of iron and copper respectively.

The three systems are heated in a metal block heater for 72 hours at 130°C. At the end of the test the total fluid is tested for acidity (I.P. 1/64, method A) and the tube examined for deposits. The iron and copper specimens are weighed before and after the test.

Equipment

Thermostat bath

This should be an aluminium block heater, thermostatically controlled at 130±0·5°C.

Test tubes

Tubes of the following dimensions are used:

Length (including B24 socket joint) .	210±2 mm
External diameter	25 mm
Internal diameter	22·5±0·5 mm
Wall thickness	1·25 mm
Volume	65 ml (approx.)

Air condenser

An air condenser of the following dimensions is used:

Length (including B24 cone joint) .	915 mm
Internal diameter	12·5 mm

Metal specimens

Five centimetres of 1·63 mm diameter pure soft electrolytic copper wire, and 5 cm of 1·59 mm diameter low metalloid steel wire are used in test (3). The lengths of wire are cleaned with absorbent cloth wet with heptane, followed by abrasion with 00 abrasive cloth until a fresh metal surface is exposed. Wipe with dry absorbent cotton until all loose particles of abrasive and metal have been removed. In subsequent operations handle the wires with absorbent cotton or tweezers to prevent them coming into contact with the skin. Roll into a ring (2·0 cm o.d.) and weigh before use.

The cleaning and weighing operations should be carried out immediately prior to use.

Procedure

Weigh 5 g of fluid into three clean and dry test tubes.

Fit an air condenser into the first tube and insert the test tube into the thermostat bath.

Add 5 g of distilled water to the second tube, fit an air condenser and insert into the thermostat bath.

Add pre-weighed copper and iron specimens to the third tube, fit an air condenser and insert in the thermostat bath. After half an hour in the bath add 5 g of distilled water.

Leave the tubes in the bath for 72 hours.

Remove tubes from the thermostat bath and allow to cool. Determine acid value of the fluid (and water) using I.P. 1/64, method A. Wash the fluid (and water) from the tube and condenser with a small quantity (approximately 20 ml) of neutralized titration solvent.

The metal specimens from test (3) should be washed in warm acetone, dried and weighed.

Examine the tube for deposits and the metal specimens for corrosion.

Each test should be carried out in duplicate.

The repeatability of this test has not yet been determined, but sufficient data are available to show that it adequately differentiates between materials.

APPENDIX 3

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Communications

Mr P. Collignon (Brussels, Belgium)—The present contribution to the development of knowledge concerning the use of fire-resistant fluids in the regulation of steam turbines, is based on the excellent results obtained on turbines with powers ranging from 60 MW to 110 MW.

The oldest bath has reached at present 60 000 hours of service and the most recent one has an activity of 29 000 hours.

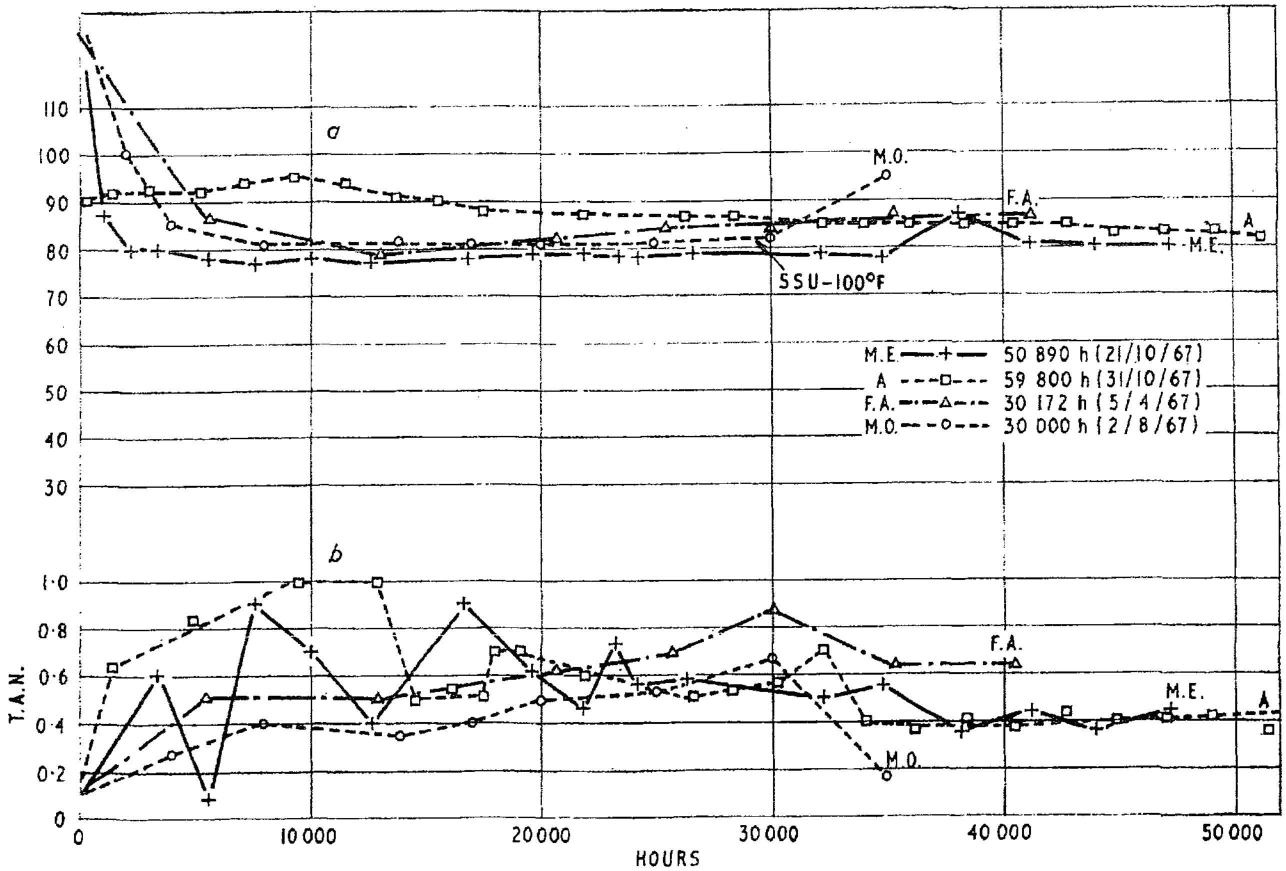
In all cases, the fluid used is a phosphate ester with the following characteristics: specific gravity 1·13; viscosity, 100°F 31 cS, 210°F 8 cS; viscosity index 170; pour point -48°C; autoignition T° 593°C.

The development of characteristics in service is favourable and we cannot, at present, note any unfavourable influence of the product on the parts of the regulation circuit.

Viscosity

The viscosity of the fluid drops rapidly after starting operation, which confirms the results registered at the sonic oscillator test. The viscosity, however, maintains itself afterwards to a stable value of the order of 80 S.S.U. at 100°F (Fig. 1*a*).

This variation of the viscosity does not affect the functioning of the system and no trouble has been noted in



a Viscosity, S.S.U. at 100°F.
b Total acid number.

Fig. 1. Fire-resistant fluid of phosphate ester type

case of starting at low temperature. The viscosity index which reaches 170 *for the fluid as new* maintains itself during operation to a value equivalent to that of mineral oils, i.e. 85 to 95.

Total acid number

The curves of Fig. 1*b* show that the T.A.N. maintains itself during operation at 0·6 mg KOH/g and below. This constancy of value is achieved by incorporation in the regulation circuit of a filtration system on activated clay. The periodical operation of this filtration gives very favourable results, as well as the periodical additions of new product which are necessary in order to maintain the normal level in the tanks.

It will be noticed, on the other hand, that a T.A.N. value of 0·6 mg KOH/g must be considered as normal and does not occasion any unfavourable remark concerning the condition of the material.

Anti-rust and corrosion properties

The corrosion of metals does not happen with the use of fire-resistant fluids.

The examination of deposits taken in the filtration systems or samples taken during operation, showed that the concentrations in metals are extremely low. The practical experience acquired here enables us to confirm that there is no link between results obtained in the laboratory (oxydation on thermal stability, acidity change) and actual service. Besides, the results of corrosion tests do not show any corrosion increase in comparison with the T.A.N.

Other properties

Only one case of foam formation has been noted, but it was soon proved that the origin of the fault located was at the aspiration of the pump.

The joints which equip the system must be carefully selected in accordance with the nature of carrying fluid and it is therefore imperative to follow the instructions of the builder implicitly.

To conclude, the use of fire-resistant fluids of phosphate ester type demands a different practice than that of conventional lubricants but permits in those conditions a profitable working, whilst eliminating the risks of fire.

Mr C. L. Early (St Louis, Missouri, U.S.A.)—At various places in the paper, Mr Wilson points out a basic fact often overlooked regarding fire-resistant fluids, i.e. the direct substitution of fire-resistant fluids into systems *designed for petroleum oils* can lead to serious service problems. It is necessary to consider system design as well as fluid properties in applying fire-resistant fluids to new or old systems; unfortunately one cannot normally substitute synthetic fluid for oil without some system modifications.

Mr Wilson's paper is concerned primarily with laboratory assessment of fluid properties which relate to performance in turbine systems. Principal turbine applications for fire-resistant fluids are also identified, but further correlation between specific laboratory tests and performance in specific field applications is required. Therefore, this discussion will describe a few known field experiences and problem areas with commercial fire-resistant fluids. These field experiences fall into two categories: *hydraulic* fluids for high-pressure turbine control systems, and *lubricants* for turbine bearings.

Hydraulic fluids for turbine control systems

Actually three types of synthetic fire-resistant fluids are now used commercially and successfully in hydraulic control systems. These fluid types are as follows:

(1) 'Straight' phosphate ester (P.E.).

(2) Mixed phosphate ester/chlorinated hydrocarbon (P.E./Cl.H.C.).

(3) Mixed phosphate ester/chlorinated hydrocarbon/heavy oil type (P.E./Cl.H.C./O.).

Additives of the type described by Mr Wilson may be included in commercial versions of these three fluid types.

Despite successful performance in numerous systems around the world for periods of a few months to several years, problems have occurred. For example:

(*a*) A major U.S. electrical manufacturer has reported a 'corrosion–erosion' problem in servohydraulic systems with fluids containing small amounts of chlorine-containing fluids (6). No such problem with chlorine-free phosphate esters was reported. More recently, however, no such problem was observed on a chlorinated fluid of the P.E./Cl.H.C./O. type. The fluid was tested in a prototype hydraulic test system with no more servovalve erosion than would be expected with phosphate ester fluids. Duration of the test was 4500 hours. Why the discrepancy? What laboratory tests could accurately predict performance characteristics in this regard?

(*b*) As Mr Wilson notes, there has been shear down of viscosity index-improved polymers (and concomitant viscosity loss) with certain fluids. In some commercial systems, polymer shear down has caused pump leakage or wear problems; in other systems, sometimes with the same design and with the same fluid, no such problems occur. For example, some Companie Electro-Mechanique (C.E.M.) turbines in France have given shear down problems with a VI-improved P.E./Cl.H.C. fluid, whereas similar turbines (Brown Boveri) with the same fluid in Germany have performed well. C.E.M. and Brown Boveri turbine control systems are similar in design. A non-V.I.-improved P.E./Cl.H.C./O. fluid is replacing the shear susceptible P.E./Cl.H.C. fluid in certain C.E.M. turbines in France and is giving good service in BBC turbines in Denmark and Holland. To date power station managers in Germany, however, prefer to continue operation with the P.E./Cl.H.C. fluid. Design, equipment layout, and operational variations even in similar turbines cause differences in performance.

(*c*) Reportedly, acid build-up with P.E. fluids is more acute in some systems than in others. The author does not have data regarding this report; however, if acid increase rate varies, why? Design or fluid variances?

Lubricants for gas and steam turbine journal bearings

The same three types of fluid listed above are in commercial service today in gas and/or steam turbine bearing systems. In industrial gas turbine lubricant systems, both P.E. and P.E./Cl.H.C. fluid types are used in North America. In Europe two small, commercial steam turbine bearing systems are being lubricated successfully with P.E./Cl.H.C./O. fluids and trials are in progress with straight P.E. fluids as mentioned in Mr Wilson's paper.

Despite these favourable commercial experiences, the much-publicized 'machining' or 'wire-wooling' effect is sometimes associated with chlorinated fluids and sometimes not. Shaft metallurgy and/or speed is known to play a role (perhaps) equally as important as fluid chemistry in preventing turbine shaft scoring (7) (8) (9) (10).

In summary

Mr Wilson has measured important properties of several fire-resistant fluids in potentially useful laboratory tests. Because of wide variations in field performance with commercial fluids, there exists a wide gap between laboratory data and field performance. It would seem very desirable to establish quantitative limits in laboratory tests of the type employed by Mr Wilson to predict more accurately performance of a given fluid for a given application. Actually a different set of limits would probably be required for turbine hydraulic control fluids than for turbine lubricants. Laboratory results of the type obtained by Mr Wilson will become even more significant if these can be related better to service performance.

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Mr H. J. Fortune, B.Sc. (Barnet, Herts.)—There are two aspects not referred to directly on which I would be pleased if the author would comment:

(1) How do the fire-resistant fluids compare with mineral oils, considering only their lubricating properties?

(2) Are there any significant hazards to health when using fire-resistant fluids, due to toxicity or similar effects, bearing in mind the risks to which the fluids are to be subjected, including dripping or spraying on to surfaces at temperatures up to 600°C?

Mr K. C. Fryer, C.Eng., A.M.I.Mech.E.—I would like to add my comments on the subject of the maintenance of the fire-resistant fluids. I have been concerned with the design and manufacture of the purifiers which were installed at Richborough power station.

An earlier appreciation by a turbine manufacturer of the possible danger of degradation of the fluids by water and finely divided solids led to discussions on the provision of purifiers which eventually led to the installation of purifiers at Richborough power station. It was agreed that the purifiers would need to reduce and maintain the water content well below saturation and at the same time reduce the solids content to a minimum.

The edge type paper filter was chosen from successful past experience with similar fluids used in aircraft hydraulic systems. This filter would be sufficiently efficient to remove most of the particles down to 1 micron, these in the main being oxidized metallic particles which could possibly accelerate the fluid degradation.

This filter was combined with vacuum treatment in a unit similar to those already in use on turbine mineral lubricating oils. This arrangement was capable of reducing the water content in the fluid from about 1 per cent (10 000 parts per million) to about 100 parts per million, and as the water saturation in these fluids is about 8000 parts per million at 60°C, the final water content will be well below saturation. This result is impossible to achieve by any other method of purification.

As the specific gravity of the fluid is greater than 1·0, any water will tend to collect on the surface of the fluid so that it was necessary to arrange the take-off from the main storage tank to be via a floating suction device to the purifier. This device was adjusted to take the fluid from just below the surface where the maximum concentration of water is located. On the purifier itself special drain points were installed to remove any settled water which had collected at the tops of the chambers instead of at the bottoms of the chambers as would be the case when purifying mineral oils.

The rate of flow through each purifier which is on a bypass circuit is 50 gal/h where the system capacity is approximately 900 gallons, this rate being quite sufficient to deal with the normal system contamination rate.

The purifier performance reflects the results quoted in Mr Wilson's paper. When the fluid was unstable or caused corrosion the purifier became heavily loaded with solids and needed frequent attention, but when the fluid was satisfactory, the purifier maintained a clean dry system.

Mr D. B. Haines (Reading, Berks.) and **Mr J. H. D.**

Harvey—In regard to polydimethyl silicone fluids for hydraulic systems, in Mr Wilson's paper the properties of two non-aqueous synthetic fire-resistant (f.r.) fluids were examined.

Both phosphate esters and chlorinated diphenyls were found to suffer from disadvantages which limit their use in hydraulic systems.

The polydimethyl siloxane fluids are discussed below as alternatives and are shown to hold certain advantages over mineral oils, phosphate esters and chlorinated diphenyls which should render them suitable for consideration in this application.

Mr Wilson has stated that a suitable f.r. fluid should exhibit a superiority over mineral oils in the properties listed on the second page of his paper. For the purposes of this communication two dimethyl polysiloxane fluids will be compared with the two fluids examined by Mr Wilson with regard to each of these properties.

The two silicone fluids chosen* are the 50 cS and 100 cS viscosity grades measured at 25°C (typified by MS 200/50 cS and MS 200/100 cS fluids) since these are closest in kinematic viscosity (at 37·8°C) to the f.r. fluids chosen by Mr Wilson.

Viscosity characteristics

Compared with mineral oils, polydimethyl siloxane fluids show remarkably little change in viscosity over a wide temperature range. Typical viscosity/temperature values for the two silicone fluids are given in Table 9 together with viscosity/temperature coefficients, specific gravities and pour points. Minimum pumping temperatures are not given but are likely to be in the region of −30°C or less.

Fire-resistant properties

Flash points and autoignition temperatures are given in Table 10. In addition an article by Sullivan, Wolfe and Zisman (11) arrives at the following conclusions regarding the fire-resistant properties of silicone fluids: 'The flash points are high; when the liquids are ignited the flames are readily extinguished; the spontaneous ignition temperatures are high; the spray flammability limits are high and they are practically non-flammable to incendiary fire.'

Table 9

Fluid	Viscosity/temperature coefficient†	Viscosity (cS) at‡			Specific gravity 25°C/25°C	Pour point, °C§
		37·8°C	60°C	98·9°C		
MS 200/50	0·60	42	28	16	0·96	−55
MS 200/100	0·60	80	60	31	0·97	−55

† Viscosity/temperature coefficient $= 1-\frac{\text{viscosity at } 98{\cdot}9^{\circ}\text{C}}{\text{viscosity at } 37{\cdot}8^{\circ}\text{C}}$.

‡ Figures approximate—interpolated from graph.

§ Method ASTM D-97-57.

Table 10

Fluid	Flash point (min), °C*	Auto-ignition temperature, °C†
MS 200/50 cS	260	488
MS 200/100 cS	288	490

* Open cup, method ASTM D-92-33.

† Method ASTM D-286-30

Shear stability

Polydimethyl siloxane fluids of 1000 cS and below are essentially Newtonian in behaviour and exhibit no significant reduction in viscosity after many hours at rates of shear up to 10 000 s^{-1}. At higher rates of shear there may be a reduction in apparent viscosity but when shear stress is removed viscosity returns to its original value (12).

Chemical stability

The recurring Si–O linkage in the siloxane polymer confers a high degree of stability. The fluids are thus highly resistant to hydrolysis, are oxidatively and thermally very stable and are generally unaffected by the common metals (lead may be an exception under certain conditions). They can be degraded by concentrated acids and strong alkalis.

Anti-rust and corrosion properties

The polydimethyl siloxane fluids are non-corrosive to metals (acid number <0·02 mg KOH/g) and in the unlikely case of degradation, the breakdown products themselves are non-corrosive.

Although the fluids are water-repellent they do not effectively prevent the corrosion of steel surfaces in contact with moisture. A variety of proprietary corrosion inhibiting chemicals can, however, be successfully incorporated into the fluids.

Other important properties

The specific gravity values for the two silicone fluids (0·96; 0·97) are also typical of the higher viscosity members of the polydimethyl siloxane series and should not produce any difficulties above and beyond those occurring with a mineral oil.

Natural rubber, synthetic rubbers and plastics are relatively unaffected by silicone fluids, which are often used as lubricants for these materials. Pump sealing glands and other sealing materials should therefore have a long life, although, due to the low surface tension of silicone fluids, any faults in the sealing system will be sought out and could result in more loss of fluid than would occur with a mineral oil. Low surface tension indicates high surface activity. It seems likely that this property combined with limited miscibility accounts for the fact that dimethylpolysiloxane fluids often act as remarkably effective antifoam agents in non-aqueous systems, with which they are incompatible (e.g. mineral oils).

Dimethylpolysiloxane fluids are used extensively as

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* *Similar silicone fluids are normally available from Midland Silicones Ltd in viscosities ranging from 0·65 to 100 000 cS at 25°C, but higher viscosities can be supplied.*

lubricants for a wide variety of materials including many commonly used metal combinations at extremes of temperature. When both surfaces are ferrous they have very limited load-carrying capacity and when sliding friction is involved excessive wear can occur.

More detailed information on the suitability of dimethylpolysiloxane and certain other silicone fluids for use as fire-resistant hydraulic fluids may be obtained from our company*.

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Mr F. Hardy (London) and **Dipl-Ing. J. Stoldt** (Hamburg)—We agree with the conclusions drawn from test results obtained in laboratory tests with the fluids 1–13 and would confirm that our own laboratory examinations of fire-resistant fluids (amongst others the three grades listed in Table 11, Nos. 14–16), have shown similar results.

However, we feel the conclusions should be complemented in so far as chlorinated diphenyls should not be given exclusive preference. They have significant physical and hygienic shortcomings. On the other hand, excellent field experience over a long period of time is available with phosphate esters.

Fire risks

In our opinion, greater importance should be attached to this item. Fire risks are so manifold that the tests indicated in Table 2 of the paper do not appear to cover all angles, and therefore do not allow a proper evaluation of the fluids. As an example we would mention the most indicative high pressure spray ignition test and the molten metal tests. These have shown, for instance, that fluids containing high amounts of V.I. improvers or mineral oil, such as fluids Nos. 6 and 7 in Table 1 of the paper, have very poor fire-resistance. Also, alkyl phosphate esters proved to be less satisfactory than aryl phosphate esters.

A so-called fire-resistant fluid consisting of 60 per cent chlorinated diphenyls and 40 per cent mineral oil has recently allowed a fire to spread and cause damage which was not much different from that experienced with mineral oils. Fluids such as No. 5 and No. 16 have good and adequate fire-resistance (and at the same time optimum physical properties (Table 12)). This has often been proved in practice when fire could be prevented by using these fluids.

Chemical stability

Results obtained in short-time laboratory tests do not necessarily permit a true conclusion as to practical application. It is a significant field experience that with thermosiphon effect, phosphate esters must only be heated by means of an electric heater with up to 1·0 W/cm^2 (equivalent to approximately 140°C surface temperature of the heating rod). Long-term tests (Table 13) show the good test results which are confirmed by field experience. In three major plants, the fluids Nos 14 and 16 were thermally destroyed or cracked, whereby the neutralization values increased to 2·2 or 1·6 and 0·9 respectively. Rusting occurred in the ASTM D 665A rust test, and also in the container above the fluid surface. By the addition of 1·5 per cent calcium hydroxide and earth treatment at 50°C, the neutralization number of the filling was reduced to 0·12, and the filling could be used again.

In another case, a leakage of 1000 litres of water into a three years' old filling of fluid No. 16 occurred. The water

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* *Midland Silicones Ltd.*

Table 11. Fluids examined

Fluid	Description	Additives
14	Aryl phosphate ester	Anti-rust, anti-foam, dye
15	Aryl phosphate ester	Anti-rust, anti-foam, dye
16	Aryl phosphate esters plus 20 per cent chlorinated diphenyl	Anti-rust, anti-foam, dye

Table 12. Physical characteristics

Fluid	Specific gravity 15·5°C	Viscosity, cS		Pour point, °C	800 cS pumping temperature, °C	
		37·8°C	98·9°C		Extrapolated	Actual
14	1·14	42	5·0	−30	0	0
15	1·19	22	2·1	−30	−10	−8
16	1·23	42	4·5	−25	0	+8

Table 13. Long-time stability

Fluid	Volume	Container	Thermostatic control, °C	Electric heater, W/cm^2	Neutralization values		
					Fresh	After 3 months	After 12 months
14	90 gal	Iron, air vented	40	1·1	0·30	0·30	0·36
14	130 gal	Iron, air vented	40	1·3	0·30	0·32	0·41
14	500 ml	Brass, no air	105	yes	0·29	0·55	—
15	500 ml	Brass, no air	105	yes	0·25	0·65	—

was removed by means of a special centrifuge and fluid No. 16, with a neutralization number of 0·35, could be used again without any further treatment.

Air release

Besides anti-foam properties, air release is a very important point. This especially when hydraulic pumps susceptible to cavitation are used. Field experience with fluid No. 16 as well as laboratory examinations with this fluid, using the air release impinger method of Technischer Überwachungsverein, Essen, have shown that the initial air release properties of a fluid will be impaired in plants such as foundries and die-casting works, where the air contains finest spurs of dust. Once these have caused deterioration of the fluid, they cannot be removed, not even by earth treatment. Therefore, air filtering is very important.

Summary

Our own field experience with fire-resistant fluids in turbines is limited to three turbine sets. But we have information from the United States and Switzerland (Brown Boveri & Cie) confirming that fire-resistant fluids based on phosphate esters give satisfactory performance when used with by-pass filtration.

In Europe and overseas, more than 200 hydraulic plants are satisfactorily operated with fire-resistant fluid No. 16, partly over a period of more than four years. These plants of various designs are operated under the most varied climatic conditions. Even in the few cases of overheating or water break-in, no damage occurred to the machines. The fluids could be used again after a short and inexpensive treatment.

Mr B. Knight (Richborough, Sandwich, Kent)—The third paragraph of the 'Introduction' can be somewhat misleading in the abbreviated context in which it is written, also bearing in mind that the paper was written over 12 months ago.

Regarding the nine fluid charges, these represented various products from three different manufacturers involving phosphate esters, chlorinated diphenyls and blends.

Serious troubles were experienced but in referring to the short fluid life of 24 hours it should be mentioned that this was due to oil contamination caused by mal-erection of a new turbine and not a fluid fault.

The essentially experimental nature of some fluids in large turbine hydraulic systems, particularly with regard to additives, also caused some trials to be terminated prematurely. This, however, should not be considered detrimental in the long term by virtue of the experience gained.

At the present time, the No. 1 unit has operated for 12 000 hours on a phosphate ester, No. 2 unit for 17 000 hours with a similar fluid and No. 3 unit for 9000 hours on a blended fluid.

No problems have been experienced on Nos 1 and 2 units. No. 3 unit is being run as a manufacturer's trial and, although problems were initially experienced, it would appear that the fluid will give satisfactory service.

The second paragraph under 'Maintenance of fire-resistant fluids' refers to the possibility of additive removal when treated with fuller's earth.

This treatment is used on the fluids at present in service and neither of the two manufacturers involved have reported any additive removal.

Dr A. R. Lansdown, M.Sc., (London)—Civil aviation has been in the forefront of development and application of fire-resistant hydraulic fluids, and the following comments are based on aviation experience.

A major obstacle to the introduction of fire-resistant, or any unconventional, fluids or lubricants is summed up in the author's sentence: 'Where f.r. fluids are used their properties should be as near as possible to those of the mineral oil they are to replace.'

This philosophy is valid only when a piece of equipment is designed to operate on a mineral oil and a subsequent decision is made to convert it to a fire-resistant fluid. The desirability of fire resistance has now been recognized for many years in civil aviation, mining, and other less obvious industries and it should now be the practice to design *ab initio* for the use of fire-resistant fluids in equipment which is subject to fire risk. In those circumstances the author's philosophy is a serious and unnecessary limitation on the selection of fire-resistant fluids.

To take one example there is a class of substituted silicone fluids which has very high fire resistance, extremely high viscosity index, very high thermal stability and an almost infinite shear stability, but these fluids are usually eliminated by the application of comparative tests which may be quite irrelevant. Thus, A. T. J. Hayward has shown how foaming can be eliminated from hydraulic systems by simple design features, but the need for anti-foaming characteristics is still being emphasized.

A second serious obstacle has been the absence of satisfactory test methods for fire resistance, and the methods listed in the author's Table 2 provide useful examples of the unsatisfactory nature of such tests.

Flash point °C: ASTM D92–57. This is the Cleveland open cup test, which has recently been shown (13) to have almost no value because of the influence of the test equipment. This test should in fact now be referred to as ASTM D92–66, but the revision has not solved the unsatisfactory nature of the test.

Autoignition temperature °C: ASTM D286-58 (mod.). This test uses as reaction chamber a conical flask of about 160 ml capacity. This vessel is far too small to give a meaningful autoignition temperature, as it has been shown by several authors that the ignition temperature can change with vessel size. The usual effect is for a decrease in ignition temperature with an increase in vessel size, and the decrease can be very significant. The relative rating of different fluids can be reversed as the vessel size changes until a steady value is reached at a vessel size which may be several litres. This test method has in fact been discontinued in favour of ASTM D2155-66, but the latter retains an unsatisfactory small vessel size.

Flame propagation tendency. The author has not mentioned which test is considered here, although in the text he has mentioned the range of tests which can be used. The test selection is very important because the possibility of flame propagation is highly dependent on test conditions. It is doubtful if any fluid can be said to give no propagation in all of the relevant tests. For instance, the author shows phosphate esters as giving no propagation, but they can readily be burnt in a simple wick lamp.

REFERENCE

(13) Burgoyne, J. H., Roberts, A. F. and Alexander, J. L. 'Significance of open flash points', *I. P. Jl* **53** (No. 526), 338.

Mr A. W. Parfitt, B.Sc.(Eng.), C.Eng., A.M.I.Mech.E. —From Mr Wilson's excellent survey of the properties of non-aqueous synthetic fire-resistant fluids it might be supposed that the turbine designer should have no difficulty in choosing the ideal fluid to suit his purpose; in practice it is not so easy.

The first decision to be made is of course whether to use a fire-resistant fluid at all. As far as the lubrication system is concerned, the large quantity of fluid in the system (15 000 gallons in a large turbine), the relatively high cost of fire-resistant fluids (approximately 7 times that of mineral oil), the arduous duty imposed and the low pressures used are the combined reasons why fire-resistant fluids have not been used for major turbines. For hydraulic operation of steam valves, however, their use can be more readily justified; in this case the pressures may be much higher (up to 1500 lb/in^2) the quantities in the system are smaller (1000 gallons is typical) and the proximity to hot components is greater. Here the additional cost of the fluid and system modifications is not great if compared with the possible damage and outage caused by even a moderate oil fire. As the paper points out, a number of such fires have been experienced by the C.E.G.B., mostly stemming from leaks in the relay oil system.

This paper is more concerned with the next decision: the choice of fluid. If one were to ignore fire resistance, then mineral oil has the best physical and chemical properties besides having a low cost. Given the need for fire resistance, phosphate esters have the better physical properties, whereas chlorinated diphenyls have the better chemical stability; hence a compromise is inevitable. Although a low density fluid would be preferable, those molecules which decompose on heating to produce non-combustible gases are unfortunately heavy; heavier molecules also tend to be more stable. We can, however, make good use of the fluids available providing designers and operators are aware of their limitations and requirements; to this end this paper serves a very useful purpose.

Mr R. A. Plumb, B.Sc., (London)—The brief review of experience at Richborough would perhaps warrant the conclusions drawn; more detailed study, however, shows that the opening sentence is hardly justified.

Prior to the commissioning of the Richborough turbines, Electricité de France had amassed a great deal of experience on turbines of the same size and similar design and they consider that the performance of f.r. fluids generally has been satisfactory.

Some of the lessons learnt by Electricité de France appear, however, to have been overlooked.

In the first place the three Richborough machines were filled with a fluid which had been rejected in France after unsatisfactory experience and in the second place an arbitrary limit was placed on acidity although far higher acidity figures had been demonstrated to cause no difficulty or trouble. The following will show the Richborough experience in better perspective.

Six different fluids have been used from three different manufacturers as follows:

Manufacturer A.	Fluids A.1, A.2, and A.3.
Manufacturer B.	Fluids B.1, and B.2.
Manufacturer C.	Fluid C.1.

No. 1 turbine

Start up on fluid A.1.

4000 hours (approx.)—arbitrary limit of acidity reached. Refilled with A.1.

9500 hours—arbitrary acidity again exceeded.
Fluid discarded.
System cleaned, flushed and refilled with B.1.

10 500 hours (approx.)—B.1 discarded due to excessive acidity rise and refilled with B.2.

13 500 hours (approx.)—acidity rising and some gummy deposits found. No risk of servos sticking could be tolerated and the fluid was immediately discarded. System refilled with fluid C.1.

25 000 hours—still running satisfactorily although periodic *in situ* earth treatment is used to limit acidity rise.

(*Notes.* Bearing in mind my remarks on acidity rise the first change could have been delayed until about 8000 hours and the second until about 16 000 without anticipating difficulty. With earth treatment the first charge might still be running although with marked change in viscosity due to shear down experienced with this type of fluid.)

No. 2 turbine

Start up on fluid A.1.

4000 hours—with acidity approaching arbitrary limit turbine was shut down for extended period due to

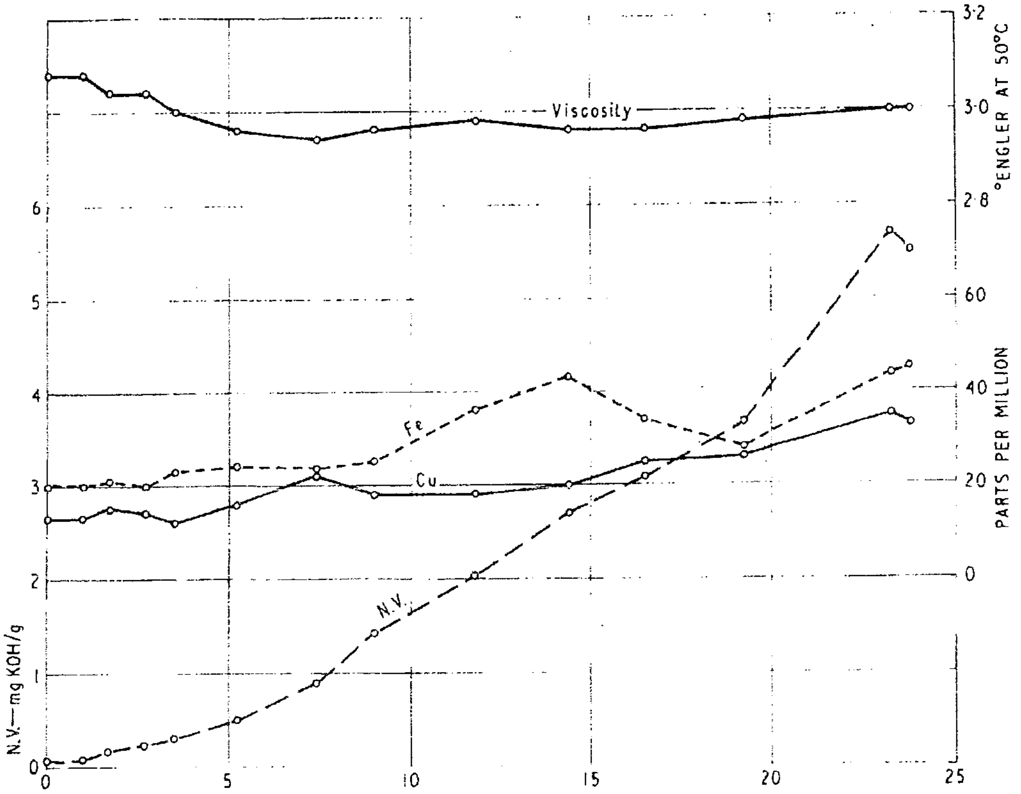


Fig. 2. Fluid history of 125 MW steam turbo-generator control system (Electricité de France)

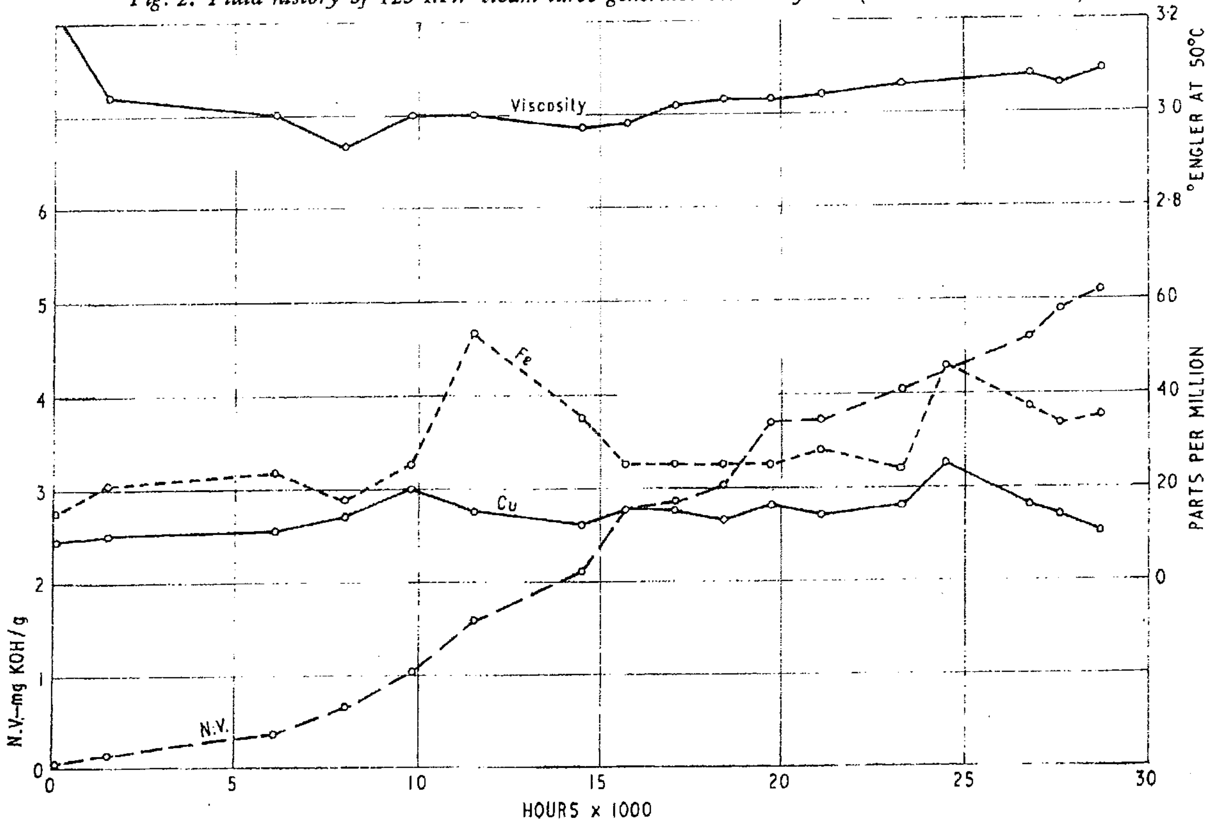


Fig. 3. Fluid history of 125 MW steam turbo-generator control system (Electricité de France)

other troubles. During this shutdown a fairly large amount of water accidentally entered the f.r. fluid reservoir without the knowledge of the station staff and on start up extensive corrosion was experienced.

The system was stripped, acid pickled, flushed with f.r. fluid and restarted on fluid C.1. (Chronologically this was prior to use of C.1 in No. 1 turbine.)

20 000 hours—fluid C.1 still running satisfactorily with occasional earth treatment.

Thus, on turbines 1 and 2 fluid C.1 has completed 27 000 hours of satisfactory running out of the total of 45 000 hours.

No. 3 turbine

Start up on fluid A.1. Owing to mechanical failure this change was heavily contaminated with mineral oil and discarded.

Restarted on fluid A.1. After approx. 4000 hours limit of acidity reached and fluid discarded.

Refilled with A.2. This fluid gave difficulty with foaming and sludge and was replaced with experimental fluid A.3 which is still running.

In each case it was fluid A.1 which showed the reported 40 per cent decrease in viscosity due to shear.

In France, where 10 or 12 turbines of 125 or 250 MW are running on fluid C.1 no arbitrary limit has been placed on acidity or fluid life, nor are the operators willing to introduce earth treatment, mainly, it is believed, for economic reasons. Instead Electricité de France, in cooperation with the fluid supplier's laboratory, do regular chemical checks of the fluid and physical examinations of the system.

The graphs in Figs 2–5 show the main checks carried out and the history of the fluid in four turbines. The spectrographic checks for iron and copper are regarded as complementary to the neutralization value and could be expected to rise rapidly if the acidity became corrosive. The shear stability is monitored by viscosity determinations. Apart from these tests the fluid is checked for colour, water content and freedom from any sludge or precipitation of insoluble matter.

The physical checks on the system take the form of visual examination of the reservoir, filters and sundry accessible internal parts of the servos and controls for any signs of sludge or precipitated matter; the system must also be free from any lacquering or gummy materials and from any signs of corrosion, erosion or other attack on the metals of construction.

Fig. 2 represents the second or third change of fluid in an early turbine; this system contains a lot of copper and is rather hard on the fluid. The improved results in the other turbines are a reflection of both improvements in the fluid and the later turbine systems, although variations in

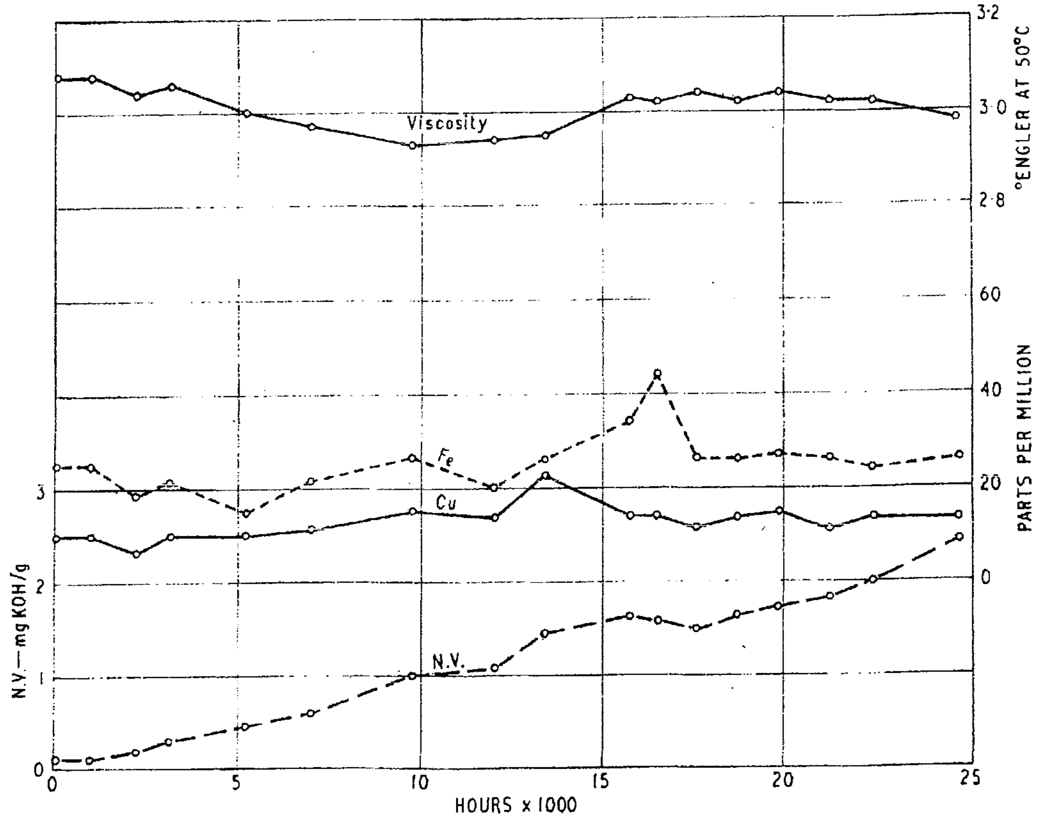


Fig. 4. Fluid history of 125 MW steam turbo-generator control system (Electricité de France)

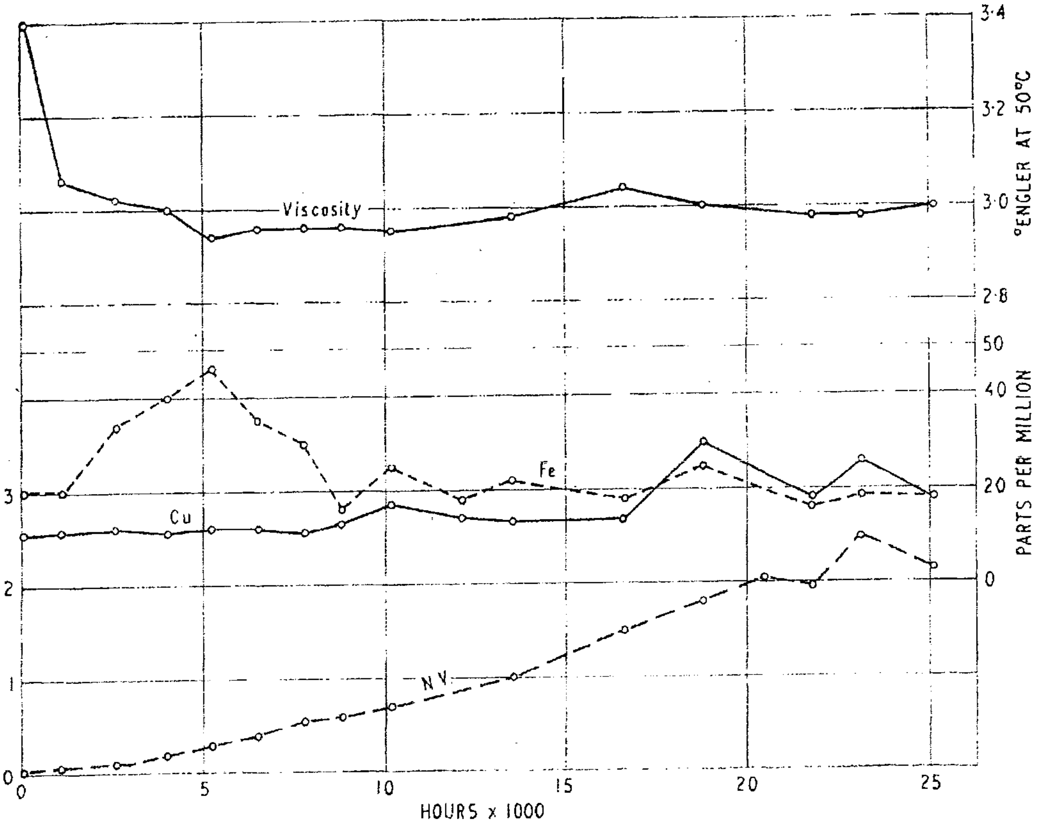


Fig. 5. Fluid history of 125 MW steam turbo-generator control system (Electricity Board, Belgium)

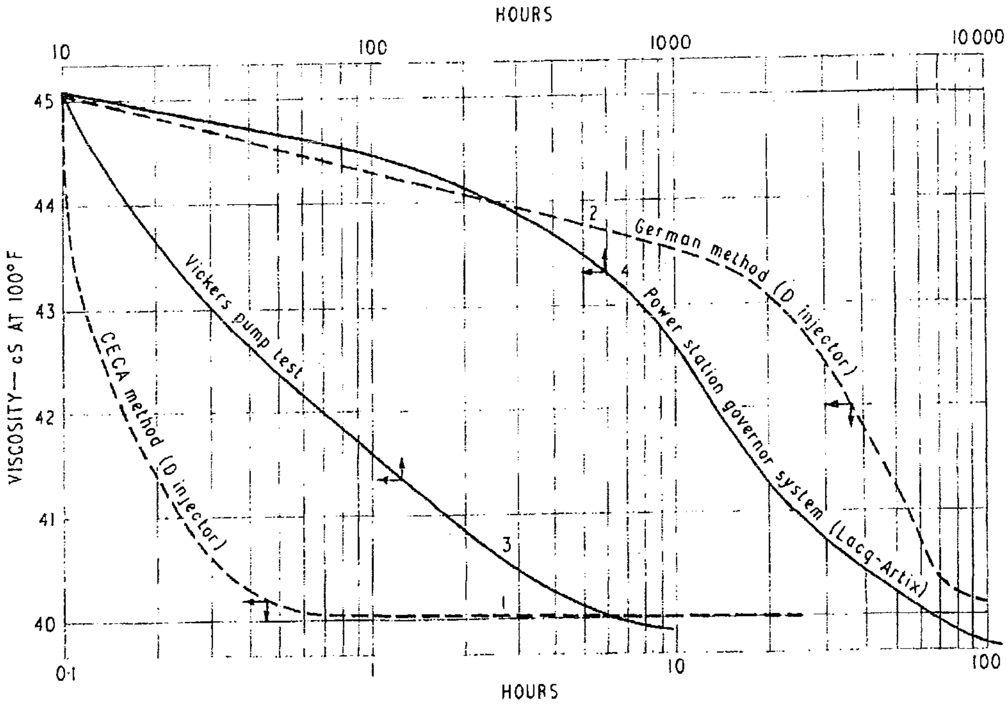


Fig. 6. Hydran FR32 shear stability

running temperature and operating conditions can have a considerable effect on the fluid. (Figs 3 and 4 relate to identical turbines running side by side.)

Some improvement of the poor viscosity–temperature characteristics of both phosphate ester and chlorinated aromatic fluids is considered essential for use in sophisticated hydraulic control systems. However, the selection of a suitable V.I. improver is far more difficult than in the case of mineral oils but reasonably shear stable blends can be obtained without detracting from other properties of the fluid. Fig. 6 shows three different test methods for shear stability compared with actual running in a turbine system. It will be seen that in each case there is some permanent reduction in viscosity but that a common equilibrium level is reached although the time varies widely according to the severity of the method.

In general a successful f.r. fluid is the result of very careful selection and treatment of the basic raw materials with a tremendous amount of research and development into suitable additives as side and cross effects appear to be more critical than with mineral oils.

In spite of many years' experience we have not yet found laboratory tests to be a substitute for full-scale turbine running. Undoubtedly there must be some basis for fluid selection and the tests discussed in this paper appear to be a reasonable starting point. It should be kept in mind, however, that these fluids are chemicals of different structure from mineral oils and it may not be advisable to attempt too close a comparison.

The demands made on the fluid vary from system to system and it may prove necessary to alter the balance of a fluid's properties or its treatment, in the light of running experience on a control system of new design or different size or characteristics.

Steam turbine control systems so far experienced appear to be very severe on fluids. Successful fluids developed for this service are more than adequate in performance for the more general type of hydraulic systems.

Dipl. Chem. J. R. Schober (Baden, Switzerland)—From Mr Wilson's paper, it is understood that chlorinated diphenyls are superior to phosphate esters with regard to thermal and chemical stability. This is no doubt a very important statement but should by no means lead us to disregard completely the phosphate ester-based hydraulic fluids. If phosphate esters are still given preference as hydraulic fluids for steam turbines regardless of their poorer chemical stability, then it is for a highly important property that had been neglected in all previous comparative considerations. This property is the lower density of phosphate esters as compared with that of chlorinated diphenyls. Even today the use of synthetic non-inflammable hydraulic fluids extends—with few exceptions—exclusively to control systems of large steam turbines. These are stationary plants with their tanks for the hydraulic fluids placed frequently far below the machine for reasons of limited space. This results in conveying heights which would call for a considerably larger outlay of construction than could be justified by the benefit possibly attainable with the use of much heavier chlorinated diphenyls.

In order to obtain satisfactory results in service when using phosphate ester-based fluids despite their lower chemical and thermal stability, the following measures are recommended.

Regarding the selection of suitable fluids

Selection of suitable fluids follows the general rules, i.e. chemical and thermal stability, corrosion-protection properties, density and viscosity. Ways for testing these properties have been shown by Mr Wilson. I should like to ask him, however, whether the reactions at 130°C still follow the same laws as at service temperatures, i.e. 60–80°C.

For the viscosity the normal service temperature is the criterion. The viscosity temperature behaviour is somewhat less important, since turbines, the hydraulic system of which is run with f.r. fluids, are in most cases heavy duty turbines maintaining almost constant temperature conditions. For this reason an addition of V.I.-improvers may be omitted. It is even advisable to do this as such improvers often show much too low a shear-stability and become inactive after a relatively short period of service. The consequence is a decrease in viscosity, and often even a formation of gummy deposits as mentioned by Mr Wilson in the case of the Richborough plant.

Regarding maintenance of fluids

It is obvious that contamination with mineral oils or free water must be avoided, which does not apply to phosphate ester-based fluids alone. The necessity of a well functioning filter system has been pointed out already by Mr Wilson. Six years of experience have shown that a combination of cellulose filters with fuller's earth filters is most effective since decomposition products are continuously removed. Disadvantageous effects responsible for an extraction of essential components from the hydraulic fluids have not been observed so far. On the other hand, it could be proved that by continuously removing the acid decomposition products, the decomposition itself —probably catalysed by acids—could be reduced.

At present 95 turbines with a unit capacity of 70–550 MW, the control systems of which are filled with phosphate ester-based fluids, are in service and more or less supervised by us. After installing fuller's earth filters in the by-pass of the system service periods of far above 50 000 hours with the same filling could be proved, if occasional refillings for the benefit of balancing the losses are disregarded.

The decrease in viscosity observed with some fluids, due to poor shear stability of the added V.I.- improver has in no case led to serious difficulties.

On the whole it has been my experience that with proper filtration and careful selection of the gaskets hardly any more difficulties are to be expected than running the control system with mineral oils. This does not mean, however, that the phosphate ester-based fluids are not worthy of being improved. They should and could certainly be improved, for instance, by extracting the more or less large amounts of easily saponified portions from the phosphate ester stocks. Such treatment would considerably improve the hydrolytic stability of the phosphate esters as indicated by laboratory tests. The work of Mr Wilson is a welcome start in this direction.

Mr J. U. Signer, B.Sc., and **Mr P. T. Fisher,** B.Sc. (Glasgow)—The South of Scotland Electricity Board have carried out tests on fire-resistant fluids used as a lubricant on a steam turbine alternator at Kelty.

Before testing normal precautions were taken in cleaning out the lubrication system, changing jointing materials and modifications were carried out to prevent ingress of either the fluid or its vapout into the alternator.

No problems were encountered during 1020 hours of operation with a phosphate ester-based fluid.

The lubricant was changed to a chlorinated diphenyl-based fluid.

Thrust and journal bearing failure occurred after a very short period of operation with the chlorinated diphenyl (2 hours 50 minutes).

The material of the failed journal was 0·55 per cent molybdenum steel and the failures were of the typical wire wool machining type previously experienced with 3 per cent chromium molybdenum steel and petroleum lubricants.

B.S.R.A., reporting on failures of this type, suggest that there is little danger with shaft materials containing less than 3 per cent chromium, but the type of failure experienced at Kelty is known to have occurred in the U.S.A. when journals of 0·5 per cent molybdenum steels have been used in conjunction with lubricants containing 35 per cent by weight of chlorine.

The lubricant at Kelty contained approximately 40 per cent by weight of chlorine.

From this experience it would appear that the information given in the paper must be supplemented by investigation regarding the compatibility of materials when using chlorinated diphenyls before a choice of fluid can be made.

The accompanying illustrations show a failed thrust pad (Fig. 7) and the failed journal on the steam turbine at Kelty (Fig. 8).

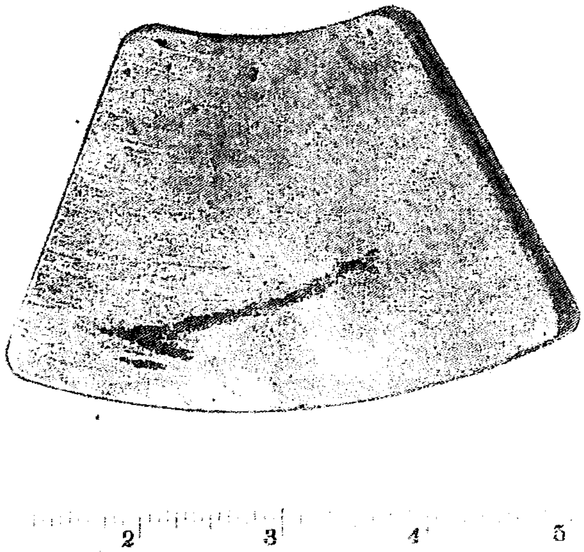


Fig. 7. Failed thrust pad

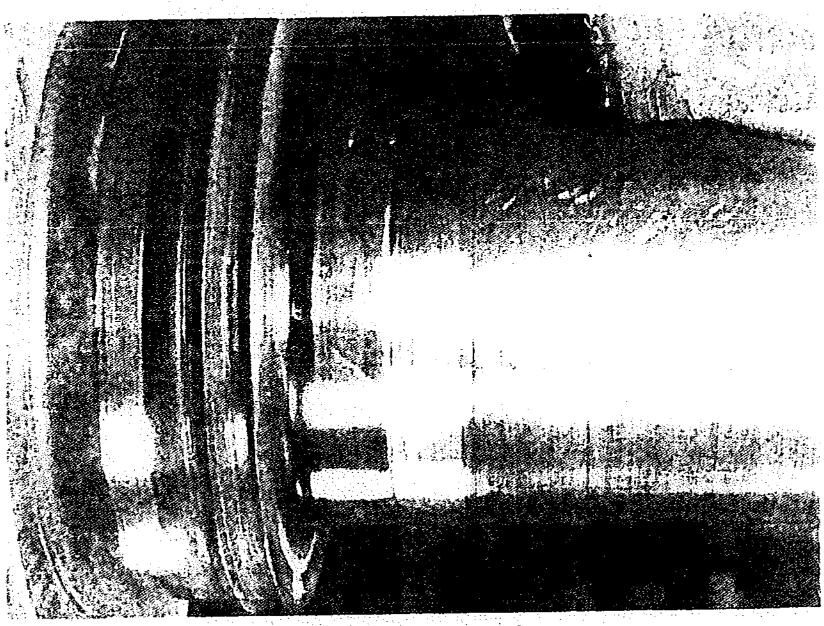


Fig. 8. Failed journal

Mr A. N. Smith, B.M.E. (Schenectady, New York, U.S.A.)—In Canada and the United States more than 60 gas turbines are operating with fire-resistant fluid as lubricant and as hydraulic control fluid. Fifty of these are using phosphate ester fluids. Stability problems developed that were generally corrected with the use of fuller's earth filtration (14).

Ten units (with which I am most familiar) have been operating up to nine years with a chlorinated hydrocarbon fire-resistant fluid. Fluid stability has been demonstrated by operation in excess of 40 000 hours without fluid replacement or significant change in fluid properties. Certainly this fluid has been a satisfactory lubricant.

From this experience, it is concluded that bearing losses are somewhat greater with fire-resistant lubricants than with petroleum oils.

Filtration and system cleanliness is a much more important factor with fire-resistant lubricants.

Operating fluid stability is significantly better with the chlorinated hydrocarbon than with phosphate ester fluids.

Consideration must be given in the system design regarding surface treatment, gaskets and seals, pumps, heat exchangers, filters, and exposed electrical equipment.

Certainly this experience with gas turbines demonstrates that with proper design, application and maintenance fire-resistant lubricants have been and are continuing to be a satisfactory lubricant and hydraulic control fluid.

REFERENCE

(14) Ritcey, D. R. 'The selection and performance of a synthetic lubricant when used in an industrial gas turbine', A.S.M.E. Paper No. 64-WA/GTP-5.

Mr C. Staley and **Mr S. W. Critchley** (Manchester)—Although a comparatively large number of laboratory tests have been described where specific phosphates and chlorinated diphenyls have been compared with hydrocarbon fluids, no correlating figures have been supplied comparing the laboratory resulrs with results obtained in practice and it would be interesting to know whether the poorer hydrolytic stability, for instance, shown up in Mr Wilson's tests on phosphates is duplicated in practice. In this respect it will also be of interest to know whether the higher acidities attained by phosphates in practice do lead to corrosion problems. The French, for example, are reported to be still obtaining satisfactory performance in steam turbine control systems from phosphates which, after many thousands of hours, have attained acid values of the order of 6·0 mg KOH/g.

Mr Wilson draws attention in his Table 5 to the fact that some phosphate esters (fluids 11b and 13b) have been prepared experimentally with improved hydrolytic stability, i.e. approaching that of chlorinated diphenyls. We would like to point out that such fluids are in fact now available commercially. Furthermore, although there does not, at the present time, appear to be a rust inhibitor available for use with these products which does not adversely affect their hydrolytic stability, it is hoped that such an additive can be developed. Other types of additives, e.g. V.I. improvers, antioxidants, etc., often have no effect on hydrolytic stability. We are also rather surprised at some of the results of chemical stability tests on straight phosphate esters quoted in Table 5.

Table 14

Fluid	Test 1 (dry)	Test 2 (wet)	Test 3 (wet and catalysts)		
	Acid value increase, mg KOH/g			Metal weight changes, mg	
				Copper	Steel
Chlorinated diphenyl	0·04	0·08	0·04	−1·0	−1·5
Phosphate ester* (standard)	0·09	1·30	0·74	+0·6	−0·8
Phosphate ester* (hydrolytically stable)	0·12	0·07	0·17	−0·8	−2·1
Phosphate ester† (standard)	0·12	1·17	0·60	nil	−0·7
Phosphate ester† (hydrolytically stable)		0·32			

* Similar in physical properties to fluids 11 and 13.

† Similar in physical properties to fluid 12.

We have carried out similar tests on phosphate esters (both standard and 'hyrolytically stable' grades) and obtained the results given in Table 14.

Admittedly, longer duration tests do tend to show more clearly the limitations of phosphates under these conditions, but the results quoted by Mr Wilson certainly seem to exaggerate the difference between the two types of fluid.

Finally, we would like to ask the author to enlarge on his conclusions in that it would be interesting to know his views on the effect of the high specific gravity of the chlorinated diphenyls on such aspects as pumping, siting of header tanks, etc. in equipment design and also whether he regards the lubricating properties of the chlorinated materials as adequate both for the control systems and, in the future, for the turbine and generator bearings themselves. Additionally, some information on types of seals and any sealant problems he has encountered would be of interest. It is well known, of course, that the choice of materials resistant to chlorinated diphenyls is very limited.

To summarize, we consider that Mr Wilson's paper possibly tends to gloss over the less attractive features of chlorinated diphenyls. We wonder whether the problems associated with the use of phosphates, i.e. keeping systems dry, filtration, etc., are not largely offset, at least for control systems, by some of the possible disadvantages of chlorinated diphenyls mentioned above.

Mr F. B. Waddington (Manchester)—Mr Wilson does not mention particle filtration. The term filter appears to be used only in reference to a fuller's earth cartridge for cleaning. This form of cleaning through a powder could introduce very fine abrasive material with the fluid; it is therefore important to incorporate a sintered metal or other form of fine filter downstream of the cartridge.

Furthermore, in our experience these fine filters have a very limited capacity and it would be advantageous to protect them by a coarse prefilter.

I would also like to ask Mr Wilson if he had any particular type of fuller's earth in mind for removing acids and moisture in preference to additives, and would he consider it feasible to use the more selective synthetic molecular sieve materials?

Mr G. Williams (Port Talbot, Glam.)—Mr Wilson states that the information reported in his most interesting paper is intended to form a more sound basis for selecting fire-resistant fluids, and so eliminate, or at least reduce, the problems encountered.

The Port Talbot Works of the Steel Company of Wales have some 12 years' experience in the use of various fire-resistant hydraulic fluids. The range includes W-1-0 emulsions, 0-1-W emulsions, water glycols and the straight synthetics. In all but a few cases, where it was possible to put the fluid directly into new plant, it has been necessary to change from standard mineral oils. In these cases full advantage has been taken of our laboratory facilities to build a better foundation for conversion to fire-resistant hydraulic fluids on existing plant.

The results of these laboratory and workshop tests help to determine certain problems before field conversion and also help in the final analysis in comparing the results of laboratory testing against field experiences.

Most industrial hydraulic systems are initially designed for conventional petroleum oils, therefore, on changeover, there are many considerations which must be carefully evaluated in the selection of a fire-resistant fluid.

The compatibility of the fluid with the system and its environment is of primary concern on all conversions and it is essential that laboratory and/or workshop tests on fluids, pumps, wear, corrosion, leakage, filtration, controls and other subjects simulate conditions applicable to the application.

Straight synthetic fire-resistant fluids

Special precautions are necessary due to the strong solvent action of these fluids on most paints, enamels and varnishes.

Special protectives must be used to withstand exposure to these fluids.

Dynamic and static seals previously in use with the petroleum oils should be changed to those compatible with straight synthetic fluids—these are normally butyl rubber, silicone or Teflon.

This also applies to the packings, gaskets, pipe joint compounds, bladders and other such components and materials in the system.

Completely draining the system of residual oils is necessary for, apart from the reduction to fire resistance, pockets of residual petroleum oils are likely to affect the material of the new seals.

All this warrants more precaution and longer shutdown on existing systems when changing from petroleum oil to a straight synthetic fluid, than from petroleum oil to one of the water-base fluids.

In hydraulic operation the synthetic fluids have shown excellent wear prevention characteristics, but care must be taken when conditions are wet and humid—this leads to corrosion within the system.

In high ambient temperatures of certain applications on steelworks plant, spillage of the phosphate ester type fire-resistant fluid has been responsible for toxic fumes which make working conditions uncomfortable for personnel in the near vicinity.

To avoid exposure of such vapours in the high temperatures usually associated with the use of these fluids, all seals, packings and joints should be checked carefully when the system is operating to prevent leaks.

Water-in-oil and water–glycol fire-resistant fluids

The invert emulsions and water–glycol type fluids have given good results as hydraulic media on steelworks plant, although, as with all fire-resistant fluids, certain precautions must be taken.

Constant temperatures above 140°F may cause excessive evaporation of water from these fluids, therefore air spaces in reservoirs and the like must be treated with the correct protective coatings. These fluids give excellent protection against rusting below the fluid level and on surfaces coated by splash.

Most seals and packings normally used for petroleum oils have been found satisfactory with the water-base fluids. However, care must be taken where certain materials in the system have a tendency to swell owing to water-absorption properties; these include asbestos, cork and leather.

Many of the engineering metals commonly used in system equipment are unaffected by the use of water-base fluids, but zinc, cadmium coated or plated parts should be avoided.

Oil-in-water fire-resistant fluids

The oil-in-water emulsions provide maximum fire-resistance compared with other fire-resistant fluids but have had, until recently, a very limited field of application within industry.

These fluids have been the subject of an extensive research programme at the Port Talbot Works. Laboratory and workshop tests were exercised to improve lubricity, corrosion resistance, viscosity, foaming and other characteristics of the oil-in-water emulsions.

From these tests a special oil-in-water fire-resistant hydraulic fluid has been developed, primarily for use on hydraulic control systems of automatic regulators that govern the pressure, vacuum, flow, temperature and other physical conditions of furnaces. This grade of fluid has been in operation under plant conditions for over 12 months.

Conclusion

Existing plant, which must be immediately operative on key production work following maintenance or off-production schedule does not give time for experiments or teething troubles that can be expected on new work, therefore on hydraulic system conversion to fire-resistant fluids such items as operating temperatures, solvent action, wear characteristics of pumps, cavitation in fluid operation, filtration, effects on sealing materials, hoses, etc., must all be taken into consideration prior to changeover.

Fire-resistant hydraulic fluids, for obvious reasons, are used in special applications only; therefore, each application must be treated on its merit. Compared with straight mineral oils additional precautions must be given to all fire-resistant hydraulic fluids when used as hydraulic media. However, none of the precautionary factors are costly enough to be significant if hazardous conditions clearly indicate the use of a fire-resistant fluid.

Mr G. F. Wolfe and **Dr M. Cohen** (West Lynn, Massachusetts, U.S.A.)—The author has furnished valuable comparative data on commercially available fire-resistant fluids. We would agree with the general conclusions in the paper regarding laboratory comparisons of phosphate esters and chlorinated fire-resistant fluids. These tests are generally an excellent guide for selecting fluid for full-scale testing and designing fluid systems, particularly with regard to low temperature pumping (viscosity) problems, shear of fluids containing V.I. improvers and stability.

However, actual use applications have revealed other limitations that do not show up in laboratory tests. For example, system corrosion and servovalve erosion (**6**) phenomena have appeared in actual hydraulic applications with these fluids that could not be predicted from laboratory evaluations. Successful operation with phosphate ester fire-resistant fluids in hydraulic systems of more than 50 of our company's steam turbines have been made possible mainly by combating chemical changes in the fluid by means of fuller's earth filtration. One chlorinated fluid, while more stable in laboratory tests such as described here, proved actually more corrosive to the hydraulic system under servovalve shear conditions. However, recent data indicate that other chlorinated fluids could be used in electrohydraulic control systems with fuller's earth filtration.

A laboratory test specifying an actual pump and servovalve system would seem to be a useful addition to Mr Wilson's tests and is one we employ for screening purposes.

Also, in practice with hydraulic systems, we have encountered more rusting and corrosion problems with certain of the chlorinated fluids than with phosphate esters, without additives, which would not be predicted by our laboratory tests. This would seem again to point the need for more functional tests involving actual equipment (fluid tanks, piping, etc.) to supplement laboratory tests. These could be constructed on a laboratory scale, but would readily duplicate application conditions.

With regard to main lubrication of steam turbines, while very limited data are available, the more thermally stable chlorinated fluids still pose the problem of 'machining type bearing failures' that we have found to occur with low chromium steam turbine steels common to our manufacture, such as 2½ per cent nickel–½ per cent molybdenum–0·1 per cent vanadium with only about 0·1 per cent chromium; 1 per cent molybdenum–1 per cent chromium–0·25 per cent vanadium and carbon steel, when lubricated with chlorine containing fluids. Although no comparable field data exist with phosphate ester fluids, limited laboratory data have indicated no such problem with phosphate esters. The choice of fluids for a steam turbine lubricant would have to balance this problem with chlorinated fluids against the hydrolytic instability problem of phosphate esters.

Author's Reply

Mr A. C. M. Wilson—Mr Parfitt, Mr Smith and Mr Fryer have contributed valuable additional information on particular aspects of the needs, uses and maintenance of synthetic f.r. fluids. Whilst Mr Parfitt quite rightly considers the use of such fluids for full steam turbine lubrication as unnecessary, when judged against the fire risk and economics, Mr Smith has been using such fluids for gas turbine lubrication for many years. His trouble-free experience with chlorinated diphenyl-based fluids is particularly interesting in the light of the conclusions of my paper. The efficiency of the vacuum filter quoted by Mr Fryer shows that the levels of water content and particulate matter size can be kept well below the levels considered undesirable in lubrication systems, i.e. 0·1 per cent water and 5 microns.

Mr Williams's contribution is valuable in pointing out the particular instances in which water-based fluids would be considered in preference to synthetic fluids. This type of fluid was not considered for the investigation because of the economic preference for one type of fluid for all applications, which included conditions where water-based fluids would be unsatisfactory. The corrosion experienced by Mr Williams with synthetic fluids in wet and humid conditions confirms the need for anti-rust and corrosion tests on this type of fluid. With respect to seals Viton A and B are considered the most versatile materials as they can be used with any type of fluid, including mineral oil. The use of butyl seals should be considered carefully because of their incompatability with mineral oil, as some synthetic fluids contain some mineral oil, and many components are tested at the manufacturer's works with mineral oil.

Mr Collignon, Mr Hardy and Dipl.-Ing. Stoldt add to our experience of the service performance of phosphate ester-based fluids. Mr Collignon seems to have been fortunate in the operating conditions for his fluid, which is similar to fluid 6, rejected by both E. de F. and C.E.G.B. I cannot agree that corrosion of metals does not occur with f.r. fluids, except in the case of a system that has been designed with non-corrosive metals, and this would be a costly process. Presumably the remark refers to dry systems where the acidity is kept below 0·5 mg KOH/g. The lack of corrosion increase in comparison to acidity (i.e. T.A.N.) between service performance and laboratory tests is explained by the homogeneous character of laboratory tests and the non-homogeneous environment of lubrication systems. For instance the severe corrosion of a small component, due to local severe fluid degradation, would not be indicated by changes in bulk fluid properties which, because of dilution, would be insignificant compared to the local changes. Mr Hardy and Dipl.-Ing. Stoldt's comments on the capacity of electric heaters for warming phosphate esters and the effects of environment on air release are most useful.

Mr Plumb has given a detailed account of the performance of the six different formulations used at Richborough, and with the exception of fluids A.3 and C.2, it is fair to say that the fluids were unsatisfactory. The lessons learnt by E. de F. were, unfortunately, not known to the C.E.G.B. in time to change the first fills at Richborough. The E. de F. practice of ignoring acidity level and rejecting earth filtration must be considered against the consequences of rapid corrosion of vulnerable system components. If E. de F. found fluid A.1 unsatisfactory at high acidities then this is not surprising as the figures in Table 15, fluid 6, show this fluid to be very much more corrosive under dry, as well as wet, conditions than any other fluid examined. Fluid C.1 (i.e. fluid 8 in Table 15), which is used by E. de F., as well as in Nos 1 and 2 units at Richborough, is reasonably non-corrosive under dry conditions up to an acidity of 0·7 mg KOH/g, but is much more corrosive under wet conditions when the acidity exceeds 1·0 mg KOH/g. However, even at acidities less than 0·5 mg KOH/g, with control by earth filtration, fluid 8 fails the IP 135 distilled water rust test after only 15 000 hours' service. Water contamination of the system, whether local or general, can therefore be expected to result in corrosion. Whilst the experience at Richborough is the only service performance given in detail, phosphate ester fluids have given unsatisfactory service in boiler hydraulic equipment, e.g. case history; fluid No. 11a in Tables 5 and 15, service period approximately 1000 hours; acidity 15·0 mg KOH/g; corrosion severe enough to prevent operation of equipment; water ingress to system confirmed probably due to humid atmosphere. Other less serious cases have also been reported and confirm Mr William's experience.

Mr Knight quite rightly points out the reason for the 24 hour fluid life quoted in my paper, and the sudden loss of equipment due to fluid shortcomings is perhaps best illustrated by unit No. 2 at Richborough when water ingress occurred (see Mr Plumb's tabulation of fluid performances). The fuller's earth used for filtering these fluids has been carefully chosen, but it cannot be considered sufficiently selective to eliminate the possibility of

Table 15. Changes in fluid stability and corrosion properties, 1963–1968

Fluid (see Table 1 for description)		6 (1963)	11a (1963)	8b (1964)	9c (1967)	3(1) (1965)
Chemical stability						
Test 1 acid value (mg KOH/g)	72 h	2·0	0·85	0·25	0·20	0·15
	500 h	20	2·1	0·40	0·20	0·10
Test 2 acid value (mg KOH/g)	72 h	2·6	15·2	27	4·8	0·40
	500 h	40	100	51	145	0·15
Test 3 acid value (mg KOH/g)	72 h	0·20	0·35	1·1	0·70	0·10
	500 h	9·0	7·3	4·0	2·80	0·15
Copper corrosion (mg loss)	72 h	0·8	8·7	0·5	0·3	0·2
	500 h	40	42	56	0·9	+0·1
Iron corrosion (mg loss)	72 h	1·5	3·4	0·3	2·5	0·2
	500 h	38	30	65	43	0·1
Test 4*(2) acid value (mg KOH/g)	72 h	0·30	0·35	0·10	0·2	0·10
	500 h	70	2·8	0·70	0·2	0·20
Copper corrosion (mg loss)	72 h	1·7	1·2	0·4	+0·2	Nil
	500 h	238	2·0	0·4	0·4	0·4
Iron corrosion (mg loss)	72 h	26	0·2	Nil	Nil	0·1
	500 h	19	0·3	0·4	0·4	0·2
Anti-rust properties						
IP 135 salt water (rust)		heavy	heavy	heavy	light	absent
distilled water (rust)		heavy	heavy	absent	absent	absent

(1) Chlorinated diphenyl-based material for comparison.
(2) Identical to test 3 but without water.

additive removal. The loss of anti-rust properties, quoted in my reply to Mr Plumb, may be partly attributable to additive removal.

Mr Signer and Mr Fisher point out the necessity for carrying out material compatibility tests, particularly with a view to evaluating the lubrication properties of the fluid under what has been shown by many workers, mentioned by Mr Early in his comment, to be due to fault or dirty conditions. I agree for the necessity of such tests. As Mr Wolfe and Dr Cohen point out, the fluid–material compatibility problem of chlorinated diphenyls must be balanced against the hydrolytic instability problem of phosphate esters for journal bearing lubrication. However, the satisfactory lubrication of gas turbines quoted by Mr Smith, and of the C.E.G.B. bearing rig (15), on similar fluids, show that the former problem can be overcome. At present there is no known economic answer to the latter problem for wet turbine systems.

The corrosion-erosion problem mentioned by Mr Wolfe and Dr Cohen is perhaps another case of fluid–material compatibility. At the time of the Uskmouth disaster (16) work carried out at C.E.R.L. showed that, within certain limits of trace contamination of mineral turbine oil with water, sodium chloride and magnetite, corrosion of relay pistons occurred, with compaction of the corrosion products causing piston sticking, when cast iron was the material of construction. A change of material to stainless steel, bronze or chromium plated steel prevented corrosion and compaction (17). However, the conclusions reached by Mr Wolfe and Dr Cohen, in their paper (6), regarding the use of earth filtration for chlorinated diphenyls must be considered.

Mr Early gives useful information on the uses and service performance of the main types of synthetic f.r. fluids. He asks whether the differing service performance is due to differences in equipment design or in fluid quality. My answer in this case is that either may be responsible depending on the circumstances. We have learnt over the years that mineral oils from dissimilar sources cannot be expected to give similar performance in severe applications, yet it is common for phosphate esters from all sources to be regarded as pure chemicals of identical characteristics. The figures in my Tables 5 and 15 show the error of this assumption. Similarly two turbines of the same design and manufacture are considered identical, but a closer scrutiny of the erection of the machines usually shows important differences. For instance the three Richborough machines are known to be different from many 'identical' machines, i.e. machines built to the same manufacturer's design, in that they have the fluid reservoir below pump level whereas many of these machines on the Continent have a header fluid tank, and therefore a gravity feed to the pump. The Richborough machines also have stagnant, or near stagnant, fluid at the power pistons whereas it has been found desirable to have fluid flow past these pistons on the Continental machines. Two other features which were originally built into No. 3 machine at Richborough were (1) a fluid return pipe in close proximity to the suction and (2) hot steam pipes lagged to the fluid delivery pipe. These differences can obviously be the cause of a variation in the performance of the same fluid where borderline levels of fluid or material properties are involved. Although Mr Early asked the question I know he appreciates that such unknown differences as these make laboratory evaluation, and correlation between this evaluation and service performance, so difficult.

Mr Staley and Mr Critchley also raise the question of the correlation of laboratory evaluation with service performance. This can of course be a difficult and lengthy process and often has to be inferred rather than proven. However, the shear instability of fluids has been amply demonstrated in both the laboratory and service, see Table 4, as also has the lack of anti-rust properties of fluids 6 and 11a (see earlier replies). Similarly the rapid acidity rise of fluid 11a under wet conditions is a case where its poor hydrolytic stability in laboratory tests can be inferred to have been demonstrated in practice (see earlier reply). Having demonstrated the hydrolytic instability of phosphate esters, more attention has of course been paid to keeping both fluid and equipment dry. As regards correlation between chlorinated diphenyl-based materials and phosphate esters, Mr Smith's experience with gas turbines proves the chemical stability superiority of the former.

The French experience with high acidities may not look so good should they ever have water contamination.

The hydrolytic stability results quoted are of the order obtained by myself on the products mentioned. Other suppliers' products are not necessarily so good. The improvement in the stability of phosphate esters over the last few years are shown in Table 15, where test results are given at 500 hours as well as at 72 hours. The anti-rust properties are still poor, however, compared to mineral oils and chlorinated diphenyls. A suitable anti-rust additive, as well as a hydrolytically stable fluid, is therefore required if phosphate esters are to be seriously considered for the lubrication of steam turbine bearings. The optimism of the contributors in respect of anti-rust additives is therefore welcome.

Mr Williams in his contribution mentioned seal materials, and in my paper I did say the solvent power of the chlorinated diphenyls was greater than that of the phosphate esters. Although this is generally true specific cases have been brought to my notice of a seal material which swells more, and of a surface coating material which dissolves more easily in phosphate esters than in chlorinated diphenyls. Apart from accumulator bladder materials, which still seem to pose some problems, there appears to be no difficulty in obtaining seals or surface coatings for chlorinated diphenyls.

The density of these fluids must obviously be taken into account in designing the system and Mr Smith's experience and Mr Parfitt's comments are applicable to this question.

In reply to Mr Waddington, the contribution by Mr Fryer generally answers the question of particle filtration and moisture removal. The carry-over of earth from fuller's earth filters must be avoided, and the cartridges used at Richborough are followed by a cellulose pack to guard against this. A vacuum paper edge filter backing an earth filter does, however, make an ideal combination.

The earth filter used at Richborough is based on an Atapulgus clay and is the same material as used by Mr Wolfe and Dr Cohen, i.e. Birfield-Hilco, Green Label, Hilite 60/90 mesh, RHP6, FFC00. As mentioned earlier any earth filter must be expected to remove additives, but the manufacturers state that the amount removed by this material is small, and that additive saturation of the earth occurs followed by adsorption of acid material. The amount of additive removed is therefore dependent upon the amount of earth used, and this is governed by the rate of acid formation.

Molecular sieves are very selective in their choice of sorbate, but there seems to be no reason why a composite filter could not be developed for this application.

The first question asked by Mr Fortune has been adequately answered by several previous contributors. Bearing in mind the complexity of material compatibility in differing system environments, and assuming the absence of contaminants, the quick answer is that systems can be designed to be satisfactorily lubricated by both phosphate esters and chlorinated diphenyls without serious departure from mineral oil design factors.

Mr Williams, in his contribution, mentioned experiencing uncomfortable working conditions due to fumes formed from fluids decomposed on hot surfaces. His recommendations are sensible and necessary. To quote Richborough's experience, 'small leaks of fluid dropping on to hot steam pipes (*circa* 538°C) have been encountered without discomfort, which would have resulted in a fire and immediate shutdown had mineral oil been used'. A more serious leak would have to be dealt with urgently, but would allow normal turbine rundown without the disruption and cost of a fire.

The silicone fluids mentioned by Mr Haines and Mr Harvey are not unknown to me and they have certain advantages over the phosphate esters and chlorinated diphenyls. Their shortcomings must, however, be taken into account, and an important one is their price.

Dr Lansdown's comments regarding the basic philosophy behind my choice of fluids and fluid characteristics may be acceptable in the field of aircraft design, but are unacceptable in industrial fields. It is not unreasonable to compromise between redevelopment of equipment and fluid characteristics. On this basis a reformulation of what are basically acceptable fluids, to meet the characteristics known to be compatible with general system design and environment, is the most economical way. In fairness to Dr Lansdown I did not state the volumes of fluid involved

Table 16. Fluid volumes and cost

System	Aircraft	Boiler control	Turbine control	Turbine lubrication
Approx. volume (litres)	90	180	4 500	90 000
Approx. cost (£) of:				
mineral oil	5	10	250	5 000
phosphate ester	40	80	2 000	40 000
chlorinated diphenyl	40	80	2 000	40 000
silicone	200	400	10 000	200 000

and he would therefore be unaware of the order of fluid cost. These are as given in Table 16.

The modified silicone fluid mentioned by Dr Lansdown is, I believe, even more expensive, and still not without its problems.

All reasonable steps were taken to ensure a satisfactory level of fire resistance for the field of application covered by my paper, and this included observing tests on fluids under the leak conditions envisaged in C.E.G.B. equipment. However, one area of fire resistance testing not investigated by others, so far as I am aware, is the field of spontaneous combustion in lagging soaked with fluid from an external drip. This may be a vulnerable condition to the C.E.G.B. who experience mineral oil fires from this cause. The experience quoted by Mr Hardy and Dipl-Ing. Stoldt with f.r. fluid blends containing mineral oil may well apply in this case. To this end the C.E.G.B. are carrying out tests in conjunction with the Fire Research Station on the various fluid blends which are of interest.

Currently available fire-resistance tests are not the only tests which have severe limitations. Any test carried out under one set of conditions can lead to serious misrating, and the misleading information given by the available chemical stability and corrosion tests led to the original experimental work described in my paper.

REFERENCES

(15) 'Bearing rig tests with phosphate ester and chlorinated hydrocarbon fire-resistant fluids', C.E.G.B. Internal Report, 1967.

(16) Lindley, A. L. G. and Brown, F. H. S. 'Failure of a 60-MW steam turbo-generator at Uskmouth power station', *Proc. Instn mech. Engrs* 1958 **172**, 627.

(17) 'Failure of No. 5 Machine, Uskmouth power station. Prevention of the compaction of magnetite by the use of corrosion resistant materials for the construction of control pistons and cylinders', C.E.R.L. Internal Report, 1958.

11-20-81

SILVER GATE POWER PLANT
DOWELL VERTAN 675 CHEMICAL CLEANING INSTRUCTIONS AND SCHEDULE FOR BOILERS 5 & 6

CONTRACTOR: Dow Industrial Service CLEANING DATE: December 4, 1981 0800

P.O. NO: ______________ ELECTRIC PRODUCTION CHARGE ACCOUNT NO: 502.2

PURPOSE

The boiler will be chemically cleaned with aqueous solution of ammoniated EDTA (Vertan Chelants) for removal of fouling scales. The waste produced in this chemical cleaning process typically contains dissolved metals, such as iron, copper, chromium, and nickel, that have accumulated in the boiler since its last cleaning. Only the generating surfaces of the boiler will be cleaned. The superheating sections will be filled with condensate to prevent carryover of cleaning chemicals.

Plant personnel will have all temporary piping in place for the chemical cleaning contractor. With the aid of operations, the contractor will clean the boilers.

CHEMICAL-CLEANING OUTLINE

The boiler will be cleaned with approximately 10 to 12% Vertan 675, a compounded chelant, and approximately 0.2 to 0.4% inhibitor.

After the boiler has been filled with Vertan and inhibitor, have the lab do an inhibitor test. Do not put fires to the boiler until the inhibitor is verified by the lab.

After the inhibitor check, fire the boiler to 325°F. After temperature is reached, secure fires, leave ignitors on, and fan cool boiler to 275°F. Continue the cycle of firing and cooling for approximately twenty-four to thirty hours. Each heating and cooling cycle takes approximately two hours. Alternate firing, using only one burner between Nos. 1, 4, 5, and 8 burners. Using the wing burners will aid in better boiler circulation.

During the cleaning process, the laboratory and Dowell will be monitoring the cleaning. When it is determined the cleaning process is completed, operations will be notified.

After the cyclic heating and cooling for iron pick-up, the boiler is now cooled to approximately 160 to 180°F taking between four and six hours to cool. Using service air, alternate air blowing every fifteen minutes between north, south waterwall drains, mud drum drain, and economizer drain with recirculation valves closed. The laboratory and Dowell will determine when the copper pickup, by air blowing, is completed (it will take approximately two hours).

After the completion of air blowing, the boiler will be drained to the Baker tank under the service air at 50 PSI. IT Corporation will haul cleaning waste off to a disposal site.

The boiler is then filled through the bottom connection with city water (approximately 100°F warmed to prevent thermal shock to the drums) to rinse out the remains of the Vertan 675 solution. The rinse will be done two times using city water, and the remaining two rinses will be done using good condensate. All rinse water will be drained to Waste Water Void 1 and treated before discharge to outfall.

The boiler will be hydro-tested to 500 psi. Before draining the last rinse water from the boiler, when the hydro has been completed, the boiler will be drained and the steam drum opened for inspection.

PREPARATION

Done A. Check and connect the vent pipe from the north steam drum vent to the north alley. Cap vent line to Boiler 6 -- do not connect superheater vents.

Done B. Check and test acid line from north alley to make-up pump 3.

Done C. Check and test acid sample line and valves at make-up pump 3.

Done D. Provide city water hose at the north alley and in the basement in the vicinity of make-up pump 3.

Done E. Hang "NO SMOKING" and "NO OPEN LIGHTS" signs in the vicinity of the make-up pump and in the north alley at the acid delivery point.

Done F. Air hose at south drum vent and in basement to boiler blowdown system.

Done G. Remove boiler casing as necessary to provide access to upper and lower water-wall headers (for temperature check and inspection).

ITCH Done H. Connect drum metal thermocouples to "AZAR" and check calibration.

LAB Done I. Check out sampling equipment at make-up pump and blowdown line. (Plastic sampling bottles, not glass because of silica.)

ITCH Done J. Check thermometer at the MU pump discharge. Move from Make-up Pump 4 to Make-up Pump 3.

Done K. Erect titrating bench at MU pump discharge sampling line.

SUPVR L. Provide contact pyrometer.

SUPVR M. Provide walkee talkee.

Dow Done N. Connect 500 barrel tank to Boiler 5+6 drain lines.

Done O. City water spool to Surge Tank 3.

Done P. Install blank flanges in soot hopper drain funnels.

OK, Q. Check and repair leaks in both Unit 3 & 4 blowdown systems.

ADJUST BOILER TEMPERATURE

1. Done Fill Boiler 5 to light-off level using BLR wtr ~~condensate~~ from Surge Tank 3 + #3 DA.

2. Done Fill superheaters (takes approximately one hour); transfer condensate from other units to Surge Tank 3 (4,000 gal); add two pints hydrazine and use this water to fill S.H. through their drain lines. The boiler stop and check valves should be closed (close blowdown valves and crossover valve at blowdown tank).

3. 0158 Light off boiler using eight ignitors and rotating ~~one main gas fire~~ using burners. Close drum vent when steam forms. DO NOT FREEBLOW. Raise temperature to approximately 180 to 200°F metal temperature. Bank boiler. @ 50# (Too much Press)

Bank - 0350

Leave Superheaters Empty.

4. While firing boiler for temperature set, ~~heat up approximately 3,000 gal condensate to approximately [illegible]d~~ Cold Condensate N/A. top off superheaters before draining boilers. Fill through prim Sup Htr inlet.

Start 0415

5. Drain Boiler 5 through mud drum and water wall drains only (the contractor will arrive at Dec. 4, [illegible]) 0800

Finished 0730

5A. 0415 (Start Drain) ~~When temperature conditions have been approved by the contractor~~, connect the air hose to the south steam drum and turn on the air to 45#.

5B. 0730 (Conplete Drain) Drain boiler to the surge tank, pumping up to DA storage tank to conserve temperature. Drain economizer through the recirculating valves.

NOTE: With both Vertan and flushes, drain the boiler in four separate steps - N waterwall S-waterwall - mud drum with recirculating valves closed, then open recirculating valves for final flush through economizer to mud drum.

6. ✓ Filling with Vertan 675 (target date and time)

Done A. Before filling the boiler with Vertan 675 solution, check all blowdown valves and instrument connections to steam and watersides for closed. Leave boiler gauge glass in service. Yarway + Drum Level Recorder Returned To service Press gauge in service

✓ B. During filling, venting will be through the drum vent to N. alley. Note explosive H_2 gas is liberated by the action of Vertan 675 - NO SMOKING IN THIS AREA.

6.

start 0835 C. The Vertan 675 solution will be mixed with the hot boiler water discharge of No. 3 MU Pump and will be transferred to the mud drum and waterwall valves. The contractor will control Vertan pumping rate to produce the proper concentration. Sampling will be done by the contractor through the sampling line provided at the M.U.P. discharge.

stop 0900

start 0910 [illegible]

cont- 0945 D. Continue to fill the boiler to the firing level in the gauge glass (three ports in glass). DO NOT OVERFILL - the solution will swell when heated.

Complete Vertan Fill 0955

Done E. Before the boiler is fired, the lab will check the inhibitor in Vertan.

Burner #	Time Start	Time End
1-	1011	1045
8-	1119	1247
4-	1444	1519
5-	1521	1555
1-	1902	1930
8-	1930	2000
4-	2328	2348
1-	0028	0152
8-	0349	0420
5	0503	0523

5- 2000 to 2030

F. The boiler will then be fired to 325°F drum metal temperature, then secure main fire.

During this time samples will be taken. (Do not freeblow)

G. The boiler will then be fan-cooled until a temperature of 275°F is attained.

Then relight main fire until 325° is again reached.

(Rotate burners using 1-4-5-8)

H. Steps F and G above, of firing and cooling, will continue until iron concentration and Vertan concentration stabilizes. The total time of firing and cooling will take approximately 24-30 hours. The contractor will take a series of sample concentrations during the firing and cooling procedure to determine the required amount of firing. If the Vertan does not stabilize, more Vertan may have to be added.

1817-1831 Drain To approx 1600 gal Baker tk.

1843-1855 Added 800 gal vertan 700 gal Drain Returned

7. Time

COOLING BOILER PRIOR TO AIR BLOW

Start	End	
0523	1100 165°	A. The boiler will then be cooled by fanning to a temperature of 150°-160°F.
1035	1045	B. The contractor will then readjust the Vertan concentration in preparation for copper removal stage.
0750	0815	C. Near the end of the air-cooling stage, condensate should be added to the primary S.H. to flood the superheater sections.

0930-935 Drained approx 300 gal to Baker tank

035 Pumping 350 gal vertan into steam drum for air blow

8. AIR BLOW BOILER

✓ A. Air will be blown through the boiler via the blowdowns with the steam drum vent open. Water wall mud drum and economizer will be blown separately.

Time	
Start	End
1100	1400

B. The contractor will provide temporary hosing to catch any foam or liquid going to N. alley.

1 So mud drum

C. The air will be alternately blown through each waterwall mud drum and econ. drain valves until the contractor's analysis indicates that the copper concentration has leveled off. The boiler will be made ready for draining.

2 north mud drum
3 South Hdr ✓ 15 min each,
4 No. Hdr.
5- Econ.

1115 D. While Vertan solution is in the boiler, refill the surge and DA tanks with city water for the first rinse (25,000 gal. city water heated to approximately 100°F), use the surge tank steam heater.

9. (VERTAN DRAIN UNDER AIR)

✓ A. Close MUP discharge valve to boiler; fill and drain system.

✓ B. The boiler blowdown line (lower) valve to B.O.T. and the crossover valve remain closed. On both Units 3 and 4 insure Unit 4 blowdown system is isolated at the boiler and surge.

1405 C. Open the following valves one at a time until air appears at 500 bbl tank:

✓ 1. Waterwall header - south
✓ 2. Mud drum - south
✓ 3. Mud drum - north
✓ 4. Water wall header - north
✓ 5. Economizer inlet header recirculating valves.
__ 6. Mud drum drain valve north
7- Near the End of air blow open all blowdown valves

1405 D. Open valves in the blowdown line (stub valve near stair's landing) to the 500-barrel tank, Units 3 and 4.

1405 E. ~~Impress 50# air pressure on the~~ south drum vent to expedite the draining of boiler; ~~close~~ north drum vent to N. Alley.

9. ✓ F. Obtain a drain sample every 15 minutes during the Vertan drain. Tag each sample bottle. Please mark the time of day and the temperature.

✓ G. When air appears at the 500-barrel tank, rotate the drain valves as shown in Paragraph 9-C.

✓ H. Close all boiler blowdown valves, then open them individually to determine when the drum, water walls, and economizer are drained.

1700 I. Secure the air valve and the 500-bbl tank valve Units 3 and ~~4~~ draining completed. Open drum vent to north alley to relieve air pressure.

10. FIRST RINSE - (FILL) START 1730 COMPLETE 1840

✓ A. Check the bottom blowdown drain line valve at B.O.T. for closed.

✓ B. Repeat Operation No.6 using city water only. Cold ~~Heat the~~ 670 ~~city water to 100ºF with the~~ surge tank steam ~~heater~~. Fill until the water appears at fourth port in the gauge glass.

11. FIRST RINSE (DRAIN) TO VOID No.1 via air preheater wash water system

✓ A. Open the two cross-connecting valves between the boiler blowdown system and the air preheater wash water drain system, one at the north side of the boiler and one at the south side just above M.U.P.

✓ B. Impress 50# air pressure on the steam drum; close north drum vent.

1845 C. Open the drain valves as indicated in "9-C" until the boiler is empty (air will blow at #1 Void).

CAUTION: Air can also escape from the upper end of all air preheater wash lines on Boilers 5 & 6.

NOTE: When the drain at Void 1 subsides or seems to blow air, close all valves and check individually. Make sure the economizer recirculating valves are open.

2010 D. Draining completed. Shut off air; open north drum vent.

Done E. While the first rinse is draining, refill ~~DA~~ and surge tank with 25,000 gals. of city water.

12 SECOND RINSE (FILL) START 2020 COMPLETE 2132

✓ A. Repeat Step 10 above using city water only.

13. SECOND RINSE (DRAIN) START 2140 COMPLETE 2340

✓ A. Repeat Step 11.

✓ B. While the second rinse is draining, flush No. 3 DA and No. 3 Surge with condensate and refill with 25,000 gal. of good condensate.

14. THIRD RINSE (FILL) START 2350 COMPLETE 0215

Flush 5 HTrS A. Repeat Step 10 using condensate only.

15. THIRD RINSE (DRAIN) START 0235 COMPLETE 0405

____ A. Repeat Step 11. + Econ START-0420 } Econ.
END-0450 } Flush

____ B. While the third rinse is draining, refill DA and surge tank with 25,000 gals. of good condensate.

16. FOURTH RINSE (FILL) START 0500 COMPLETE 0615

____ A. Repeat Step 10.

____ ~~B. Open the steam drum gauge line valve~~.

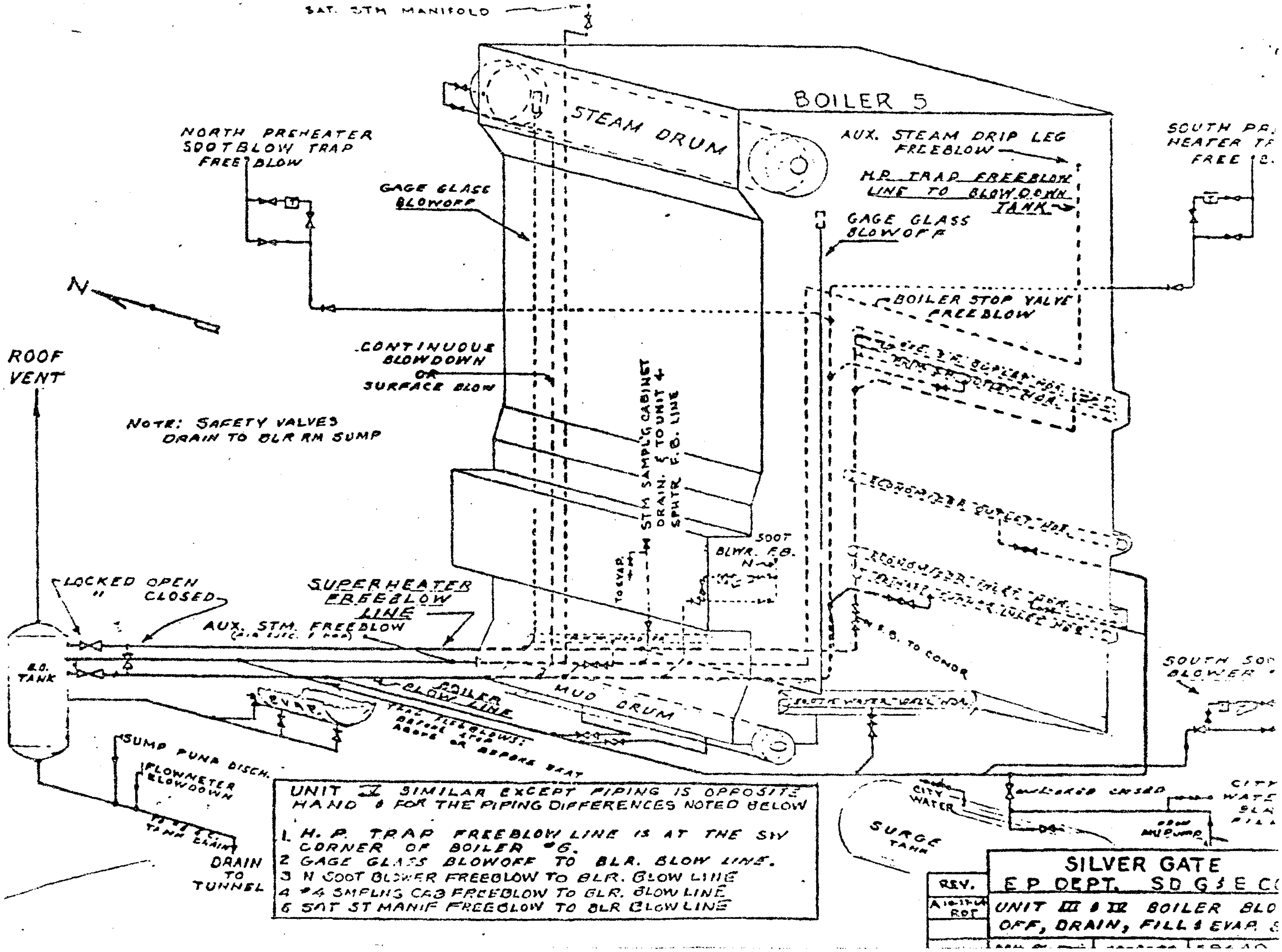
X ~~C. Check the boiler for leaks. Hydro to 500# using a boiler feed pump; check water level in DA.~~

17. FOURTH RINSE (DRAIN) START 0635 COMPLETE ____

____ A. Repeat Step 11.

18. X Fill the boiler ~~[illegible]~~ and DA to light-off level with good condensate. Contact the lab for chemicals that will be needed in the boiler.

NOTE: After the Third and Fourth Rinse drains (with the boiler empty), close economizer recirculating valves and use BFP to flush out the economizer.



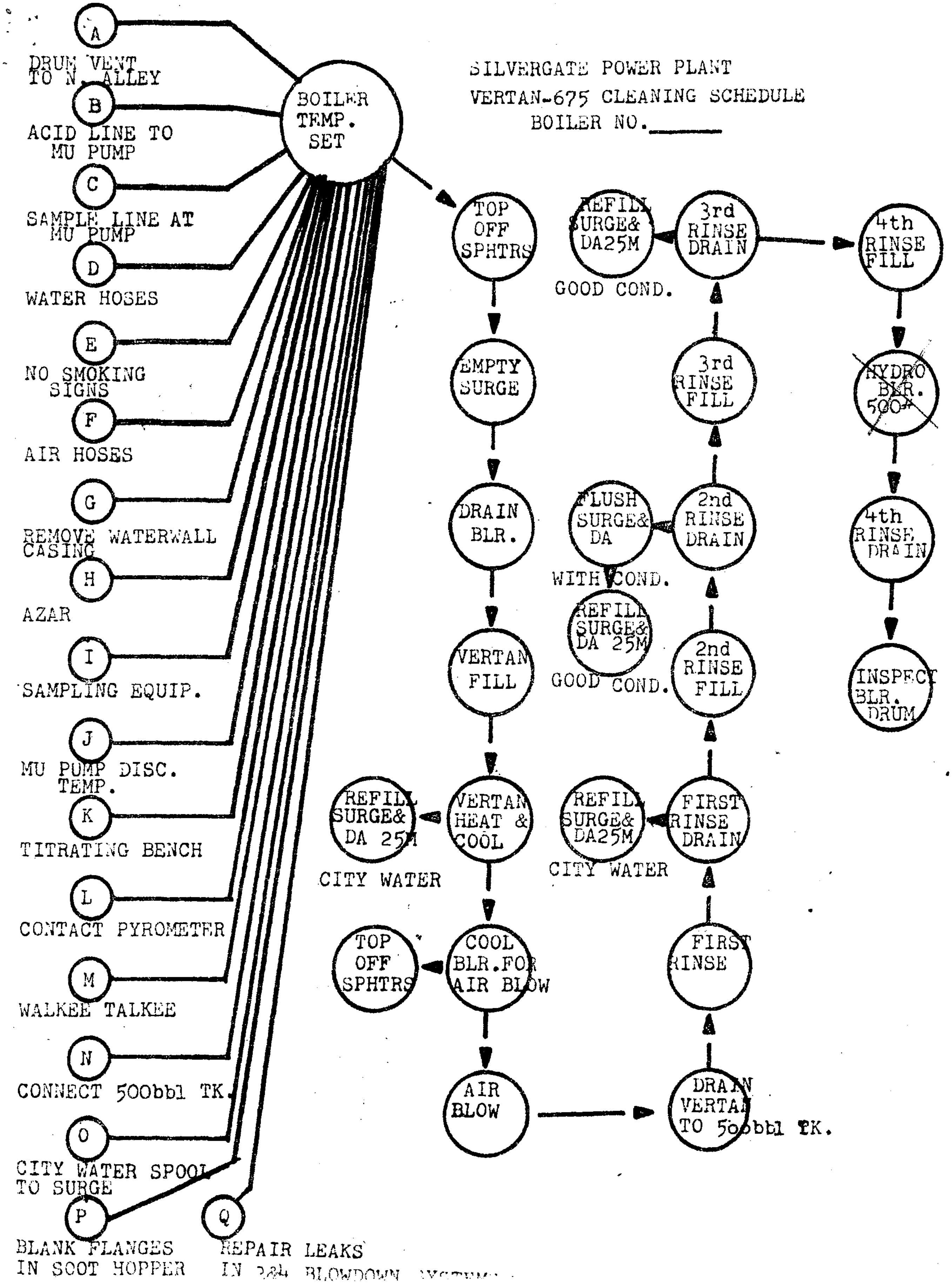
UNIT IV SIMILAR EXCEPT PIPING IS OPPOSITE HAND & FOR THE PIPING DIFFERENCES NOTED BELOW

1. H. P. TRAP FREEBLOW LINE IS AT THE SW CORNER OF BOILER #6.
2. GAGE GLASS BLOWOFF TO BLR. BLOW LINE.
3. N SOOT BLOWER FREEBLOW TO BLR. BLOW LINE
4. #4 SMPLNG CAB FREEBLOW TO BLR. BLOW LINE
6. SAT ST MANIF FREEBLOW TO BLR BLOW LINE

REV.	SILVER GATE E P DEPT. SD G & E C
A	UNIT III & IV BOILER BLO OFF, DRAIN, FILL & EVAP.

SILVERGATE POWER PLANT
VERTAN-675 CLEANING SCHEDULE

BOILER NO.______



UNIT #3

advance preparation and follow thru

1) The operations co-ordinator should ensure that all valving operations are included in the procedure.

2) The operations co-ordinator should ensure that a adequate DI/condensate water supply is available.

3) There should be a meeting of the operations co-ordinator, Engineering, maintenance, and the laboratory a few days before the clean. The purpose of the meeting is to ensure that everyone involved understands the sequence of events and who is responsible for what.

4) The operations co-ordinator should personally observe the following operations: bromate fill and Drain, Vertan fill, Fire and swell drain (to insure vertan is not blown to blow off tank), and the Vertan drain and rinse. The rest of the process can be observed by th Eng or Lab representative.

5.) The procedure should be put in the control room and basement in advance for operator familiarization.

DOWELL DIVISION OF DOW CHEMICAL U.S.A.
301 CRENSHAW BLVD. TORRANCE, CA 90503

November 12, 1981

San Diego Gas & Electric Company
Silvergate Station
P.O. Box 1831
San Diego, CA

Gentlemen:

acid

Our enclosed quotation is for chemically cleaning the Silvergate Station using a fill of 5% Hydrochloric Acid and containing 1.5% Throurea.

We are also furnishing a 500 barrel tank for draining the boiler.

As in the past, San Diego Gas & Electric will furnish the necessary boil out chemicals.

Our estimate charge for using an alternate method (Alkaline Copper Removal Treatment - Vertan 675) is based on the amount of chemicals used and is as follows:

Vertan

1. 30,000 lbs. Vertan 675 @ $0.71/lb	$21,300.00
2. 4,200 lbs. of Dowell E-1218 @ $1.50/lb.	6,300.00
3. 40 gallons E-224 Inhibitor @ $27.00/gal.	1,080.00
4. 50 gallons Ammonium Hydroxide @ $2.20/gal.	110.00
TOTAL CHEMICAL CHARGES	$28,790.00
5. Personnel and equipment charge (Includes Baker Tank @ $1,100.00)	4,572.00
TOTAL ESTIMATED CHARGE PER BOILER	$35,089.00

The above chemicals are sufficent to remove approximately 1,600 lbs. of iron and 200 lbs. of Copper for the boiler. The 4,200 lbs. of E-1218 will treat 200 lbs. of Copper in the biler drain.

Very truly yours,

D J Kessinger
D.J. KESSINGER
SALES ENGINEER

DJK:jmm

AN OPERATING UNIT OF THE DOW CHEMICAL COMPANY

VERTAN CLEANINIG APPROXIMATE TIME SCHEDULE

12/4/81 Boiler 5 Filled to light off level and superheaters filled with condensate.

0200 Light off boiler for temperature set.

0500 Bank boiler.

0510 Top off superheaters.

0600 Start draining boiler.

0730 Complete draining boiler. Buck will be In @ 0600

0800 Start vertan fill.

0910 Complete vertan fill.

0940 Light off boiler,start heat/cool stage.

12/5/81 Saturday

1400 Complete heat/cool stage,cool boiler for air blow.

1700 Top off superheaters.

1730 Boiler cooled for air blow.

1735 Start air blow.

1930 Complete air blow.

1945 Start vertan drain.

~~12/6/81 Sunday~~

2100 Complete vertan drain.

2115 Start first rinse fill.

2230 Complete first rinse fill.

2240 Start first rinse drain.

2400 Complete first rinse drain.

0010 Start second rinse fill.

0110 Complete second rinse fill.

0120 Start second rinse drain.

0240 Complete second rinse drain

0250 Start third rinse fill.

0400 Complete third rinse fill.

0410 Start third rinse drain.

0540 Complete third rinse drain,flush economizers.

0550 Start fourth rinse fill.

0710 Complete fourth rinse fill.

0710 Squeeze boiler to 500 psi. for hydro.

0830 Hydro inspection conpleted.

0840 Start fourth rinse drain.

1000 Complete fourth rinse drain.

1020 Flush economizers.

1100 Drain superheaters.

1200 Steam drum open for inspection.

"Complete"

Remarks

VERTAN CLEANINIG APPROXIMATE TIME SCHEDULE

12/4/81 Boiler 5 Filled to light off level and superheaters filled with condensate.

0200 Light off boiler for temperature set.

0500 Bank boiler.

0510 Top off superheaters.

0600 Start draining boiler. — Buck will be in @ 0600

0730 Complete draining boiler.

0800 Start vertan fill.

0910 Complete vertan fill.

0940 Light off boiler, start heat/cool stage.

12/5/81 Saturday

1400 Complete heat/cool stage, cool boiler for air blow.

1700 Top off superheaters.

1730 Boiler cooled for air blow.

1735 Start air blow.

1930 Complete air blow.

1945 Start vertan drain.

[illegible]

2100 Complete vertan drain.

2115 Start first rinse fill.

2230 Complete first rinse fill.

2240 Start first rinse drain.

2400 Complete first rinse drain.

0010 Start second rinse fill.

0110 Complete second rinse fill.

0120 Start second rinse drain.

0240 Complete second rinse drain

0250 Start third rinse fill.
0400 Complete third rinse fill.
0410 Start third rinse drain.
0540 Complete third rinse drain, flush economizers.
0550 Start fourth rinse fill.
0710 Complete fourth rinse fill.
0730 Squeeze boiler to 500 psi. for hydro.
0830 Hydro inspection completed.
0840 Start fourth rinse drain.
1000 Complete fourth rinse drain.
1020 Flush economizers.
1100 Drain superheaters.
1200 Steam drum open for inspection.

"Complete"

Remarks

DATE 2-15-83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #15 Load Trans. LOCATION: Silver Gate West 2978783

DATE OF INSPECTION: 2-15-83

DATE OF LEAK DISCOVERY: 11-22-82

NAME OF INSPECTOR: J C Bonk

ESTIMATE OF FLUID LEAKED: Medium leak at sample Value and small leak at the small drain Value

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED: no action taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED: none

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS: no action taken

DATE 2-15-83

Rec'd 2/16/83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #15, Lighting Trans. LOCATION: Silver Gate West 2978512

DATE OF INSPECTION: 2-15-83

DATE OF LEAK DISCOVERY: 2-11-83

NAME OF INSPECTOR: J. C. Bonk

ESTIMATE OF FLUID LEAKED: Small leak around packing of drain Valve

DATE OF CLEAN-UP(S), CONTAINMENT,
OR REPAIR PERFORMED: no action taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT,
OR REPAIR PERFORMED: None

RESULTS OF ANY CONTAINMENT AND DAILY
INSPECTION FOR UNCORRECTED ACTIVE LEAKS: no action taken

DATE 2-15-83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1 N. Load Trans, LOCATION: Silver Gate West 2978782

DATE OF INSPECTION: 2-15-83

DATE OF LEAK DISCOVERY: 11-22-82

NAME OF INSPECTOR: J C Bank

ESTIMATE OF FLUID LEAKED: Small leaks at drain and Sample Valves

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED: no action taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED: none

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS: no action taken

DATE 2-15-83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1 N. Lighting Trans LOCATION: Silver Gate West 2978511

DATE OF INSPECTION: 2-15-83

DATE OF LEAK DISCOVERY: 2-11-83

NAME OF INSPECTOR: J C Bonk

ESTIMATE OF FLUID LEAKED: Dampness around drain Valve packi and small leak at the plug in the end of the Valve.

DATE OF CLEAN-UP(S), CONTAINMENT,
OR REPAIR PERFORMED: no action taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT,
OR REPAIR PERFORMED: none

RESULTS OF ANY CONTAINMENT AND DAILY
INSPECTION FOR UNCORRECTED ACTIVE LEAKS: no action taken

DATE MON FEB 14 1983

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1 S. LIGHTING TRANS LOCATION: SILVERGATE
West 2978512

DATE OF INSPECTION: 2-14-83

DATE OF LEAK DISCOVERY: 2-11-83

NAME OF INSPECTOR: D.R. SPATE

ESTIMATE OF FLUID LEAKED: SMALL LEAK AT DRAIN VALVE PACKING

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED: NO ACTION TAKEN

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED: NONE

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS: NO ACTION TAKEN

DATE JUN FEB 14 1983

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1 N PWR TRANS WEST 2978782

LOCATION: SILVER GATE

DATE OF INSPECTION: 2-14-83

DATE OF LEAK DISCOVERY: 2 11-83

NAME OF INSPECTOR: D.R. SPATE

ESTIMATE OF FLUID LEAKED: SMALL LEAK AT DRAIN VALVE

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED: NO ACTION TAKEN

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED: NONE

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS: NO ACTION TAKEN

DATE MON FEB 14 1983

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1 N. LTG West Trans LOCATION: SILVERGATE
2978511

DATE OF INSPECTION: 2-14-83

DATE OF LEAK DISCOVERY: 2-11-83

NAME OF INSPECTOR: D.R. SPATE

ESTIMATE OF FLUID LEAKED: LEAK AT DRAIN VALVE VERY SMALL

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED: NO ACTION TAKEN

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED: NONE

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS: NO ACTION TAKEN

DATE MON FEB 14 1983

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1 S. LOAD ~~[illegible]~~ TRANS. LOCATION: SILVER GATE
UNIT. 2978783

DATE OF INSPECTION: 2-14-83

DATE OF LEAK DISCOVERY: 2-11-83

NAME OF INSPECTOR: D. R. SPATE

ESTIMATE OF FLUID LEAKED: SMALL LEAK AT DRAIN VALVE PLUG

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED: NO ACTION TAKEN

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED: NONE

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS:

NO ACTION TAKEN

DATE 2-13-83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #/S Lighting Trans West 297 852

LOCATION: Silver Gate

DATE OF INSPECTION: 2-13-83

DATE OF LEAK DISCOVERY: 2-11-83

NAME OF INSPECTOR: Gary L. Gentz

ESTIMATE OF FLUID LEAKED: Small leak around packing of drain valve

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED: No action taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED: None

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS: No action taken

DATE 2-13-83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: 15 Load Trans West 2978783

LOCATION: Silver Gate

DATE OF INSPECTION: 2-13-83

DATE OF LEAK DISCOVERY: 11-22-82

NAME OF INSPECTOR: G.L. Gentz

ESTIMATE OF FLUID LEAKED: Medium leak at sample valve and small leak at the small drain valve

DATE OF CLEAN-UP(S), CONTAINMENT,
OR REPAIR PERFORMED: No Action Taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT,
OR REPAIR PERFORMED: None

RESULTS OF ANY CONTAINMENT AND DAILY
INSPECTION FOR UNCORRECTED ACTIVE LEAKS: No Action Taken

DATE 2-13-83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1N. Load Trans LOCATION: Silver Gate West 2978782

DATE OF INSPECTION: 2-13-83

DATE OF LEAK DISCOVERY: 11-22-82

NAME OF INSPECTOR: GL Gentz

ESTIMATE OF FLUID LEAKED: Small leak at drain and sample valves

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED: No Action Taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED: None

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS: No Action Taken

DATE 2-13-83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: 1N. Lighting Trans West 297851 LOCATION: Silver Gate

DATE OF INSPECTION: 2-13-83

DATE OF LEAK DISCOVERY: 2-11-83

NAME OF INSPECTOR: G.L. Gentz

ESTIMATE OF FLUID LEAKED: Dampness around drain valve packing and small leak at the plug in the end of the valve.

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED: No Action Taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED: None

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS: No Action Taken

DATE **SAT** FEB 1 2 1983

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1 N. LOAD TRANS West 2978782 LOCATION: Silver Gate

DATE OF INSPECTION: **SAT** FEB 1 2 1983

DATE OF LEAK DISCOVERY: 11/22/82

NAME OF INSPECTOR: OLKSER, J

ESTIMATE OF FLUID LEAKED: Small leaks at DRAIN AND SAMPLE valve

DATE OF CLEAN-UP(S), CONTAINMENT,
OR REPAIR PERFORMED:

No Action taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT,
OR REPAIR PERFORMED:

NONE

RESULTS OF ANY CONTAINMENT AND DAILY
INSPECTION FOR UNCORRECTED ACTIVE LEAKS:

No action taken

DATE **SAT** FEB 12 1983

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: 1 N. Lighting trans LOCATION: Silver Gate West 29[illegible]511

DATE OF INSPECTION: **SAT** FEB 12 1983

DATE OF LEAK DISCOVERY: 2/22/82

NAME OF INSPECTOR: OLKJER, J

ESTIMATE OF FLUID LEAKED: Dampness around Drain valve packing and small leak at the plug in the end of the valve –

DATE OF CLEAN-UP(S), CONTAINMENT,
OR REPAIR PERFORMED:

No action taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT,
OR REPAIR PERFORMED:

None

RESULTS OF ANY CONTAINMENT AND DAILY
INSPECTION FOR UNCORRECTED ACTIVE LEAKS:

No action taken

DATE **SAT** FEB 12 1983

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #115 LOAD TRANS LOCATION: SILVERGATE WEST 278783

DATE OF INSPECTION: **SAT** FEB 12 1983

DATE OF LEAK DISCOVERY: 2/22/82

NAME OF INSPECTOR: [illegible]

ESTIMATE OF FLUID LEAKED: MEDIUM LEAK AT SAMPLE VALVE AND SMALL LEAK AT THE SMALL DRAIN VALVE -

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED:

NO ACTION TAKEN

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED:

NONE

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS:

NO ACTION TAKEN

DATE 2/11/83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1 N. Load trans. LOCATION: Silver Gate West. 2978782

DATE OF INSPECTION: 2/11/83

DATE OF LEAK DISCOVERY: 11/22/82

NAME OF INSPECTOR: R Manes

ESTIMATE OF FLUID LEAKED: Small leaks at drain and sample valves

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED: No action taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED: None

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS: No action taken

DATE 2/11/83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1 S. Load trans. LOCATION: Silver Gate West. 2978783

DATE OF INSPECTION: 2/11/83

DATE OF LEAK DISCOVERY: 11/22/82

NAME OF INSPECTOR: R. Manes

ESTIMATE OF FLUID LEAKED: Medium leak at sample valve and small leak at the small drain valve

DATE OF CLEAN-UP(S), CONTAINMENT, OR REPAIR PERFORMED: No action taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT, OR REPAIR PERFORMED: None

RESULTS OF ANY CONTAINMENT AND DAILY INSPECTION FOR UNCORRECTED ACTIVE LEAKS: No action taken

DATE 2/11/83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1 N. Lighting trans. LOCATION: Silver Gate West. 2978511

DATE OF INSPECTION: 2/11/83

DATE OF LEAK DISCOVERY: 2/11/83

NAME OF INSPECTOR: R Manes

ESTIMATE OF FLUID LEAKED: Dampness around drain value packing and small leak at the plug in the end of the value.

DATE OF CLEAN-UP(S), CONTAINMENT,
OR REPAIR PERFORMED: No action taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT,
OR REPAIR PERFORMED: None

RESULTS OF ANY CONTAINMENT AND DAILY
INSPECTION FOR UNCORRECTED ACTIVE LEAKS: No action taken

DATE 2/11/83

DAILY PCB INSPECTION REPORT

PCB EQUIPMENT: #1 S. Lighting trans. LOCATION: Silver Gate West. 2978512

DATE OF INSPECTION: 2/11/83

DATE OF LEAK DISCOVERY: 2/11/83

NAME OF INSPECTOR: R. Manes

ESTIMATE OF FLUID LEAKED: Small leak around packing of drain valve.

DATE OF CLEAN-UP(S), CONTAINMENT,
OR REPAIR PERFORMED: No action taken

DESCRIPTION OF CLEAN-UP, CONTAINMENT,
OR REPAIR PERFORMED: None

RESULTS OF ANY CONTAINMENT AND DAILY
INSPECTION FOR UNCORRECTED ACTIVE LEAKS: No action taken

2 FD
CC: SUPVR, ENVIRONMENTAL PROGRAMS
L & E

SDGE

W/O # 701214

INST. No. 700.9.0.0
REV. NO. 1
ISSUE NO.
PAGE ____ OF ____

Attachment B-2 Silver Gate

	Equipment Con ining PCB's	Date	Inspected by	Comments/Corrective Action Taken
1)	#1N Lightin transformer West. s/n 2 8511	1/31/83	F. Stephenson	VERY SMALL LEAK AT DRAIN VALVE.
2)	#1S Lightin transformer West. s/n 2 8512	1/31/83	F. Stephenson	No LEAKS
3)	#1N Load tr sformer West. s/n 2 8782	1/31/83	F. Stephenson	LEAKS AT SAMPLE VALVE + DRAIN VALVES
4)	#1S Load tr sformer West. s/n 2 8783	1/31/83	F. Stephenson	MEDIUM LEAK AT SAMPLE VALVE
9)	#3 Gen Neut Gnd. transformer	1/31/83	F. Stephenson	No LEAKS
10)	#4 Gen Neut. Gnd. transformer	1/31/83	F. Stephenson	No LEAKS

WE ARE WAITING FOR PURCHASING DEPT TO MAKE ARRANGEMENTS FOR G.E. TO MAKE PERMANENT REPAIRS TO THE ABOVE LEAKING TRANSFORMERS. RMS FOR QUOTES WAS SUBMITTED IN OCTOBER 1982. RARodriguez

SDGE

W6 454256
Acct. 811-730-02

INST. No. 700.9.0.0
REV. NO. 1
ISSUE NO.
PAGE ____ OF ____

Attachment B-2 Silver Gate

Equipment Contai ng PCB's	Date	Inspected by	Comments/Corrective Action Taken
#1N Lighting t nsformer West. s/n 2978 1	11/22/82	F. Stephenson	No LEAKS
#1S Lighting t nsformer West. s/n 2978 2	11/22/82	F. Stephenson	No LEAKS.
#1N Load trans rmer West. s/n 2978 2	11/22/82	F. Stephenson	SMALL LEAKS AT DRAIN + SAMPLE VALVES.
#1S Load trans rmer West. s/n 2978 3	11/22/82	F. Stephenson	MEDIUM LEAK AT SAMPLE VALVE, SMALL LEAK AT SMALL DRAIN VALVE.
#3 Gen Neut. G . transformer	11/22/82	F. Stephenson	No LEAKS
#4 Gen Neut. G . transformer	11/22/82	F. Stephenson	No LEAKS

REMARKS: LE KS HAVE BEEN CLEANED PER INSTRUCTIONS. WE TINGHOUSE AND GE HAVE HAD JOB WALKS AND WILL BID ON JOB TO REPAIR THE LEAK SOURCES.

R.A. RODRIGUEZ
11/29/82

RECEIVED
San Diego Gas & Electric
NOV 30 1982
LICENSING & ENVIROMENTAL DEPT.

10

FEB 000
8-8-2
(IMP - SG)

SAN DIEGO GAS & ELECTRIC COMPANY
INTERNAL CORRESPONDENCE
15 6143C

FROM R. A. Rodriguez

TO J.F.P. Williams

DATE May 14, 1981

FILE NUMBER ADE 110
X-FEB 000

SUBJECT PCB Clean Up - Silver Gate

On April 7, 1981, Electric Construction and Maintenance (ECM) were notified by Brian Heramb, Safety Representative, that PCB fluid was leaking from transformers located at Silver Gate Power Plant. An ECM crew, consisting of Don Swinney and others, soon met with Heramb and Don Darbonne, Silver Gate Foreman.

The transformer leaks were pointed out to the ECM crew at this time, but to date no action has been taken by ECM to clean up the spill and recommend necessary repairs.

I realize that verbal requests have a tendency to be forgotten, therefore, we will submit written requests to you when ECM personnel are needed to clean up and provide recommend procedures to stop PCB leaks in the future.

The attached request will serve as notice that four Silver Gate transformers are in need of servicing for PCB leakage.

R. A. Rodriguez

RAR : ac
Attachment

cc: WJVelte
JDDarbonne
BIHeramb
JEDietz ✓
AWHovland
GHConnelly

ECEIVED
San o Gas & Electric Company
MAY 14 1981

Ext.2088

SDG&E

INST. No. 700.S[illegible]
REV. NO.
ISSUE NO.
PAGE ____ OF ____

FROM: R A RODRIGUEZ
TO: J F P WILLIAMS

PLEASE SEND A CLEAN UP CREW TO SERVICE THE FIRST 4 TRANSFORMERS LISTED BELOW.

Attachment B-2 Silver Gate

Equipment Containing PCB's	Date	Inspected by	Comments/Corrective Action Taken
1) 01N Lighting transformer West. s/n 297[illegible]511	4/29/81	F. L. Stephenson	*1. MODERATE LEAK AT DRAIN VALVE, APPEARS TO BE FROM PACKING GLAND. 2. VERY SMALL LEAK AT SAMPLE VALVE.
2) 01S Lighting transformer West. s/n (2978782)	4/29/81	F. L. Stephenson	1. BOTH DRAIN VALVES SMALL TO MODERATE LEAKS 2. FILL VALVE SMALL LEAK. 3. SAMPLE VALVE MODERATE LEAK.
3) 01N Load transformer West. s/n (2978512)	4/29/81	F. L. Stephenson	1. SLIGHT LEAK AT DRAIN & FILL VALVE.
4) 01S Load transformer West. s/n 297[illegible]783	4/29/81	F. L. Stephenson	1. SAMPLE VALVE LEAKING RUNNING DOWN SIDE OF UNIT. 2. SMALL LEAK AT FILL VALVE PLUG. 3. SLIGHT LEAK AT DRAIN VALVE. 4. FLUID LEVEL IS LOW.
9) 03 Gen Neut. Gnd. transformer	4/29/81	F. L. Stephenson	CONDITIONS, NORMAL
10) 04 Gen Neut. Gnd. transformer	4/29/81	F. L. Stephenson	CONDITIONS, NORMAL.

* MODERATE LEAKS REQUIRE SERVICING WITHIN 2 BUSINESS DAYS FROM THE DATE THE LEAK IS OBSERVED.

FEB 000
8-f-2 (IMP

SDGE

INST. No.	700.9.0.0 4/29/81
REV. NO.	1
ISSUE NO.	
PAGE ____ OF ____	

Attachment B-2 Silver Gate

Equipment Containing PCB's	Date	Inspected by	Comments/Corrective Action Taken
1) #1N Lighting transformer West. s/n 2978511	4/29/81	F.L. Stephenson	1. MODERATE LEAK AT DRAIN VALUE, APPEARS TO BE FROM PACKING GLAND. 2. VERY SMALL LEAK AT SAMPLE VALUE.
2) #1S Lighting transformer West. s/n 2978512 (2978782)	4/29/81	F.L. Stephenson	1. BOTH DRAIN VALUES SMALL TO MODERATE LEAKS 2. FILL VALUE SMALL LEAK. 3. SAMPLE VALVE MODERATE LEAK.
3) #1N Load transformer West. s/n 2978782 (2978512)	4/29/81	F.L. Stephenson	1. SLIGHT LEAK AT DRAIN + FILL VALUE.
4) #1S Load transformer West. s/n 2978783	4/29/81	F.L. Stephenson	1. SAMPLE VALUE LEAKING, RUNNING DOWN SIDE OF UNIT. 2. SMALL LEAK AT FILL VALUE PLUG. 3. SLIGHT LEAK AT DRAIN VALUE. 4. FLUID LEVEL IS LOW.
~~5) #2N Lighting transformer~~			
~~6) #2S Lighting transformer~~			
~~7) #2N Load transformer~~			
~~8) #2S Load transformer~~			
9) #3 Gen Neut. Gnd. transformer	4/29/81	F.L. Stephenson	CONDITIONS, NORMAL
10) #4 Gen Neut. Gnd. transformer	4/29/81	F.L. Stephenson	CONDITIONS, NORMAL.

RECEIVED
San [illegible]go Gas & Electric Company
MAY 1 1981

SDGE

REV. NO. 1
ISSUE NO.
PAGE ____ OF ____

PCB 000
8-8-2 (SG

Attachment B-2 Silver Gate

Equipment Containing PCB's	Date	Inspected by	Comments/Corrective Action Taken
1) #1N Lighting transformer West. s/n 2978511	4/29/81	F.L. Stephenson	1. MODERATE LEAK AT DRAIN VALVE, APPEARS TO BE FROM PACKING GLAND. 2. VERY SMALL LEAK AT SAMPLE VALVE.
2) #1S Lighting transformer West. s/n 2978512 (2978782)	4/29/81	F.L. Stephenson	1. BOTH DRAIN VALVES SMALL TO MODERATE LEAKS 2. FILL VALVE SMALL LEAK. 3. SAMPLE VALVE MODERATE LEAK.
3) #1N Load transformer West. s/n 2978782 (2978512)	4/29/81	F.L. Stephenson	1. SLIGHT LEAK AT DRAIN + FILL VALVE.
4) #1S Load transformer West. s/n 2978783	4/29/81	F.L. Stephenson	1. SAMPLE VALVE LEAKING RUNNING DOWN SIDE OF UNIT. 2. SMALL LEAK AT FILL VALVE PLUG. 3. SLIGHT LEAK AT DRAIN VALVE. 4. FLUID LEVEL IS LOW.
~~5) #2N Lighting transformer~~ Delete			
~~6) #2S Lighting transformer~~			
~~7) #2N Load transformer~~			
~~8) #2S Load transformer~~			
9) #3 Gen Neut. Gnd. transformer	4/29/81	F.L. Stephenson	CONDITIONS, NORMAL
10) #4 Gen Neut. Gnd. transformer	4/29/81	F.L. Stephenson	CONDITIONS, NORMAL.

RECEIVED
San Diego Gas & Electric Company
JUL 28 1982
Licensing & Environmental Dept.

SAN DIEGO GAS & ELECTRIC

PCB TRANSFORMERS

Facility

Silver Gate Power Plant

	Equipment	Gallons	Weight Kg
1.	#1N Lighting transf. West. s/n 2978511	85	467.5
2.	#1S lighting transf. West. s/n 2978512	85	467.5
3.	#1N load transf. West. s/n 2978782	458	2519.
4.	#1S load transf. West. s/n 2978783	458	2519.
5.	#3 Gen Neut.Gnd. transf.	20	110.
6.	#4 Gen Neut. Gnd. transf.	20	110.

11

SDGE

San Diego Gas & Electric

FILE NO. FEB 000
8-F-2
(STA. B)

November 27, 1985

Fire Marshal
City of San Diego
1222 First Avenue
San Diego, CA 92101

Dear Sir:

SUBJECT: <u>PCB TRANSFORMER LOCATIONS REGISTRATION</u>

The Environmental Protection Agency (EPA) published amendments to the existing EPA Rule 40 CFR 761 concerning the use of Polychlorinated Biphenyls (PCB's) in the July 17, 1985, Federal Register. These amendments were in effect August 16, 1985, and require registration by December 1, 1985.

Rule 40 CFR 761.30(a)(1)(IV) requires the registration of all PCB transformers with the fire response personnel having primary jurisdiction. This letter is being provided to you for those PCB transformers owned by San Diego Gas & Electric Company in your areas of responsibility.

CENTRAL FILES COPY

POST OFFICE BOX 1831 • SAN DIEGO, CALIFORNIA 92112 • TELEPHONE: 619/696-2000

Redacted

SILVER GATE POWER PLANT

Silver Gate Power Plant is located at 1348 Sampson Street, San Diego.

There are thirty (~~30~~ 32) PCB transformers at this facility all containing PCB's with a concentration of 60% or greater.

Two (2) transformers are located within a reinforced concrete bunker at the south side of the power plant. PCB labels are posted on the southeast truck entry gates and at the entrance to the bunker. Two (2) transformers are located on the north side of the power plant adjacent to the north driveway. The northeast driveway gate is marked with a PCB label. Two (2) PCB transformers are located in the power plant, basement level, within steel mesh compartments. One is below the Unit 3 turbine, and the other is beneath the Unit 4 turbine. The compartments have locked steel gates to which a PCB label has been affixed.

Silver Gate Power Plant Substation is located north of the power plant building and is accessible only through a locked gate or the power plant. The substation has 26 small potential transformers (PCB) located overhead. Each transformer is PCB labelled. The northeast driveway gate is also marked with a PCB label.

In the event of a fire not reported by Silver Gate Power Plant personnel, notify the plant by calling the following number, 234-5469.

Redacted

In the event of a fire, notify San Diego Gas & Electric at 234-6234.

If you have any questions with regard to the above information, please call me at (619) 696-2512.

Sincerely,

Joseph F Dietz

Joseph F. Dietz
Environmental Advisor

JFD:mel

bcc: LJBrunton
WJVelte
LCSiebrand
ANStewart

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INSPECTION REPORT
U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION 9
TOXICS AND WASTE MANAGEMENT DIVISION
FIELD OPERATIONS BRANCH

Purpose:	TSCA §6 PCB Investigation
Facility:	San Diego Gas & Electric Silvergate Power Plant 1348 Sampson Street San Diego, CA 92113
EPA ID Number:	CAT000618934
Report Number:	T(87)F043
Dates of Investigation:	5 February 1987
EPA Investigators:	Ayn Schmit Field Investigator William Weis Field Investigator
State Representatives:	Clarence Berman Hazardous Waste Specialist Bill Mortensen Hazardous Waste Specialist
Facility Representatives:	Kathy Nolan Senior Environmental Analyst Bob Bjordal Acting Senior Operations Supervisor
Report Prepared By:	Ayn Schmit
Report Date:	27 April 1987

§761.30, §761.40, and §761.60 USE CONDITIONS
PCB/PCB Contaminated Transformers in Use or Storage for Reuse

							§761.60 (d)(1)			§761.30 (a)(viii)	§761.40 (c)(1)	§761.40 (j)
REF. NO.	PHOTO NUMBERS	TRANSFORMER LOCATION	TRANSFORMER MANUFACTURER	SERIAL NUMBER	FLUID TYPE	FLUID VOLUME	DOES TRANSFORMER HAVE:		IF SPILL EST. SIZE OF SPILL AREA?	STORED COMBUSTIBLES IN AREA?	M_L?	M_L ON ENTRY?
							LEAKS?	SPILLS?				
1	1	Silvergate Gen. 4 Neutral Ground	Unknown	Unknown	Unknown	Unknwn	---Unknown---- (see photo)		N/A	N	Y	Y
2	2-5	Silvergate South Load	Westinghouse	2978783	Inerteen	458gal	Y	Y	< 1 pt.	N	Y	Y
3	6-8	Silvergate South Lighting	Westinghouse	2978512	Inerteen	85 gal	Y	Y	< 1 pt.	N	Y	Y
4	9-10	Silvergate North Lighting	Westinghouse	2978511	Inerteen	85 gal	Y	N	N/A	N	Y	Y
5	11-14	Silvergate North Load	Westinghouse	2978782	Inerteen	458gal	Y	Y	< 1 pt.	N	Y	Y

COMMENTS: There was 1 other PCB transformer at Silvergate Power Plant (the Gen. 3 Neutral Ground transformer). There were no apparent deficiencies associated with this transformer.

INVESTIGATION NUMBER T (8 7) E 0 4 3

POTENTIAL VIOLATIONS

SUBPART B

§761.60(d)(1)	Fluid leaking from 5 of the 6 PCB transformers at the Silvergate Power Plant constitutes the unauthorized disposal of PCBs.

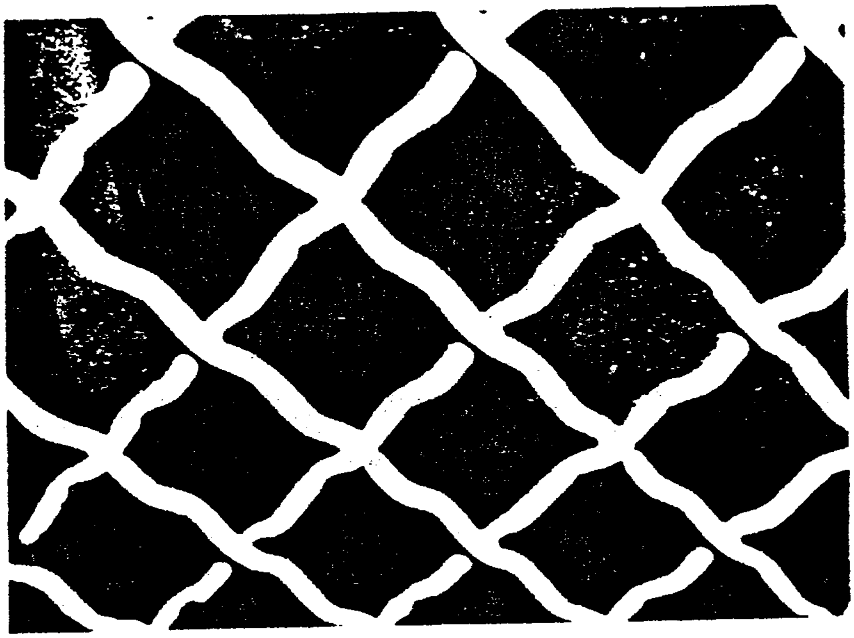


PHOTO NUMBEP: 1

SI"TE: SDG&F Silvergate PP DATE: 2/5/87

DESCRIPTION: View through cage at Generator 4 Neutral Ground transformer (at right). Note drip pan with sorbent placed beneath main drain tap/valve.

PHOTOG: Weis

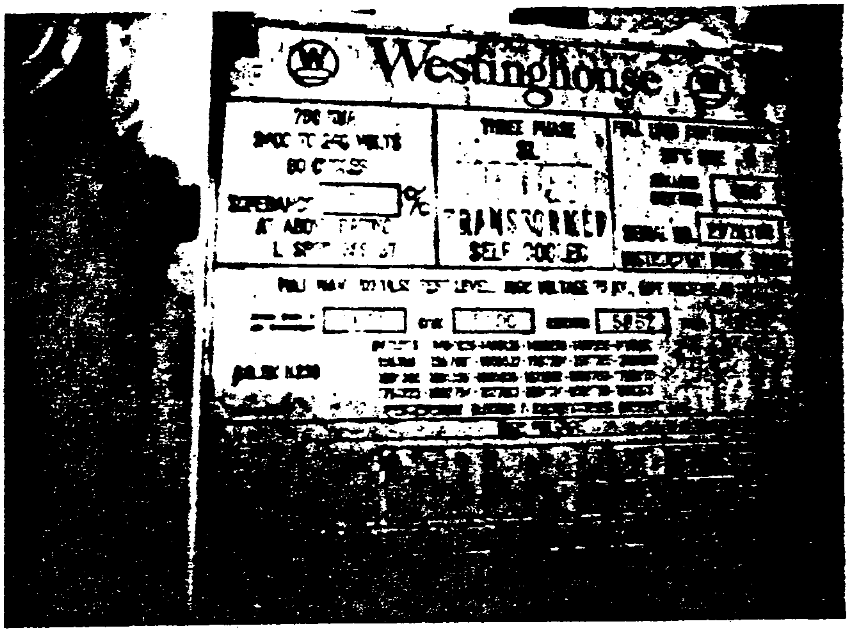


PHOTO NUMBER: 2

SITE: SDG&E Silvergate PP DATE: 2/5/87

DESCRIPTION: View of nameplate for South Load transformer.

PHOTOG: Weis

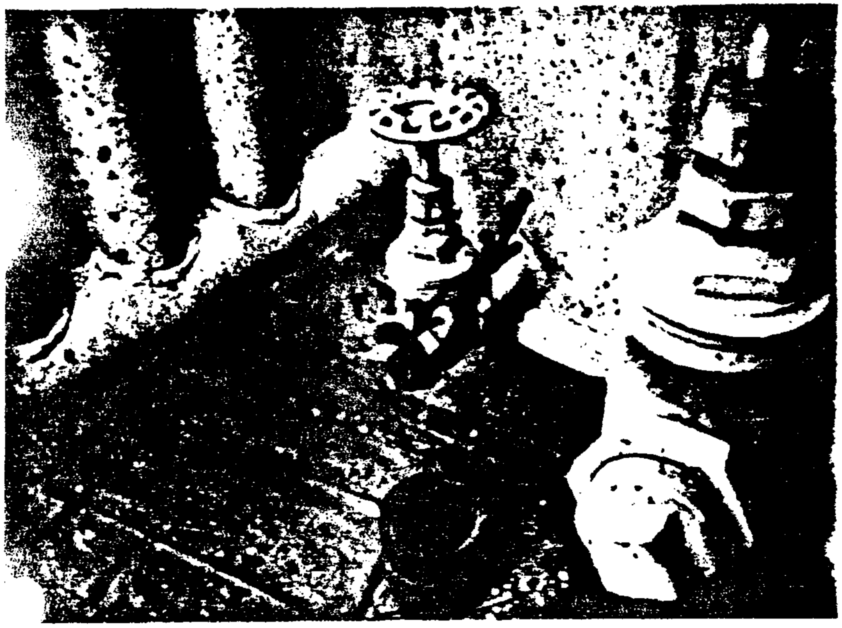


PHOTO NUMBER: 3-4

SITE: SDG&E Silvergate PP DATE: 2/5/87

DESCRIPTION: View of main and secondary drain tap/valves on South Load transformer. Note leaks at threads and on stem of secondary valve, and dark oily material in can beneath valve. Also note leaked material on main valve stem at weld to transformer body.

PHOTOG: Weis

PHOTO NUMBER: 5

SITE: SDG&E Silvergate PP DATE: 2/5/87

DESCRIPTION: Leak at sample tap on South Load transformer.

PHOTOG: Weis

PHOTO NUMBER: 6

SITE: SDG&E Silvergate PP DATE: 2/5/87

DESCRIPTION: View of nameplate for South Lighting transformer.

PHOTOG: Weis

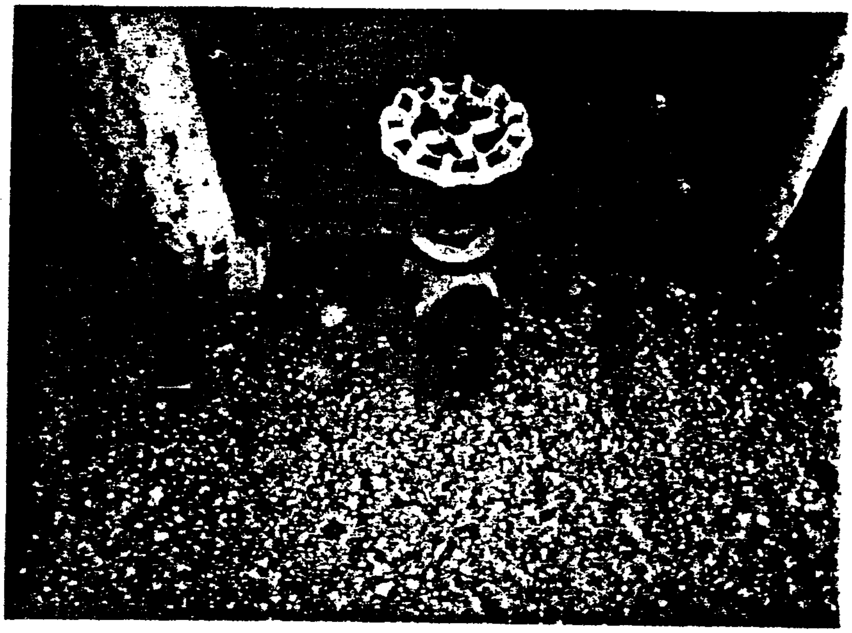


PHOTO NUMBER: 7-8

SITE: SDG&E Silvergate PP DATE: 2/5/87

DESCRIPTION: View of leaking valves on South Lighting transformer. Upper photo depicts main drain tap/valve, while bottom photo shows raised secondary drain tap/valve on corner of transformer.

PHOTOG: Weis

PHOTO NUMBER: 9

SITE: SDG&E Silvergate PP DATE: 2/5/87

DESCRIPTION: View of nameplate for North Lighting transformer.

PHOTOG: Weis

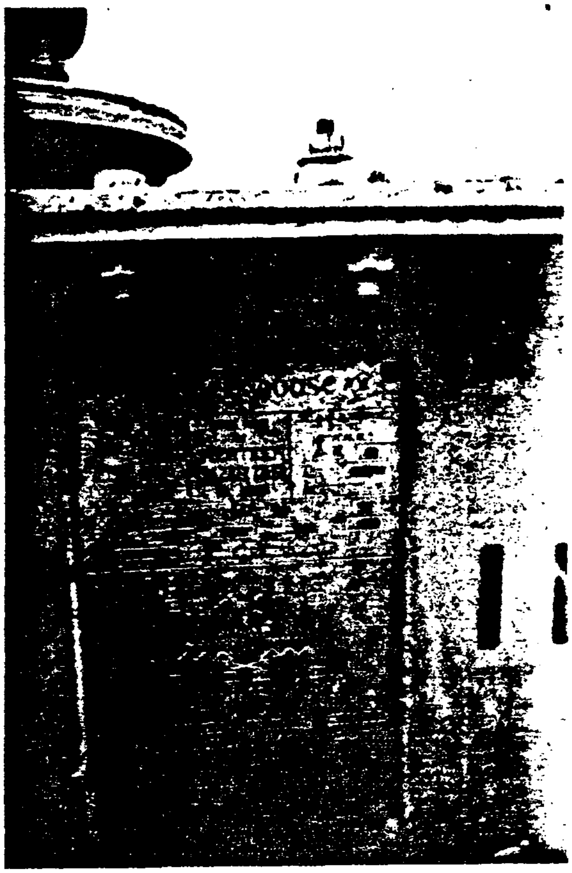


PHOTO NUMBER: 10

SITE: SDG&E Silvergate PP DATE: 2/5/87

DESCRIPTION: Leaks from main drain tap/ valve on North Lighting transformer. Note second leak from stem onto base of transformer behind valve.

PHOTOG: Weis

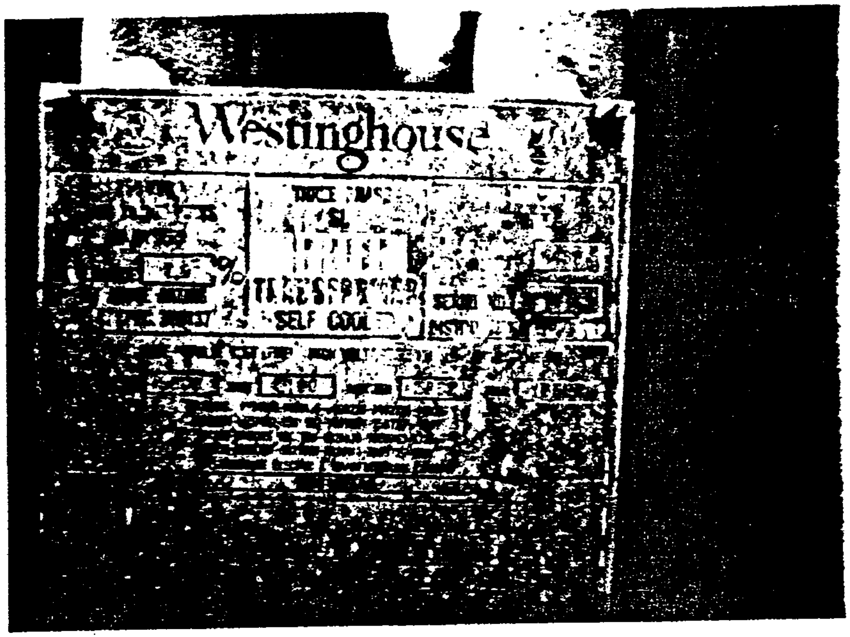


PHOTO NUMBER: 11

SITE: SDG&E Silvergate PP DATE: 2/5/87

DESCRIPTION: View of nameplate for North Load transformer.

PHOTOG: Weis

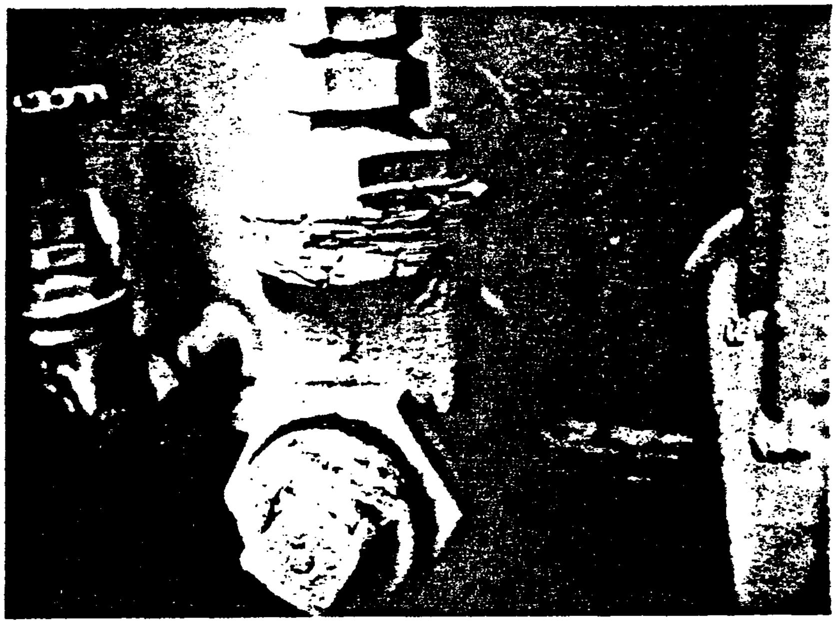


PHOTO NUMBER: 12

SITE: SDG&E Silvergate PP DATE: 2/5/87

DESCRIPTION: Leaks from main drain tap/ valve on North Load transformer.

PHOTOG: Weis

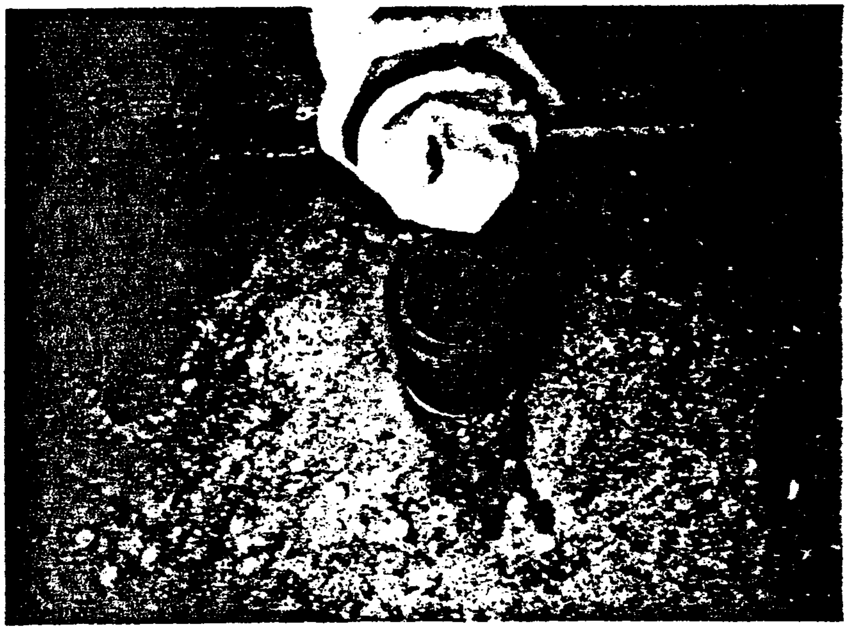
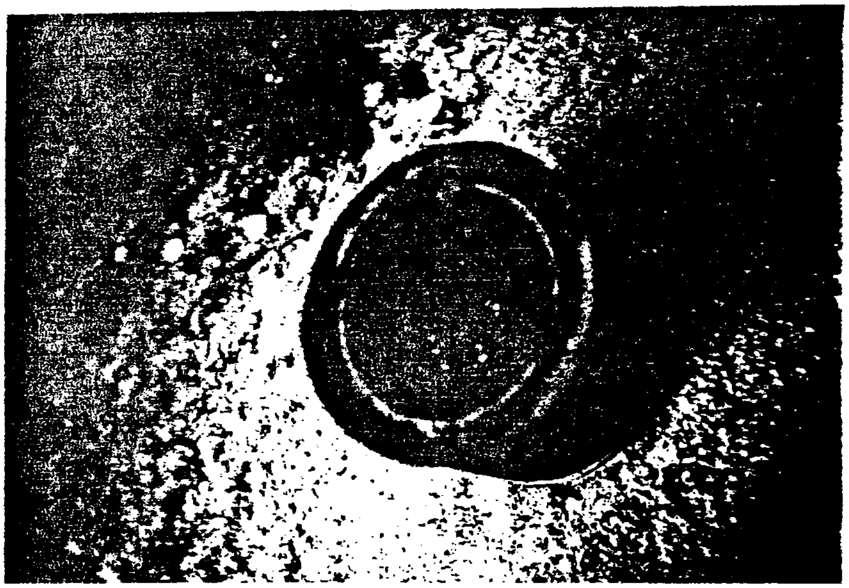


PHOTO NUMBER: 13-14

SITE: SDG&E Silvergate PP DATE: 2/5/87

DESCRIPTION: Can receiving spilled fluid from main drain tap of North Load transformer (shown in Photo #12). Note fresh material in can, indicating that leak is active.

PHOTOG: Weis



§761.65 STORAGE FOR DISPOSAL
PCBs AND PCB ITEMS > 50 ppm

	YES	NO	N.A.	
§761.65				
(a)		X		All PCB Articles or Containers placed in storage for disposal after 1/1/83 were disposed of within 1 year from the date they were first placed into storage.
§761.65(b)(1)				The storage for disposal area met the following criteria:
(i)		X		Adequate roof and walls to prevent rain water from reaching stored PCBs/PCB Items.
(ii)		X		Adequate floor with a minimum 6 inch high continuous curb, providing a containment volume of at least twice the internal volume of the largest Article/Container stored therein, or 25% of the total internal volume of all Articles/Containers stored therein, whichever is greater.
(iii)		X		No floor openings of any kind that would permit liquids to flow from the curbed area.
(iv)		X		Floors and curbing constructed of smooth and impervious materials.
(v)	X			Not located at a site that is below the 100-year flood water elevation.
§761.65(c)				
(3)	X			The storage area was marked with M_L.
(4)	X			All contaminated moveable equipment used for handling stored PCBs/PCB Items was kept within the PCB storage area.
(5)	X			The facility inspects all stored PCB Articles/Containers for leaks at least once every 30 days.
(5)		X		All leaking PCB Articles/Containers were immediately transferred to marked (M_L) non-leaking containers.
(5)		X		Spilled or leaked materials were immediately cleaned up.
(8)		X		Facility had noted on all PCB Articles and Containers the date when each Item was placed into storage.
(8)		X		PCB Articles and Containers were managed so that they could be located by the date they were placed into storage.

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LOCATION	EQUIPNUM	DESIG	LastOfSAMPLE	APPRTYPE	PCB	PCBSTATUS
SAMPSON 12-S12	980159	BK1N	03/04/1996	TRN	1.7	1
SAMPSON 12-S12	980163	BK1S	03/04/1996	TRN	1.6	1
SAMPSON 12-S12	985315	CIR 70	02/29/1996	OCB	0	
SAMPSON 12-S12	985315	CIR 70	02/29/1996	OCB	0	
SAMPSON 12-S12	985315	CIR 70	02/29/1996	OCB	0	
SAMPSON 12-S12	985316	CIR 80	03/04/1996	OCB	0	
SAMPSON 12-S12	985316	CIR 80	03/04/1996	OCB	0	
SAMPSON 12-S12	985316	CIR 80	03/04/1996	OCB	0	
SAMPSON 12-S12	985317	CIR 122	02/29/1996	OCB	0	
SAMPSON 12-S12	985317	CIR 122	02/29/1996	OCB	0	
SAMPSON 12-S12	985317	CIR 122	02/29/1996	OCB	0	
SAMPSON 12-S12	985319	CIR 370	02/29/1996	OCB	0	
SAMPSON 12-S12	985319	CIR 370	02/29/1996	OCB	0	
SAMPSON 12-S12	985319	CIR 370	02/29/1996	OCB	0	
SAMPSON 12-S12	985320	CIR 129	02/29/1996	OCB	0	
SAMPSON 12-S12	985320	CIR 129	02/29/1996	OCB	0	
SAMPSON 12-S12	985320	CIR 129	02/29/1996	OCB	0	
SAMPSON 12-S12	985321	CIR 130	03/04/1996	OCB	0	
SAMPSON 12-S12	985321	CIR 130	03/04/1996	OCB	0	
SAMPSON 12-S12	985321	CIR 130	03/04/1996	OCB	0	
SAMPSON 12-S12	985322	CIR 131	02/29/1996	OCB	0	
SAMPSON 12-S12	985322	CIR 131	02/29/1996	OCB	0	
SAMPSON 12-S12	985324	CIR 133	03/04/1996	OCB	0	
SAMPSON 12-S12	985324	CIR 133	03/04/1996	OCB	0	
SAMPSON 12-S12	985324	CIR 133	03/04/1996	OCB	0	
SAMPSON 12-S12	985325	TRFR	03/04/1996	OCB	0	
SAMPSON 12-S12	985325	TRFR	03/04/1996	OCB	0	
SAMPSON 12-S12	985325	TRFR	03/04/1996	OCB	1	
SAMPSON 12-S12	985326	3103	02/29/1996	OCB	0	
SAMPSON 12-S12	985326	3103	02/29/1996	OCB	0	
SAMPSON 12-S12	985326	3103	02/29/1996	OCB	0	
SAMPSON 12-S12	985327	3203	02/29/1996	OCB	0	
SAMPSON 12-S12	985327	3203	02/29/1996	OCB	0	
SAMPSON 12-S12	985327	3203	02/29/1996	OCB	1.5	
SAMPSON 12-S12	985328	BK 10	02/29/1996	OCB	0	
SAMPSON 12-S12	985328	BK 10	02/29/1996	OCB	0	
SAMPSON 12-S12	985328	BK 10	02/29/1996	OCB	0	
SAMPSON 12-S12	985637	BT	02/29/1996	OCB	0	
SAMPSON 12-S12	985637	BT	02/29/1996	OCB	0	
SAMPSON 12-S12	985637	BT	02/29/1996	OCB	0	
SAMPSON 12-S12	985812	CIR 132	02/29/1996	OCB	0	
SAMPSON 12-S12	985812	CIR 132	02/29/1996	OCB	0	
SAMPSON 12-S12	985812	CIR 132	02/29/1996	OCB	0	
SAMPSON 12-S12	986000	CIR 371	03/04/1996	OCB	0	
SAMPSON 12-S12	986283	CIR 128	02/29/1996	OCB	0	
SAMPSON 12-S12	986638	3001	02/29/1996	OCB	0	
SAMPSON 12-S12	986638	3001	02/29/1996	OCB	0	
SAMPSON 12-S12	986638	3001	02/29/1996	OCB	0	
SAMPSON 12-S12	986642	3021	02/29/1996	OCB	0	
SAMPSON 12-S12	986642	3021	02/29/1996	OCB	0	
SAMPSON 12-S12	986642	3021	02/29/1996	OCB	0	
SAMPSON 12-S12	986644	3302	02/13/1996	OCB	0	
SAMPSON 12-S12	986646	3018	02/29/1996	OCB	0	

qTOA_Sampson12_LastDate 11/03/2004

LOCATION	EQUIPNUM	DESIG	LastOfSAMPLE	APPRTYPE	PCB	PCBSTATUS
SAMPSON 12-S12	986646	3018	02/29/1996	OCB	0	
SAMPSON 12-S12	986646	3018	02/29/1996	OCB	0	
SAMPSON 12-S12	986650	3001	03/04/1996	OCB	0	
SAMPSON 12-S12	986650	3001	03/04/1996	OCB	0	
SAMPSON 12-S12	986650	3001	03/04/1996	OCB	0	
SAMPSON 12-S12	[redacted]	CIR S4	03/15/2003	SREG RFS	Not in 0	Sub, 1
SAMPSON 12-S12	989139	CIR S4	03/15/2003	SREG		0
SAMPSON 12-S12	989152	CIR S2	03/15/2003	SREG	0	1
SAMPSON 12-S12	989152	CIR S2	03/15/2003	SREG	6.9	1
SAMPSON 12-S12	989153	CIR S3	03/15/2003	SREG	3	1
SAMPSON 12-S12	989153	CIR S3	03/15/2003	SREG	0	1
SAMPSON 12-S12	989154	CIR S1	06/15/2004	SREG	2.7	
SAMPSON 12-S12	989154	CIR S1	06/15/2004	SREG RFS	Not in 1.1	Sub
SAMPSON 12-S12	[redacted]	[redacted]	03/15/2003	SREG	1.7	1
SAMPSON 12-S12	[redacted]	[redacted]	03/15/2003	SREG	1.1	1
SAMPSON 12-S12	[redacted]	[redacted]	03/15/2003	SREG	0	1
SAMPSON 12-S12	[redacted]	[redacted]	03/15/2003	SREG	0	1
SAMPSON 12-S12	[redacted]	[redacted]	03/15/2003	SREG	0	1
SAMPSON 12-S12	[redacted]	[redacted]	03/15/2003	SREG	0	1
SAMPSON 69-S69	980221	BK 3-N	01/22/2003	TRN	0	1
SAMPSON 69-S69	980222	BK 3S	01/22/2003	TRN	2.5	1
SAMPSON 69-S69	980297	BK 4S	01/22/2003	TRN	0	1
SAMPSON 69-S69	980298	BK 4N	01/22/2003	TRN	0	1
SAMPSON 69-S69	980364		03/11/2003	TRN	24	1
SAMPSON 69-S69	980365		03/16/2002	TRN	30	1
SAMPSON 69-S69	985827	OCB 5	03/04/1996	OCB	0	
SAMPSON 69-S69	985827	OCB 5	03/04/1996	OCB	0	
SAMPSON 69-S69	985827	OCB 5	03/04/1996	OCB	0	
SAMPSON 69-S69	985853	OCB 8	03/04/1996	OCB	0	
SAMPSON 69-S69	985853	OCB 8	03/04/1996	OCB	0	
SAMPSON 69-S69	985853	OCB 8	03/04/1996	OCB	0	
SAMPSON 69-S69	985864	OCB 1	03/04/1996	OCB	0	
SAMPSON 69-S69	985864	OCB 1.	03/04/1996	OCB	0	
SAMPSON 69-S69	985864	OCB 1	03/04/1996	OCB	0	
SAMPSON 69-S69	985867	OCB 12	03/04/1996	OCB	0	
SAMPSON 69-S69	985867	OCB 12	03/04/1996	OCB	0	
SAMPSON 69-S69	985867	OCB 12	03/04/1996	OCB	0	
SAMPSON 69-S69	985869	OCB 6	03/04/1996	OCB	0	
SAMPSON 69-S69	985869	OCB 6	03/04/1996	OCB	0	
SAMPSON 69-S69	985869	OCB 6	03/04/1996	OCB	0	
SAMPSON 69-S69	985870	OCB 3	03/04/1996	OCB	0	
SAMPSON 69-S69	985870	OCB 3	03/04/1996	OCB	0	
SAMPSON 69-S69	985870	OCB 3	03/04/1996	OCB	0	
SAMPSON 69-S69	985871	OCB 7	03/04/1996	OCB	0	
SAMPSON 69-S69	985871	OCB 7	03/04/1996	OCB	0	
SAMPSON 69-S69	985871	OCB 7	03/04/1996	OCB	0	
SAMPSON 69-S69	985872	OCB 10	03/04/1996	OCB	0	
SAMPSON 69-S69	985872	OCB 10	03/04/1996	OCB	0	
SAMPSON 69-S69	985872	OCB 10	03/04/1996	OCB	0	
SAMPSON -S	980806	BK 30	08/23/2004	TRN NEW BK	0	

Fluid Quality History

SAMPSON 12-S12 BK 1N (980159 TRN)

Equipment ID	980159	Manufacturer	Westinghouse	Owner	SDG&E
Apparatus Type	TRN	Serial No	3778347	Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	BK 1N
Fluid Cap.	5453 US Gal	Model/Type	UNR	Description	TRANSFORMER
Analysis Rules	OILTRN	kV Rating	69000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks	enterprise_id	
MAIN (IEEE)	1			SDGE		03/04/1996		9603004-22a		SUE CAMPBELL		03/14/1996					OILTRN TO 69	
1	1								1.7									
														11/16/1999			-9999849	
MAIN (IEEE)	1					02/29/1996		9603004-23A						SUE CAMPBELL			OILTRN TO 69	
1	1								3.4									
														11/19/1999			-9999849	

Fluid Quality History

SAMPSON 12-S12 BK 1S (980163 TRN)

Equipment ID	980163	Manufacturer	Westinghouse	Owner	SDG&E
Apparatus Type	TRN	Serial No	3778351	Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	BK 1S
Fluid Cap.	5453 US Gal	Model/Type	UNR	Description	TRANSFORMER
Analysis Rules	OILTRN	kV Rating	69000	Preservation	
		MVA Rating		Cooling	

Tank F Al	P Ca	No Acid Cu	IFT Fe	Lab D877 Pb	D1816 Li	Date PF25 Ni	PF100 Si	Lab Ref Water Ag	PCB Na	Sampler Inhib Sn	SG Zn	Lab Date Visual Pour Pt	Visc	Reason Color Rec Date	Fire Pt	Temp C Flash Pt Remarks	Std Sulfur	Furan enterprise_id
LTC COMP (IEEE)		1				02/29/1996		9603004-13A						SUE CAMPBELL			OILTRN TO 69	
1	1								1.7									
														11/19/1999				-9999849
MAIN (IEEE)		1		SDGE		03/04/1996		9603004-11a		SUE CAMPBELL		03/14/1996					OILTRN TO 69	
1	1								1.6									
														11/16/1999				-9999849
MAIN (IEEE)		1				02/29/1996		9603004-12A						SUE CAMPBELL			OILTRN TO 69	
1	1								1.5									
														11/19/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR 70 (985315 OCB)

Equipment ID	985315	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	CIR 70
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No		Lab			Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
TANK 1	1		SDGE			02/29/1996		9602168-19a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2	1		SDGE			02/29/1996		9602168-20a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 3	1		SDGE			02/29/1996		9602168 21a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR 80 (985316 OCB)

Equipment ID	985316	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	CIR 80
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
TANK 1	1			SDGE		03/04/1996		9603004-17a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2	1			SDGE		03/04/1996		9603004-18a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 3	1			SDGE		03/04/1996		9603004-19a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849

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Fluid Quality History

SAMPSON 12-S12 CIR 370 (985319 OCB)

Equipment ID	985319	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	CIR 370
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank			No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
	F	P		Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
	Al	Ca		Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
TANK 1			1			SDGE		02/29/1996		9602168-22a				03/14/1996					OILCB (IEEE)	
											0									
																11/16/1999				-9999849
TANK 2			1			SDGE		02/29/1996		9602168-23a				03/14/1996					OILCB (IEEE)	
											0									
																11/16/1999				-9999849
TANK 3			1			SDGE		02/29/1996		9602168-24a				03/14/1996					OILCB (IEEE)	
											0									
																11/16/1999				-9999849

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Fluid Quality History

SAMPSON 12-S12 CIR 129 (985320 OCB)

Equipment ID	985320	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	CIR 129
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank F Al	No P Ca	Acid Cu	IFT Fe	Lab D877 Pb	D1816 Li	Date PF25 Ni	PF100 Si	Lab Ref Water Ag	PCB Na	Sampler Inhib Sn	SG Zn	Lab Date Visual Pour Pt	Visc	Reason Color Rec Date	Fire Pt	Temp C Flash Pt Remarks	Std Sulfur	Furan enterprise_id
TANK 1	1			SDGE		02/29/1996		9602168-25a				03/14/1996					OILCB	(IEEE)
									0									
														11/16/1999				-9999849
TANK 2	1			SDGE		02/29/1996		9602168-26a				03/14/1996					OILCB	(IEEE)
									0									
														11/16/1999				-9999849
TANK 3	1			SDGE		02/29/1996		9602168-27a				03/14/1996					OILCB	(IEEE)
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR 130 (985321 OCB)

Equipment ID	985321	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	CIR 130
Fluid Cap.	315 US Gal	Model/Type	RFA2-TV-2H	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
TANK 1	1			SDGE		03/04/1996		9603004-02a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2	1			SDGE		03/04/1996		9603004-03a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 3	1			SDGE		03/04/1996		9603004-04a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849

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Fluid Quality History

SAMPSON 12-S12 CIR 131 (985322 OCB)

Equipment ID	985322	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	CIR 131
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
TANK 1	2			SDGE		05/17/1996		9605092-02a		JTQ		05/31/1996					OILCB	(IEEE)
									0									
														11/16/1999				-9999849
TANK 1	1			SDGE		03/04/1996		9603004-20a		SUE CAMPBELL		03/14/1996					OILCB	(IEEE)
									0									
														11/16/1999				-9999849
TANK 2	4			SDGE		05/17/1996		9605092-03a		JTQ		05/31/1996					OILCB	(IEEE)
									0									
														11/16/1999				-9999849
TANK 2	3			SDGE		02/29/1996		9602168-41a				03/14/1996					OILCB	(IEEE)
									0									
														11/16/1999				-9999849
TANK 3	1			SDGE		02/29/1996		9602168-42a				03/14/1996					OILCB	(IEEE)
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR 133 (985324 OCB)

Equipment ID	985324	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	CIR 133
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank F Al	 P Ca	No Acid Cu	 IFT Fe	Lab D877 Pb	 D1816 Li	Date PF25 Ni	 PF100 Si	Lab Ref Water Ag	 PCB Na	Sampler Inhib Sn	 SG Zn	Lab Date Visual Pour Pt	 Visc	Reason Color Rec Date	 Fire Pt 	Temp C Flash Pt Remarks	Std Sulfur 	 Furan enterprise_id
TANK 1		1		SDGE		03/04/1996		9603004-14a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2		1		SDGE		03/04/1996		9603004-15a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 3		1		SDGE		03/04/1996		9603004-16a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849

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Fluid Quality History

SAMPSON 12-S12 TRFR (985325 OCB)

Equipment ID	985325	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	TRFR
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank F Al	No P Ca	Acid Cu	IFT Fe	Lab D877 Pb	D1816 Li	Date PF25 Ni	PF100 Si	Lab Ref Water Ag	PCB Na	Sampler Inhib Sn	SG Zn	Lab Date Visual Pour Pt	Visc	Reason Color Rec Date	Fire Pt	Temp C Flash Pt Remarks	Std Sulfur	Furan enterprise_id
TANK 1	1			SDGE		03/04/1996		9603004-05a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2	1			SDGE		03/04/1996		9603004-06a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									1									
														11/16/1999				-9999849
TANK 3	1			SDGE		03/04/1996		9603004-07a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 3103 (985326 OCB)

Equipment ID	985326	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	3103
Fluid Cap.	400 US Gal	Model/Type	15-RFA2-H	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	F Al	No P Ca	Acid Cu	IFT Fe	Lab D877 Pb	D1816 Li	Date PF25 Ni	PF100 Si	Lab Ref Water Ag	PCB Na	Sampler Inhib Sn	SG Zn	Lab Date Visual Pour Pt	Visc	Reason Color Rec Date	Fire Pt	Temp C Flash Pt Remarks	Std Sulfur	Furan enterprise_id
TANK 1		1			SDGE		02/29/1996		9602168-37a				03/14/1996					OILCB (IEEE)	
										0									
															11/16/1999				-9999849
TANK 2		1			SDGE		02/29/1996		9602168-38a				03/14/1996					OILCB (IEEE)	
										0									
															11/16/1999				-9999849
TANK 3		1			SDGE		02/29/1996		9602168-39a				03/14/1996					OILCB (IEEE)	
										0									
															11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 3203 (985327 OCB)

Equipment ID	985327	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	3203
Fluid Cap.	400 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
TANK 1	1			SDGE		02/29/1996		9602168-07a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2	1			SDGE		02/29/1996		9602168-08a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 3	1			SDGE		02/29/1996		9602168-09a				03/14/1996					OILCB (IEEE)	
									1.5									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 BK 10 (985328 OCB)

Equipment ID	985328	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	BK 10
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
TANK 1	1			SDGE		02/29/1996		9602168-01a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2	1			SDGE		02/29/1996		9602168-02a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 3	1			SDGE		02/29/1996		9602168-03a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 BT (985637 OCB)

Equipment ID	985637	Manufacturer	Westinghouse	Owner	SDG&E
Apparatus Type	OCB	Serial No	32Y3437	Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1954	Designation	BT
Fluid Cap.	45 US Gal	Model/Type	14.4-GC-1500	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
TANK 1	1			SDGE		02/29/1996		9602168-04a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2	1			SDGE		02/29/1996		9602168-05a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 3	1			SDGE		02/29/1996		9602168-06a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR 132 (985812 OCB)

Equipment ID	985812	Manufacturer	Allis-Chalme	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1959	Designation	CIR 132
Fluid Cap.	235 US Gal	Model/Type	FZO-15-1000	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
TANK 1	1			SDGE		02/29/1996		9602168-31a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2	1			SDGE		02/29/1996		9602168-32a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 3	1			SDGE		02/29/1996		9602168-33a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR 371 (986000 OCB)

Equipment ID	986000	Manufacturer	I.T.E.	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1964	Designation	CIR 371
Fluid Cap.	76 US Gal	Model/Type	14KS-500-12D	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank		No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std		
	F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt		Sulfur	Furan
	Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks			enterprise_id
MAIN		1			SDGE		03/04/1996		9603004-21a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)		
										0										
															11/16/1999					-9999849

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Fluid Quality History

SAMPSON 12-S12 CIR 128 (986283 OCB)

Equipment ID	986283	Manufacturer	I.T.E.	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1972	Designation	CIR 128
Fluid Cap.	76 US Gal	Model/Type	14KS-500-12D	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank			No	Lab			Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
	F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
	Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
MAIN			1	SDGE			02/29/1996		9602168-40a				03/14/1996					OILCB (IEEE)	
										0									
															11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 3001 (986638 OCB)

Equipment ID	986638	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	3001
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
TANK 1	1			SDGE		02/29/1996		9602168-16a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2	1			SDGE		02/29/1996		9602168-17a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 3	1			SDGE		02/29/1996		9602168-18a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 3021 (986642 OCB)

Equipment ID	986642	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	3021
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-H	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
TANK 1	1			SDGE		02/29/1996		9602168-34a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2	1			SDGE		02/29/1996		9602168-35a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 3	1			SDGE		02/29/1996		9602168-36a				03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 3302 (986644 OCB)

Equipment ID	986644	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	3302
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-H	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank		No		Lab			Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
	F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
	Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
MAIN		1		SDGE			02/13/1996		9602049-07a		SUE CAMPBELL		02/20/1996					OILCB (IEEE)	
										0									
															11/16/1999				-9999849

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Fluid Quality History

SAMPSON 12-S12 3018 (986646 OCB)

Equipment ID	986646	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	3018
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No	Lab	Date	Lab Ref	Sampler	Lab Date	Reason	Temp C	Std	F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual	Color	Fire Pt	Flash Pt	Sulfur	Furan	Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date	Remarks	enterprise_id
TANK 1	1	SDGE	02/29/1996	9602168-13a		03/14/1996			OILCB (IEEE)										0																							11/16/1999		-9999849
TANK 2	1	SDGE	02/29/1996	9602168-14a		03/14/1996			OILCB (IEEE)										0																							11/16/1999		-9999849
TANK 3	1	SDGE	02/29/1996	9602168-15a		03/14/1996			OILCB (IEEE)										0																							11/16/1999		-9999849

Fluid Quality History

SAMPSON 12-S12 3001 (986650 OCB)

Equipment ID	986650	Manufacturer	Kelman	Owner	SDG&E
Apparatus Type	OCB	Serial No		Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg	1947	Designation	3001
Fluid Cap.	315 US Gal	Model/Type	15-RFA2-F	Description	BREAKER
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank F Al	No P Ca	Acid Cu	IFT Fe	Lab D877 Pb	D1816 Li	Date PF25 Ni	PF100 Si	Lab Ref Water Ag	PCB Na	Sampler Inhib Sn	SG Zn	Lab Date Visual Pour Pt	Visc	Reason Color Rec Date	Fire Pt	Temp C Flash Pt Remarks	Std Sulfur	Furan enterprise_id
TANK 1	1			SDGE		03/04/1996		9603004-08a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 2	1			SDGE		03/04/1996		9603004-09a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849
TANK 3	1			SDGE		03/04/1996		9603004-10a		SUE CAMPBELL		03/14/1996					OILCB (IEEE)	
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR S4 (989139 SREG)

Equipment ID	989139	Manufacturer	Westinghouse	Owner	SDG&E
Apparatus Type	SREG	Serial No	2981093	Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg		Designation	CIR S4
Fluid Cap.		Model/Type		Description	
Analysis Rules	OILCB	kV Rating	4000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
LTC COMP (IEEE)	3			SDGE		03/15/2003		0303102-08		Lozano, Ray		03/28/2003		AL DAVIDSON			OILTRN 345 UP	
2	1	.061	20.8	32				30	0					1.8				
														03/31/2003				-9999849
LTC COMP	1			SDGE		03/04/1996		9603004-35a		SUE CAMPBELL		03/14/1996						
									0									
														11/16/1999				-9999849
MAIN (IEEE)	2			SDGE		03/15/2003		0303102-07		Lozano, Ray		03/28/2003		AL DAVIDSON		25	OILTRN 345 UP	
1	0																	
														03/31/2003				-9999849
MAIN	1					08/26/1999		9908148-06A						AL DAVIDSON				
									0									
														11/19/1999				-9999849
MAIN	1			SDGE		03/04/1996		9603004-34a		SUE CAMPBELL		03/14/1996						
									2.6									
														11/16/1999				-9999849

Report Date 11/03/2004

Transformer Oil Analyst 3.3

Fluid Quality History

SAMPSON 12-S12 CIR S2 (989152 SREG)

Equipment ID	989152	Manufacturer	Westinghouse	Owner	SDG&E
Apparatus Type	SREG	Serial No	3012098	Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg		Designation	CIR S2
Fluid Cap.		Model/Type		Description	
Analysis Rules	OILCB	kV Rating	4000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
LTC COMP (IEEE)	3			SDGE		03/15/2003		0303102-04		Lozano, Ray		03/28/2003		AL DAVIDSON			OILTRN 345 UP	
2	1	.18	19.7	34				29	6.9					2				
														03/28/2003				-9999849
LTC COMP	1			SDGE		03/04/1996		9603004-37a		SUE CAMPBELL		03/14/1996						
									2.6									
														11/16/1999				-9999849
MAIN (IEEE)	2			SDGE		03/15/2003		0303102-03		Lozano, Ray		03/28/2003		AL DAVIDSON		24	OILTRN 345 UP	
2	1	.17	18.3	24				25	0					1.6				
														03/28/2003				-9999849
MAIN	1					08/26/1999		9908148-04A						AL DAVIDSON				
									5.1									
														11/19/1999				-9999849
MAIN	1			SDGE		03/04/1996		9603004-36a		SUE CAMPBELL		03/14/1996						
									1.2									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR S3 (989153 SREG)

Equipment ID	989153	Manufacturer	Westinghouse	Owner	SDG&E
Apparatus Type	SREG	Serial No	3012099	Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg		Designation	CIR S3
Fluid Cap.		Model/Type		Description	
Analysis Rules	OILCB	kV Rating	4000	Preservation	
		MVA Rating		Cooling	

Tank F Al	No P Ca	Acid Cu	IFT Fe	Lab D877 Pb	D1816 Li	Date PF25 Ni	PF100 Si	Lab Ref Water Ag	PCB Na	Sampler Inhib Sn	SG Zn	Lab Date Visual Pour Pt	Visc	Reason Color Rec Date	Fire Pt	Temp C Flash Pt Remarks	Std Sulfur	Furan enterprise_id
LTC COMP (IEEE)	3			SDGE		03/15/2003		0303102-06		Lozano, Ray		03/28/2003		AL DAVIDSON			OILTRN 345 UP	
2	1	.19	17.9	31				28	3					2				
														03/31/2003				-9999849
LTC COMP	1			SDGE		03/04/1996		9603004-30a		SUE CAMPBELL		03/14/1996						
									4.3									
														11/16/1999				-9999849
MAIN (IEEE)	2			SDGE		03/15/2003		0303102-05		Lozano, Ray		03/28/2003		AL DAVIDSON			OILTRN 345 UP	
2	1	.16	19.5	42				22	0					1.5				
														03/31/2003				-9999849
MAIN	1					08/26/1999		9908148-05A						AL DAVIDSON				
									0									
														11/19/1999				-9999849
MAIN	1			SDGE		03/04/1996		9603004-29a		SUE CAMPBELL		03/14/1996						
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR S1 (989154 SREG)

Equipment ID	989154	Manufacturer	Westinghouse	Owner	SDG&E
Apparatus Type	SREG	Serial No	3012100	Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg		Designation	CIR S1
Fluid Cap.		Model/Type		Description	
Analysis Rules	OILCB	kV Rating	4000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
LTC (IEEE)	4			SDGE		06/15/2004		0406083-02		Lozano, Ray		06/28/2004		AL DAVIDSON		30.6	OILTRN 345 UP	
		.07	19.8	30				36	1.1					3				
														06/28/2004				-9999849
LTC COMP (IEEE)	3			SDGE		03/15/2003		0303102-02		Lozano, Ray		03/28/2003		AL DAVIDSON			OILTRN 345 UP	
2	1	.077	21.1	39				29	0					2				
														03/28/2003				-9999849
LTC COMP	1			SDGE		03/04/1996		9603004-32a		SUE CAMPBELL		03/14/1996						
									0									
														11/16/1999				-9999849
MAIN (IEEE)	3			SDGE		06/15/2004		0406083-01		Lozano, Ray		06/28/2004		AL DAVIDSON		30.6	OILTRN 345 UP	
		.05	21.7	40				30	2.7					1				
														06/28/2004				-9999849
MAIN (IEEE)	2			SDGE		03/15/2003		0303102-01		Lozano, Ray		03/28/2003		AL DAVIDSON		21	OILTRN 345 UP	
2	1	.16	18	28				21	0					1.5				
														03/28/2003				-9999849
MAIN	1					08/26/1999		9908148-03A						AL DAVIDSON				
									0									
														11/19/1999				-9999849
MAIN	1			SDGE		03/04/1996		9603004-31a		SUE CAMPBELL		03/14/1996						
									1.1									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR 129 (989168 SREG)

Equipment ID	989168	Manufacturer	Allis-Chalme	Owner	SDG&E
Apparatus Type	SREG	Serial No	2-0110-7522-2	Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg		Designation	CIR 129
Fluid Cap.		Model/Type	AFR	Description	
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
LTC COMP	1			SDGE		02/29/1996		9602168-44a				03/14/1996						
									1.8									
														11/16/1999				-9999849
MAIN (IEEE)	2			SDGE		03/15/2003		0303102-13		Lozano, Ray		03/28/2003				34	OILTRN	345 UP
2	1	.18	18.8	32				27	1.7					1.5				
														03/31/2003				-9999849
MAIN (IEEE)	3			SDGE		03/15/2003		0303102-14		Lozano, Ray		03/28/2003					OILTRN	345 UP
2	1	.18	20	29				25	1.1					1.5				
														03/31/2003				-9999849
MAIN	1			SDGE		02/29/1996		9602168-43a				03/14/1996						
									2.2									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR 130 (989169 SREG)

Equipment ID	989169	Manufacturer	Allis-Chalme	Owner	SDG&E
Apparatus Type	SREG	Serial No	2-0110-7522-3	Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg		Designation	CIR 130
Fluid Cap.		Model/Type	AFR	Description	
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
LTC COMP	3			SDGE		03/15/2003		0303102-10		Lozano, Ray		03/28/2003					OILTRN 345 UP	
(IEEE)																		
2	1	.21	18.9	34				23	0					1.6				
														03/31/2003				-9999849
LTC COMP	1			SDGE		03/04/1996		9603004-28a		SUE CAMPBELL		03/14/1996						
									4.3									
														11/16/1999				-9999849
MAIN	2			SDGE		03/15/2003		0303102-09		Lozano, Ray		03/28/2003				35	OILTRN 345 UP	
(IEEE)																		
2	1	.044	19.3	48				25	0					1.6				
														03/31/2003				-9999849
MAIN	1			SDGE		03/04/1996		9603004-27a		SUE CAMPBELL		03/14/1996						
									0									
														11/16/1999				-9999849

Fluid Quality History

SAMPSON 12-S12 CIR 133 (989171 SREG)

Equipment ID	989171	Manufacturer	Allis-Chalme	Owner	SDG&E
Apparatus Type	SREG	Serial No	2-0110-7522-5	Location	SAMPSON 12-S12
Fluid Type	OIL	Year Mfg		Designation	CIR 133
Fluid Cap.		Model/Type	AFR	Description	
Analysis Rules	OILCB	kV Rating	12000	Preservation	
		MVA Rating		Cooling	

Tank	No			Lab		Date		Lab Ref		Sampler		Lab Date		Reason		Temp C	Std	
F	P	Acid	IFT	D877	D1816	PF25	PF100	Water	PCB	Inhib	SG	Visual		Color	Fire Pt	Flash Pt	Sulfur	Furan
Al	Ca	Cu	Fe	Pb	Li	Ni	Si	Ag	Na	Sn	Zn	Pour Pt	Visc	Rec Date		Remarks		enterprise_id
LTC COMP (IEEE)	3			SDGE		03/15/2003		0303102-12		Lozano, Ray		03/28/2003					OILTRN 345 UP	
2	1	.048	19.1	36				22	0					1.6				
														03/31/2003				-9999849
LTC COMP	1			SDGE		03/04/1996		9603004-26a		SUE CAMPBELL		03/14/1996						
									0									
														11/16/1999				-9999849
MAIN (IEEE)	2			SDGE		03/15/2003		0303102-11		Lozano, Ray		03/28/2003				40	OILTRN 345 UP	
2	1	.2	18.8	46				23	0					1.6				
														03/31/2003				-9999849
MAIN	1			SDGE		03/04/1996		9603004-25a		SUE CAMPBELL		03/14/1996						
									0									
														11/16/1999				-9999849

EPA/ESD/R09-97/042
1997

EPA Superfund
Explanation of Significant Differences:

WESTINGHOUSE ELECTRIC CORP. (SUNNYVALE PLANT)
EPA ID: CAD001864081
OU 01
SUNNYVALE, CA
02/14/1997

<IMG SRC 970420>
<IMG SRC 97042A>

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105

EXPLANATION OF SIGNIFICANT DIFFERENCES
FOR THE
1991 RECORD OF DECISION
AT THE
WESTINGHOUSE SUPERFUND SITE
IN
SUNNYVALE, CALIFORNIA

MARCH 1997

EXPLANATION OF SIGNIFICANT DIFFERENCES
FOR THE
1991 RECORD OF DECISION
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Introduction

The U.S. Environmental Protection Agency (U.S. EPA) is issuing this Explanation of Significant Differences (ESD) for the 1991 Record of Decision for the Westinghouse Superfund Site.

A fact sheet is being sent to community members pursuant to Section 117(c) of CERCLA in order to provide an explanation of a significant difference to the remedial action selected in 1991 for the site.

Site Background

The 75-acre Westinghouse property is located at 401 E. Hendy Avenue in Sunnyvale, California ("the site"). The site is bounded by California Avenue to the north, Hendy Avenue to the south, North Sunnyvale Avenue to the west, and North Fair Oaks Avenue to the east (see Figure 1). During the mid-1950's Westinghouse manufactured transformers which contained Inerteen and mineral oil as insulating fluids. Inerteen was the Westinghouse trade name for an askarel consisting of approximately 60 percent polychlorinated biphenyl (PCB, Aroclor 1260) and 40 percent trichlorobenzene (TCB).

Inerteen was stored in a 7,000 gallon aboveground storage tank. Mineral oil was also stored onsite in three 16,000 gallon aboveground storage tanks and one 20,000 gallon underground storage tank. Inerteen liquid and mineral oil were delivered from their associated tanks to two areas of Building 21 via underground piping. The Inerteen tank was removed from the Reservoir 2 area in 1971. The mineral oil tanks were removed prior to 1974. Westinghouse also used Inerteen for weed control around the perimeter of the property and along railroad spurs on the property.

Both soil and groundwater with the highest concentrations were discovered in the vicinity of the tanks. The PCB solubility limit of 2.7 ppb was frequently exceeded in onsite wells located in the source area. Investigations also showed the presence of PCBs along the top of the A/B1 aquitard. A dense non-aqueous phase liquid (DNAPL) thickness of 2.8 feet was discovered in well W48, and a light non-aqueous phase liquid (LNAPL) thickness of 1.1 feet was found in well W3, which is located approximately 70 feet east of the former Inerteen tank. Volatile organic concentrations ranged up to 131 ppb in groundwater.

Contamination was also found in the soils beneath the underground pipelines which delivered chemicals to Building 21 for use in the manufacturing processes. PCB's in soils often exceeded 500 ppm and generally ranged up to 28,000 parts per million (ppm) from the surface to approximately 45 feet below ground surface.

Enforcement History and selected remedy

The California State Regional Water Quality Control Board (RWQCB) was the lead agency for the Site from 1981 to 1987. The RWQCB issued Orders 84-63 and 85-94 in 1984 and 1985. Pursuant to these orders, Westinghouse conducted remediation of shallow soils outside the Reservoir 2 area, and along the railroad spurs and fence lines.

In October 1984, pursuant to Section 105 of CERCLA, 42 U.S.C. Section 9605, the Westinghouse Superfund site was proposed for listing on the Federal Superfund National Priority List (NPL), set forth at 40 C.F.R. Part 300, Appendix B. The listing was finalized in June 1986. EPA assumed the lead oversight role on December 18, 1987. An Administrative Order on Consent for the performance of a Remedial Investigation and Feasibility Study ("RI/FS") was signed by Westinghouse and the EPA on August 20, 1988.

Pursuant to Section 117 of CERCLA, 42 U.S.C. Section 9617, EPA published a notice of the completion of the Feasibility Study, and of the proposed plan for remedial action on June 1, 1991, and provided opportunity for public comment on the proposed remedial action. The public comment period opened on July 1, 1991 and closed on August 29, 1991.

On October 16, 1991, the U.S. EPA signed a Record of Decision (ROD), selecting the following remedy:

1. Permanent containment, by means of groundwater extraction, of contaminated groundwater in the source area where DNAPLs are detected;

2. Restoration of contaminated groundwater, using extraction, to the California Department of Health Services (CDHS) Action Level for 1,3-Dichlorobenzene(1,3-DCB), the proposed maximum contaminant levels ("MCL") for 1,2,4 Trichlorobenzene(1,2,4-TCB) and the federal and state MCL, with the exception of the standard for PCB(0.5 ppb) in the onsite source area where DNAPL occurs;

3. Treatment of the extracted groundwater to meet all applicable or relevant and appropriate requirements ("ARARs") identified in the ROD for this discharge, prior to discharge to the onsite storm sewer, unless an evaluation indicates that an alternative "end-use" for the treated effluent (such as use for facility process water) can be practicably implemented;

4. Removal of contaminated soil containing greater than 25 parts per million PCB to a depth of eight feet;

5. Offsite incineration of excavated soils at a federally permitted facility;

6. Institutional controls, such as land use restrictions, to prevent well construction (for water supply purposes) in source areas that remain contaminated. Excavation below the eight feet where soil has been removed will be restricted. Restrictions will also preclude excavation, other than temporary subsurface work in the upper eight feet and will require complete restoration of any disturbed fill or the asphalt cap once any such temporary work was completed;

7. A requirement that EPA receive notification of any future intention to cease operations in, abandon, demolish, or perform construction in (including partial demolition or construction) Building 21 (see facility map, Figure 1);

8. Permanent and ongoing monitoring of the affected aquifers to verify that the extraction system is effective in capturing and reducing the chemical concentrations and extent of the aqueous phase plume, and containing the aqueous phase contamination in the DNAPL source area.

The estimated cost of the remedy in the ROD was $8,300,000. The cleanup plan outlined in the ROD included leaving contamination above health-based levels in both soil and groundwater on the Site. In the absence of a known technology to effectively remove the DNAPL containing PCB from the shallow aquifer, a technical impracticability waiver was invoked in the ROD. This legal mechanism waived the requirement to meet the standard for PCB in the source area of the DNAPL. The waiver was invoked because EPA determined it is not technically feasible to remove PCB DNAPL in the a-aquifer source area, which represented 70 percent of the containment mass located in the source area. The other 30% of the total mass of PCB in this area was thought to be in the vadose zone soils. The ROD requires that this area be permanently contained and that land use restrictions prevent access to this contamination. Compliance points were set at the perimeter of the DNAPL source area in the groundwater. The PCB standard must be met at the following well points: W10, W24, W26, W30, W31, W43, W44, W54, W55, W57, W58, W60, W63, W64, W65, W66, and CCG-2.

Soil cleanup levels were determined based on the historical industrial use of the property, a land use restriction of continued industrial and/or commercial use, and the possibility of workers coming into contact with contaminated soil. The aquifers beneath the site are classified as potential drinking water sources.

Remedial Design/Remedial Action Enforcement History

On February 6, 1992, Westinghouse initiated the work for the remedial design for the selected remedy pursuant to an Administrative Consent Order for Remedial Design (U.S. EPA Docket No. 92-08, February 6, 1992). In accordance with CERCLA Section 122, 42 U.S.C. Section 9622, EPA issued special notice to Westinghouse on March 31, 1992.

On September 29, 1993, EPA issued an Administrative Order for Remedial Design and Remedial Action for the Westinghouse site (U.S. EPA Docket No. 93-05). The 1993 Order directed Westinghouse to implement the Remedial Design by performing the Remedial Action and terminated Docket No. 92-08 except for provisions relevant to EPA's Response Costs.

The remediation contractor mobilized at the site on October 3, 1994. Approximately 1100 tons of contaminated soils was excavated and sent to Aragonite, Utah for incineration. A 20,000 gallon underground storage tank was removed as one of the first tasks of the remedial action. Three monitoring wells and six extraction wells were also installed as part of the groundwater treatment system. Pipelines containing mineral oil and Inerteen were removed from approximately 585 lineal feet of pipeline trench. The designated remedy was constructed between October 3, 1994 and June 1995. The completion reports documenting construction of the groundwater treatment system and removal of contaminated soils were submitted during March and April of 1996.

Site Ownership

On March 1, 1996, the Northrop Grumman Corporation acquired the Westinghouse Electronics Systems Group. This acquisition included the site. Northrop Grumman Corporation is a designer, systems integrator and manufacturer of military surveillance and combat aircraft, defense electronics and systems, airspace management and information systems, marine propulsion, precision weapons and commercial and military aerostructures. The company employs more than 48,000 people, and reported 1995 sales of $6.8 billion.

SUMMARY OF REMEDY MODIFICATIONS

North Parking Lot Background

Westinghouse Electric Corporation informed EPA in 1993 that they were interested in the beneficial redevelopment of the North Parking Lot, which is located across California Avenue from the main plant property. Their contractor conducted Phase I characterization of this area in preparation for selling this land. The characterization occurred in three phases that were reported in letters from EMCON to Westinghouse date May 6, 1992, August 11, 1992, and July 14, 1993. Copies of these reports were submitted to EPA during 1993. Except for a single sampling point (PCB 729 ppm), PCBs were detected in the Parking lot at concentrations no greater than 210 ppm. The average PCB concentrations found in the North Parking Lot was 150 ppm. Westinghouse has stated their belief that the presence of the PCB's in this area are a result of spraying of PCB fluids as a weed killer.

Westinghouse subsequently requested that EPA provide a determination of whether or not the North Parking Lot was part of the Superfund site. They also requested that any soil remediated from the North Parking Lot allow the alternative disposal of land filling rather than incineration. EPA determined that the North Parking Lot was included as part of the site description in the Record of Decision and was included in the original listing package. Therefore, the North Parking Lot is subject to the provisions of the ROD.

EPA and Westinghouse/Northrop reviewed historical aerial photographs and past sampling data. As a result, EPA does agree that the source of the soil contamination located in the North Parking Lot appears to be reflective of PCB's used as a weed killer. Contaminated soils removed from the source area in 1994-5 contained averaged PCB concentrations of 25,000 ppm, which is much higher than the average 150 ppm levels found in the North Parking Lot.

REMEDY CHANGE

LANDFILLING OF NORTH PARKING LOT SOILS

This ESD is written to change the disposal method for PCB contaminated soils removed from the North Parking Lot area only. Federal regulations for PCBs are derived from the Toxic Substances Control Act (TSCA) and the Resource Conservation and Recovery Act (RCRA). This change in disposal method for PCB contaminated soils only applies to soils where contamination is thought to have been a result of using PCB's as a weed killer. All soils with PCB concentrations greater than 25 ppm will be excavated. Soils containing PCB concentrations greater than 25 ppm and 50 ppm be disposed of at a facility that meets the provisions of RCRA Subtitle C. This ESD will allow excavation and transportation to a TSCA Chemical Waste Landfill soils found in the parking lot with concentrations greater than 50 ppm and less than 500 ppm. The landfill chosen must meet the requirements for TSCA Chemical Waste Landfills as described in 40 CFR Section 761.75, and must be in compliance with the procedures for planning and implementing offsite response actions described in 40 CFR Section 300.440. All soils found during this excavation that have PCB concentrations greater than 500 ppm will be incinerated as required in the 1991 ROD.

The 1991 ROD also contains a provision for Institutional Controls at the site. The 25 ppm cleanup number is applicable for industrial land use only. The North Parking Lot can only be used for industrial and or commercial applications. A copy of this ESD must also be filed with the deed in the County Recorder's Office along with a map showing the specific areas to which it applies.

JUSTIFICATION FOR CHANGE OF DISPOSAL METHOD

TSCA was listed as a "to be considered" ARAR in the 1991 Record of Decision. TSCA regulations and OSWER Directive No. 9355.4-01 define PCB "principal threat" as soils containing greater than 500 ppm PCB. All soils found in the plant area were deemed "principal threat", therefore EPA's decision was to remove and incinerate those soils. The TSCA regulation allows for landfilling or incineration for soils found with concentrations less than 500 ppm. Sampling results show that soils contaminated with PCB in the North Parking Lot contain average concentrations of 150 ppm. Therefore, in accordance with 40 CFR Section 761.60, Disposal requirement, Westinghouse/Northrop may dispose of soils recovered from the North Parking Lot with PCB concentrations less than 500 ppm in a TSCA approved Chemical Waste Landfill.

SOIL CLEANUP SCHEDULE

In a letter dated April 23, 1996, EPA directed Westinghouse/Northrop to submit a Workplan for the removal of PCB's with concentrations greater than 25 ppm from the Parking Lot. Westinghouse/Northrop submitted the Remedial Action Work Plan for the North Parking Lot on December 20, 1996. Cleanup of the North Parking Lot will start during April 1997.

Approximately 1000 tons of contaminated soil, with PCB concentrations between 25 and 50 ppm will be excavated from the North Parking Lot. Soils will be sent to the RCRA Sub-title C Section of the Laidlaw Facility, which is located in Buttonwillow, California. This facility is located 36 miles west of Bakersfield, California. Approximately 1500 tons of contaminated soil, with PCB concentrations between 50 and 500 ppm will also be excavated from the North Parking Lot and sent to Grayback Mountain. Grayback Mountain is a TSCA facility operated by U.S. Pollution Control, Inc., and is located 85 miles west of Salt Lake City, Utah. Westinghouse/Northrop does not expect to encounter any soils with concentration greater than 500 ppm. If these "principal threat" soils are encountered they will be sent to the Aptus Facility in Aragonite, Utah for incineration. This facility is located approximately 80 miles west of Salt Lake City, Utah. Addresses and phone numbers for these approved disposal facilities are given in Appendix 1.

The North Parking Lot excavation and removal is scheduled to be completed by June 1997. Westinghouse/Northrop anticipated the transfer of approximately three acres of the North Parking Lot to the new property owner during June 1997. The new owner will construct a commercial building on the three acres purchased and the Westinghouse/Northrop acreage will remain a parking lot for the near future.

Opportunity for Public Participation:

This Explanation of Significant Differences and the Remedial Action Workplan for the North Parking Lot Soils will be placed in the local repository.

The local repository for the Westinghouse Superfund Site is:

Sunnyvale Public Library
665 West Olive Avenue
Sunnyvale, CA 94088

Documents will also be maintained at:

U.S. EPA Region 9
Superfund Records Center
95 Hawthorne Street
San Francisco, CA 94105

In addition EPA conducted a community meeting to discuss the Explanation of Significant Differences and the onsite construction activities with local residents on February 20, 1997.

Support Agency Comments:

The Bay Area Regional Water Quality Control Board concurs with the above changes to the selected remedy.

Affirmation of Statutory Determination

Considering the new information that has been developed from additional sampling of the North Parking Lot and the changes that have been made to the selected remedy, the U.S. EPA believes that the remedy remains protective of human health and the environment, complies with Federal and State requirements that are applicable or relevant and appropriate to this remedial action, and is cost-effective.

<IMG SRC 97042B>
SIGNED MARCH 14, 1997

APPENDIX 1

FACILITIES APPROVED
UNDER
EPA'S OFF-SITE RULE
(Proposed by WESTINGHOUSE)

Aptus, Inc. (incinerator) (PCB>500ppm)	1600 N. Aptus Road (site) Aragonite, UT 84029	801-531-4200 (Fax) 801-531-4394
U.S. Pollution Control, Inc. TSCA (PCB 50ppm - 500ppm)	Grayback Mountain P.O. Box 22750Fax 801 323-8990 Salt Lake City, UT 84122	801 323-8900
Laidlaw Environmental Services CAD980675276 RCRA Subtitle C TSD (PCB 25 ppm - 50 ppm)	2500 West Lokern Road Buttonwillow, CA 93206	805 762-7372

<IMG SRC 97042C>

Woodward-Clyde Consultants

H 13942-001
T00322

UNDERGROUND TANK ASSESSMENT
SAN DIEGO GAS & ELECTRIC - SILVERGATE STATION
SAN DIEGO, CALIFORNIA

Prepared for:
San Diego Gas & Electric
P.O. Box 1831 (BC-850)
San Diego, California 92112

3467 Kurtz Street
San Diego, California 92110
(619) 224-2911

Woodward-Clyde Consultants

November 18, 1986
Revised: December 18, 1986
Project No. 56861K-SG01

San Diego Gas & Electric
P.O. Box 1831 (BC-850)
San Diego, California 92112

Attention: Mr. J. W. Carroll

UNDERGROUND TANK ASSESSMENT
SAN DIEGO GAS & ELECTRIC - SILVERGATE STATION
UNDERGROUND TANK NOS. 1501, 1502, AND 1503
SAN DIEGO, CALIFORNIA

Gentlemen:

Woodward-Clyde Consultants (WCC) is pleased to provide this final report of our underground tank assessment at the Silvergate Station site. Our services were performed in accordance with our work plan dated July 17, 1986 and our Purchase Order Agreement (No. B 8606 11408) for underground storage tank consulting services. We have incorporated your verbal comments received December 10, 1986 on our draft report and the results of additional laboratory analyses authorized by you.

It has been a pleasure to be of service to you, and we look forward to working with you in the future. If you have any questions, please give us a call.

Very truly yours,

WOODWARD-CLYDE CONSULTANTS

Keith A. Jones
Keith A. Jones
Project Manager

James D. Hartley
James D. Hartley
R.C.E. 038220

KAJ/JDH/RGS/kgm

REGISTERED PROFESSIONAL ENGINEER
JAMES D. HARTLEY
#38220
Exp. 3-31-89
CIVIL
STATE OF CALIFORNIA

Consulting Engineers, Geologists
and Environmental Scientists

Offices in Other Principal Cities

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UNDERGROUND TANK ASSESSMENT
SAN DIEGO GAS & ELECTRIC
SILVERGATE STATION
SAN DIEGO, CALIFORNIA

1.0 INTRODUCTION

This report presents the results of our investigation of subsurface hydrocarbon contamination at the SDG&E Silvergate Station facility, located at 1348 Sampson Street in San Diego, California. The purpose of our investigation was to assist SDG&E in obtaining a permit to operate three underground fuel storage tanks from the San Diego County Department of Health Services (CDOHS). The scope of our investigation was to inspect the interior tank surfaces, install two monitoring wells, perform analyses of soil and water samples to assess whether the tanks have leaked, and identify procedures for future groundwater monitoring. We understand that this information was specifically requested by the CDOHS.

2.0 SITE DESCRIPTION

The SDG&E Silvergate Station facility is located in the downtown area of San Diego, approximately 500 feet southwest of the intersection of Harbor Drive and Sampson Street. The location of the site is shown on Figure 1. Based on the "Comprehensive Water Quality Control Plan for the San Diego Basin," (RWQCB, 1975, and amendments through 1984), groundwater in the area of the site (San Diego Mesa Hydrographic Subunit) is not designated as having existing or potential beneficial uses.

Three underground concrete and steel-lined fuel oil tanks (Tank Nos. 1501, 1502, and 1503) are located north of the SDG&E Silvergate Station power plant as shown on Figure 2. Based on information provided by SDG&E, these tanks were installed in 1941 and have capacities of approximately 260,000 gallons each. We understand that the tanks were drained and cleaned in March 1984 and are presently empty.

Ten, 3-inch diameter, PVC wells are present at the locations shown on Figure 2. We understand, based on discussions with SDG&E personnel, that these wells were installed in the mid-1970s; however, well construction details and boring logs were not available. Soundings of the wells indicate that they are approximately 15 feet deep. Previous monitoring of these wells by SDG&E has not indicated the presence of fuel oil contamination.

3.0 FIELD INVESTIGATION

3.1 Well Installation and Soil Sampling

On August 20 and 28, 1986, two groundwater monitoring wells (MW-1 and MW-2) were drilled, sampled and installed using the procedures outlined in Appendix A. These wells were drilled to depths of approximately 25 feet. Copies of the well permits obtained from the CDOHS are included in Appendix A. Cuttings from the borings were placed in 55-gallon drums pending the results of laboratory analyses.

Soil from MW-2 was continuously sampled and was visually logged in the field. Due to difficulties in operating the soil sampling system with the drill rig mast in the down position which was required because of overhead obstructions, soil samples from MW-1 were obtained from drill cuttings. Boring logs are presented in Appendix A.

3.2 Field OVM Analyses

Soil headspace analyses (described in Appendix A) of soil samples from the borings were performed in the field using an HNU Model PI-101 organic vapor meter (OVM) calibrated with isobutylene. The results of the headspace analyses are presented in Table 1. Maximum OVM readings of soil samples from MW-1 and MW-2 were 2.6 ppm and 23 ppm, respectively. One soil sample from MW-1 and two soil samples from MW-2, selected on the basis of elevated OVM readings or proximity to the water table, were transported to a state-certified laboratory for analysis.

3.3 Well Development and Groundwater Sampling

On September 3, 1986, monitoring wells MW-1 and -2 were developed according to the procedures described in Appendix A. Wells MW-1 and -2 were purged and sampled using a submersible bladder pump on September 5, 1986. On September 9, 1986, a weighted tape coated with hydrocarbon-sensitive paste was lowered into monitoring wells MW-1 and -2, and B-1 through B-10, to measure the thickness of possible hydrocarbon product on the groundwater surface. Three additional groundwater samples were collected from MW-1 and -2 on November 19, 1986. One groundwater sample was collected from monitoring wells MW-1 and -2 using a submersible bladder pump and a third sample was bailed from the groundwater surface in MW-2. Water samples were collected, labelled, stored in an iced cooler and transported under chain-of-custody procedures to a state-certified laboratory according to the procedures described in Appendix A. Water purged from the wells during development and sampling was directed to an on-site storm drain.

3.4 Groundwater Elevation Measurement

Groundwater levels were measured in monitoring wells at the site on September 3, 5 and 9, 1986. Measurements were made using either an electric water level sounding probe or a weighted tape coated with hydrocarbon-sensitive paste. Well casing elevations were surveyed and groundwater elevation data, presented in Table 2, were estimated.

4.0 LABORATORY ANALYSES

4.1 Soil Analyses

Three soil samples, collected during drilling of the borings for the two monitoring wells, were transported to Brown and Caldwell Laboratory in Pasadena, California for analysis of total extractable hydrocarbons (TEH). Samples were prepared by EPA Method 3550 extraction and were analyzed using a modified version of EPA Method 8015. The results of these analyses are summarized in Table 1 and laboratory data sheets are provided in Appendix B.

4.2 Groundwater Analyses

Two groundwater samples collected on September 5, 1986 were analyzed for TEH (modified EPA Method 8015) and purgeable aromatic compounds (EPA Method 602) by Brown and Caldwell Laboratory in Pasadena, California. Three groundwater samples collected on November 19, 1986 were transported to the Analytical Technologies, Inc. laboratory in San Diego for analysis of total phenols (EPA Method 420.2). Laboratory data sheets are provided in Appendix B.

5.0 TANK INSPECTIONS

The conditions of the three underground tanks at the Silvergate Station were evaluated by American Engineering Laboratories, Inc. (AEL). Inspections of the tank interiors were performed by a certified welding inspector and results of the inspections were reviewed by a registered engineer at AEL. The purpose of the tank inspections was to evaluate the integrity of the tanks and the possibility of tank leakage when they are filled. The inspections consisted of visual observations of the extent of membrane coverage of the inner steel liner, visual observations of the presence of gaps or corrosion at welded joints, and thickness measurements of the steel plate lining in the tanks using an ultrasonic technique. The fuel tank evaluation report prepared by AEL is provided in Appendix C.

6.0 CONCLUSIONS

Based on our field and laboratory investigations, we observed the following conditions at the SDG&E Silvergate site.

6.1 Soil Conditions

The boring logs for MW-1 and MW-2 indicate that the site is underlain by 2 to 4 feet of fill soils and the Quaternary Bay Point Formation. The Bay Point Formation consists of interbedded sandy clays, clayey sands, and silty sands.

The soil sample from MW-1 collected from the drill cuttings had a TEH concentration of 60 mg/kg. Elevated OVM readings and hydrocarbon odors were observed in soil samples from MW-2 at depths between 4 and 8 feet in a clay horizon and at a depth of approximately 19 feet near the water table. Soil samples from the upper zone of contamination had TEH concentrations of 7,700 and 2,700 mg/kg, respectively. The lateral extent of the observed soil contamination is presently unknown.

6.2 Groundwater Conditions

Groundwater was present below the SDG&E Silvergate facility at a depth of approximately 19 feet below the ground surface, at approximately one foot above mean sea level in MW-1 and MW-2. However, the groundwater elevations in monitoring wells B-1 through B-10 were approximately 5 feet higher than those measured in MW-1 and MW-2. Because the water levels in wells B-1 through B-10 were comparatively consistent as were the water levels in MW-1 and MW-2, the differences in water levels may reflect the presence of perched groundwater or may be the result of differing well construction. The available groundwater elevation data is insufficient to estimate the direction of groundwater flow.

Free petroleum product was not detected on the groundwater surface in the twelve monitoring wells. Concentrations of TEH and purgeable aromatic compounds were below laboratory detection limits in groundwater samples from MW-1 and MW-2. Total phenols were not detected in MW-1 but were detected in groundwater samples from MW-2 at a maximum concentration of 0.20 mg/l. No clean-up standards have been issued by the CDOHS or RWQCB for this site. However, because groundwater beneath the Silvergate Station site has no designated beneficial uses and probably discharges to San Diego Bay, it is likely that the RWQCB would apply EPA saltwater aquatic toxicity standards as remediation criteria. The present acute saltwater toxicity standard for total phenols is 5.8 mg/l. The concentration of total phenols in MW-2 was more than 25 times less than the acute saltwater toxicity standard. These data indicate that no significant impairment of groundwater quality from TEH, purgeable aromatic compounds, or total phenols was present at the monitoring well locations.

6.3 Tank Integrity

The membrane coating the interior of the tanks was reported as missing in some areas, and in areas where the coating remains, blistering was prevalent. Welds joining the steel plates that line the tanks showed some indications of pitting, but no splits, cracks, or flaws were identified in the welds that were observed. Thickness measurements of the steel plate on the walls and floors of the tanks varied between 0.25 and 0.32 inches. Visual observations indicated that rain water probably leaks into the tanks through the ceilings.

The tank inspections did not provide any direct observations of defects in the liner that would indicate tank leakage had occurred. However, the detection of soil hydrocarbon contamination in the two borings adjacent to the tanks indirectly indicates possible tank system leakage. The absence of hydrocarbon contamination in the surface soils penetrated by the borings suggests that surface spillage of fuel oil is not likely to be the source of the soil contamination. However, it is not possible to identify whether leakage through the walls or floors of the tanks or leakage from associated piping systems could be potential sources of the observed soil contamination.

7.0 RECOMMENDATIONS

The following recommendations should be discussed with the CDOHS and the RWQCB prior to implementation.

7.1 Tank Investigations

Observations of the deteriorated condition of the tank membrane and the presence of soil contamination adjacent to the tanks indicate that the tank systems have leaked. Because the piping associated with the tanks could have leaked, we recommend that the piping be pressure tested and appropriate repairs be performed, if necessary. If SDG&E wishes to further evaluate the integrity of the tanks, it may be possible to perform a hydrostatic tank test. Such a test would involve filling the tanks with water, and measuring the possible decline in the water level over a period of several days or weeks using pressure transducers and data logger. A dye tracer test might also be performed that would involve spiking the water in the tanks with a tracer (such as a fluorescent compound), pumping a monitoring well adjacent to the tanks, and periodically analyzing water discharged from the well for the presence of the tracer.

7.2 Remedial Action

Due to the presence of underground utilities and the observed depth of soil contamination, it may not be practical to excavate contaminated soil. It may be possible to leave contaminated soil in place, provided that the presence of soil contamination is documented as part of any transfer of ownership of the property. Based on our present understanding of applicable water quality criteria, groundwater quality has not been impaired to the extent that the RWQCB or the CDOHS would require active remediation measures.

We also recommend that SDG&E consider lining the tanks with a synthetic, oil-resistant coating as a means of providing greater confidence in their integrity.

7.3 Monitoring

Monitoring of wells MW-1 and MW-2 should be performed daily when there is fuel oil in the tanks. Monitoring should include lowering a weighted tape coated with hydrocarbon-sensitive paste into the well and observing possible color changes in the paste which would indicate the presence of petroleum product. In addition, we recommend that a clear, acrylic bailer be lowered into the well just below the water table surface, and that the bailer be retrieved and visually checked for the presence of free petroleum product on the water surface. Record keeping and reporting requirements should conform to the California Administrative Code, Title 23, Subchapter 16, Underground Tank Regulations, and the permit to operate conditions imposed by the CDOHS.

Because construction information was unavailable for monitoring wells B-1 through B-10, and because there was an apparent difference in water levels in these wells as compared to MW-1 and MW-2, we recommend that at least one additional monitoring well be installed adjacent to the tanks. The number and location of one or more additional wells should be identified after SDG&E has determined which of the tanks will remain in service. Due to access restrictions we understand that it would not be possible to install additional monitoring wells on SDG&E property along the northern side of the tanks.

8.0 UNCERTAINTY AND LIMITATIONS

Geochemistry, hydrogeology, and the geotechnical sciences are characterized by uncertainty. The behavior of subsurface contaminants is a complex phenomenon and our conclusions are based upon limited sampling and analyses. Inspection of the tanks involved limited visual observations and ultrasonic testing of representative sections of the tanks. The engineering services provided and the judgements rendered on this project meet current professional standards and do not carry any other guarantee.

TABLE 1

OVM AND LABORATORY SOIL SAMPLE ANALYSES
SDG&E TANKS
SILVERGATE STATION

	MW-1		MW-2	
Depth (Feet)	OVM[a] (ppm)	TEH[b] (mg/kg)	OVM (ppm)	TEH (mg/kg)
1	[c]---	---	0.8	---
2	---	---	0.8	---
3	---	---	----	---
4	---	---	20	7,700
5	0.2	---	12	---
6	---	---	23	---
7	---	---	22	2,700
8	0.2	---	4.8	---
9	---	---	1	---
10	---	---	1	---
11	---	---	1.2	---
12	0.6	---	1.0	---
13	---	---	1.6	---
14	---	---	1.1	---
15	---	---	1.3	---
16	---	---	1.4	---
17[d]	---	---	1.4	---
18	2.6	---	1.2	---
∇ 19	---	---	10	---
20	---	---	1.8	---
21	2.0	60[e]	1.6	---
22	---	---	1.2	---
23	---	---	1.0	---
24	---	---	1.3	---
25	---	---	---	---

Notes:

[a] Field headspace analysis using an HNU OVM (see Appendix A).

[b] Total extractable hydrocarbon concentrations by EPA Method 8015 (see Appendix B).

[c] --- = Not sampled or not measured.

[d] Water table at time of drilling.

[e] Soil sample from drill cuttings. Depth of sample approximated.

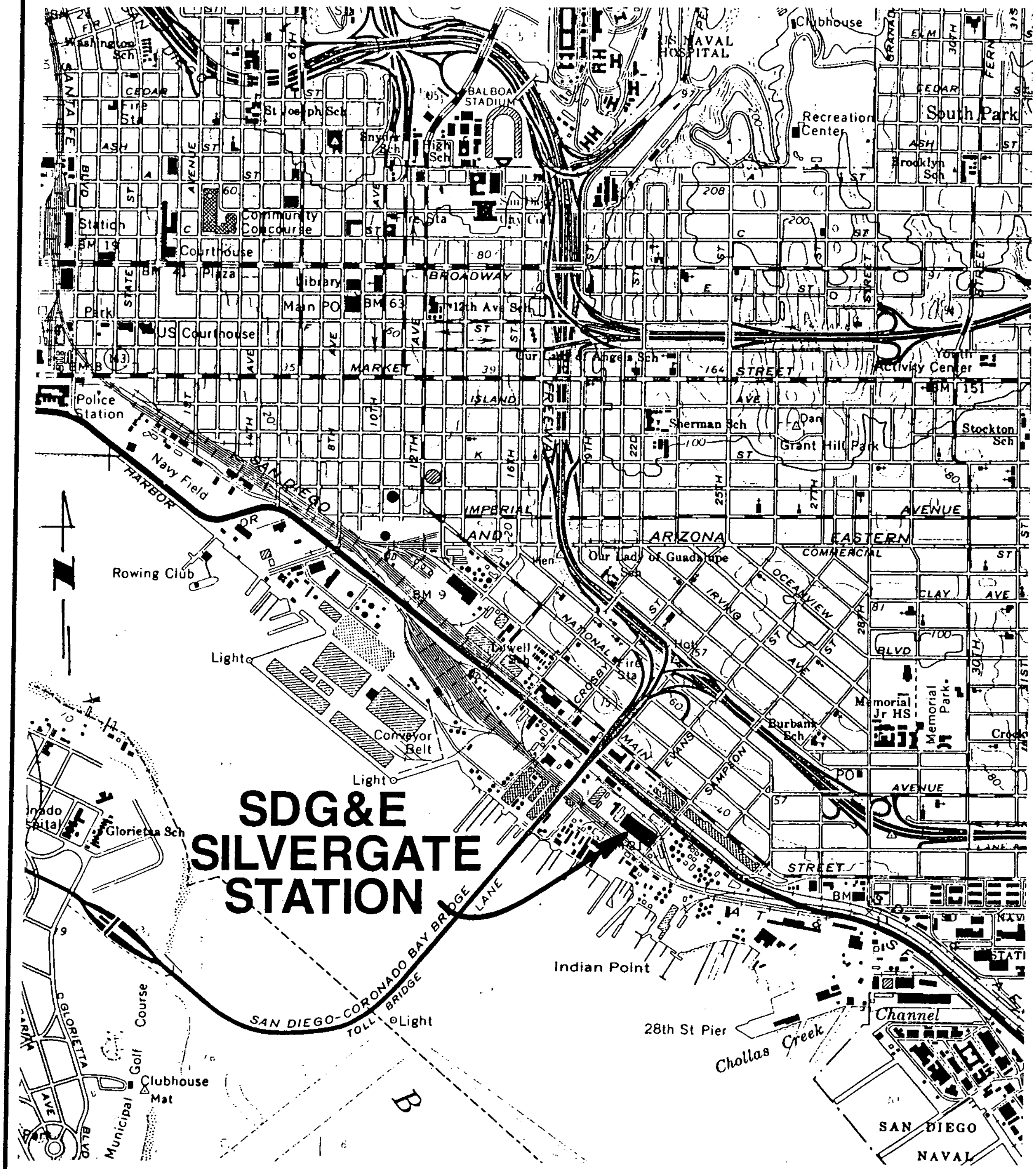
TABLE 2

GROUNDWATER ELEVATION DATA
SDG&E TANKS
SILVERGATE STATION

Well	Date Measured	Top of Casing Elevation (feet)[a]	Depth to Groundwater (feet)[c]	Groundwater Elevation (feet)[a]
MW-1	9-3-86	20.50	----	----[b]
	9-5-86		19.57	0.93
	9-9-86		19.50	1.00
MW-2	9-3-86	19.96	19.04	0.92
	9-5-86		19.04	0.92
	9-9-86		19.04	0.92
B-1	9-9-86	20.23	dry[d]	dry
B-2	9-9-86	20.51	13.96	6.55
B-3	9-9-86	20.00	14.04	5.96
B-4	9-9-86	20.00	14.15	5.85
B-5	9-9-86	19.59	dry[d]	dry
B-6	9-9-86	20.25	14.25	6.00
B-7	9-9-86	20.17	14.17	6.00
B-8	9-9-86	20.36	15.08	5.28
B-9	9-9-86	20.25	14.13	6.12
B-10	9-9-86	20.43	14.17	6.26

Notes:

[a] Elevations are relative to an assumed elevation of 20.00 feet MSL for B-3.
[b] -- Not measured.
[c] Depth below top of well casing.
[d] Dry at depths of approximately 15 feet.



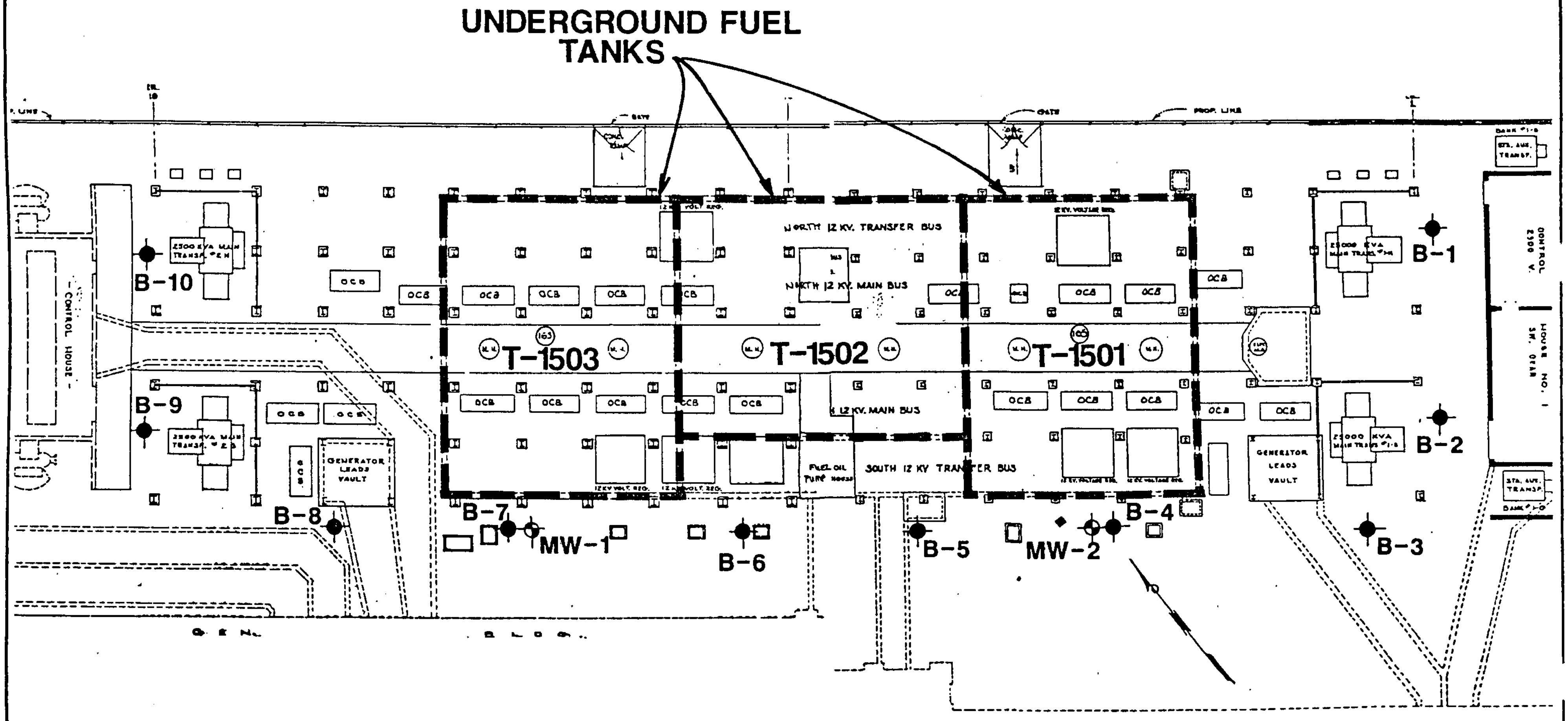
Reference: USGS 7.5' Point Loma Quadrangle
Photo revised 1975

SCALE: 1" = 2000'

LOCATION MAP
SDG&E SILVERGATE POWER PLANT

DRAWN BY: ch	CHECKED BY: KAJ	PROJECT NO: 56861K-SG01	DATE: 9-5-86	FIGURE NO: 1

WOODWARD-CLYDE CONSULTANTS



LEGEND:

MW-1 ⌖ Indicates approximate location of Test Boring and Monitoring Well.

B-1 ● Indicates approximate location of Monitoring Well installed prior to this investigation.

0 16 32

Graphic Scale (Feet)

SITE PLAN
SDG&E SILVERGATE POWER PLANT

DRAWN BY:	ch	CHECKED BY:	KAJ	FIGURE NO:	2
DATE:	9-5-86	PROJECT NO:	56861K-SG01		

WOODWARD-CLYDE CONSULTANTS

SAN DIEGO BLUE PRINT CO. 85488

7.

File with Unit #3 correspondence.
Possibly all memos to const. Supt. should go into a special section of the file or under Misc.

SILVER GATE STATION May 1, 1950

Mr. M. Hjalmarson,
Supt. Construction

In a recent survey of Unit #3 construction, the following items were noted:

1. It is noted that our water disposal lake on the tide lands has been overflowing, and a ditch has been cut to the water's edge. This cannot be permitted, because oil would thereby be admitted to the bay and our company would be subject to a heavy fine by the Fish and Game Commission. It may be necessary to throw up a dike around the lake for the time being, or to take a clam shell and dig out additional space for the water's discharge.

2. Each of the induced draft fans must be provided with a drain connection at the bottom of the scroll case. This should be provided before installation work begins.

3. It is also noted that no seal welding has been done inside the fan casing. All joints must be seal welded and we would prefer to have a water test before the lagging is installed.

4. It is necessary for us to be able to remove the coupling guards on the induced and forced draft fans in such a manner that aligning bars attached to the shaft may be rotated 360° without striking any mounting brackets used for coupling guards. This will require some modification of the work already done. For quick reference your man may refer to Fans #3 and #4.

5. It is reported that the hangers on the gauge glass blow down lines rigidly fix the line at each point where a hanger is located. The expansion loop which is mounted near elevation 32' is intended to take all the expansion of this line during periods when we are blowing down the glass. All hangers above the expansion joint should be free so that the line may slip through. In this connection we may require some additional hangers to provide adequate guiding.

6. It is quite possible that the condenser vent valve on the east water box may not go in place because of congestion caused by G. E. piping. It may be well to have this checked at an early date so necessary changes can be effected.

7. We are now approaching the time for hydrostatic tests and as yet no shut off valve has been provided at the steam drum for the line serving the main steam gauge. This is covered on page 10 of Mr. Gardner's notes.

Walter A. Zitlau

WAZ/s

SAN DIEGO GAS & ELECTRIC COMPANY
POWER PLANT WASTEWATER TREATMENT FACILITIES
PROJECT 75024
PROJECT DESIGN GUIDE

26 MARCH 1976

HUGH CARTER ENGINEERING CORP.
LA JOLLA, CALIFORNIA

SAN DIEGO GAS & ELECTRIC COMPANY
POWER PLANT WASTEWATER TREATMENT FACILITIES
PROJECT 75024
PROJECT DESIGN GUIDE

INDEX

SECTION I

SECTION I: INTRODUCTION

SAN DIEGO GAS & ELECTRIC COMPANY
POWER PLANT WASTEWATER TREATMENT FACILITIES
PROJECT 75024
PROJECT DESIGN GUIDE

PURPOSE

Wastewater treatment capability is to be installed at each of the four (4) SDG&E power plants to bring them into compliance with the San Diego Regional Water Quality Control Board Rules and Regulations, and with the U.S. Environmental Protection Agency (EPA) "Steam Electric Power Generating Point Source Category, Effluent Guidelines and Statements" (Title 40, Chapter 1, Subchapter N, Part 423) dated October 8, 1974.

The power plant wastewater treatment system must be in operation by July 1, 1977, to make existing units conform to regulatory agency requirements.

San Diego Gas & Electric Company
POWER PLANT WASTEWATER TREATMENT FACILITIES
PROJECT 75024
PROJECT DESIGN GUIDE

SUMMARY OF EPA REGULATIONS

EXTENDED WASTEWATERS

pH	High 9.0 Low 6.0
Cu	1 ppm
Fe	1 ppm
Grease & Oil	Max -- 20 ppm any one day Ave -- 15 ppm 30 consecutive days
Total Suspended Solids	Max -- 100 ppm any one day Ave -- 30 ppm 30 consecutive days

LOW VOLUME WASTEWATERS

pH	High 9.0 Low 6.0
Grease & Oil	Max -- 20 ppm any one day Ave -- 15 ppm 30 consecutive days
Total Suspended Solids	Max -- 100 ppm any one day Ave -- 30 ppm 30 consecutive days

SAN DIEGO GAS & ELECTRIC COMPANY
POWER PLANT WASTEWATER TREATMENT FACILITIES
PROJECT 75024
PROJECT DESIGN GUIDE

PROJECT DESCRIPTION

A waste collection and treatment system will be installed at each of the four (4) SDG&E steam power plants to collect plant wastes, treat them and discharge acceptable effluent to the circulating water discharge tunnel. The system will also account for wastes which do not require treatment, by piping such wastes direct and untreated to the circulating water discharge tunnel. The system will have adequate capacity margins to accommodate wastes from existing units and a future Encina Unit 5.

Equipment purchasing is scheduled to begin in April, 1976, and construction in June, 1976, with commercial operation by July 1, 1977. Other design objectives, technical requirements and operational characteristics of the new facility will generally be in accordance with Sections II and III of the Project Design Guide.

Two treatment systems, both using a modified batch process, and both sized with adequate margins will be furnished. The extended waste treatment system will adjust pH and remove suspended solids, oil, copper and iron. The low volume waste treatment system will adjust pH and remove suspended solids and oil. The treatment systems will be purchased from one supplier to ensure single source responsibility.

The scope of the waste collection and treatment system includes the addition of new hold-up basins or tank, fence, rail, grating, pipe, fittings valves, strainers, grading, concrete and steel structures, sumps, tanks, pumps, motors, skimmers, storage building, motor control center, instrumentation, lighting, hose, ventilation fans, chemical showers, fire extinguishers and bulk storage facilities for acid and lime. It also includes the capping and/or abandoning and removal of existing outmoded waste collection schemes.

Piping, fittings, valves, pumps, tanks and sumps will be provided or modified to interface waste sources from the existing plant with the new treatment facilities. This includes evaporator blowdown, boiler continuous blowdown, waste sump, air heater and boiler fireside wash, wall sump, dewatering sump, trenches and boiler chemical cleaning. Piping and cable runs from the plant to the treatment area will require special care during installation to avoid existing buried pipe and cable.

PROJECT DESCRIPTION (CONTINUED)

Other piping includes instrument air and raw water. Fire protection will be provided by portable extinguishers.

A prefabricated control and chemical storage building of approximately 20 feet X 40 feet will be provided in the vicinity of the hold-up basins and tanks. It will be used to store lime, a caustic soda, and will also house the motor control center, and the treatment instrument and control panel. Ventilation and lighting will be furnished, as well as a partition wall to close off the lime storage area.

Electric power and control feeds to motors added within the existing power plant will use construction techniques consistent with the existing facilities.

A new motor control center will be installed in the control and chemical storage building, in the hold-up basin area, outside of the existing plant. A power cable will be routed with the piping system from the plant to feed this new motor control center. The motor control center will include all starters for all of the motors at the hold-up basin area. Local control system will be installed to provide safe grounding for the new facilities. Lighting in the area will consist of San Diego standard lamp poles with light fixtures selected to provide adequate illumination.

A system description including flow diagram, instrument and control logic drawings will be prepared by Hugh Carter Engineering Corp. for the complete new facility. This system description will define all interfaces with the power plant instruments and controls.

Design of the waste collection and treatment system will conform with high quality utility standards, consistent with past San Diego Gas & Electric Company requirements; fully detailed drawings as required will be prepared by Hugh Carter Engineering Corp. Instrument mounting and piping details will be prepared for any transmitters, primary elements, etc., mounted and/or connected to Hugh Carter Engineering Corp. designed piping. Procurement of material or equipment required for the new waste treatment facilities, including expediting equipment and vendor drawings, after award of purchase orders, will be by SDG&E Purchasing and Material Control Department. A CPM-type schedule will be prepared, along with network diagrams. It is assumed that the installation of all system components furnished, regardless of supplier, and also the construction and/or installation of all supporting facilities will be assigned to San Diego Gas & Electric Company's Plant Construction Department.

SECTION II

SECTION II:

CHEMICAL TREATMENT EQUIPMENT DESCRIPTIONS

SAN DIEGO GAS & ELECTRIC COMPANY
POWER PLANT WASTEWATER TREATMENT FACILITIES
PROJECT 75024
PROJECT DESIGN GUIDE

CHEMICAL TREATMENT EQUIPMENT DESCRIPTIONS

I. Introduction

The equipment manufacturer shall provide a utility wastewater treatment system, including all equipment necessary to produce an effluent quality which will meet applicable EPA guidelines.

The system shall consist of the following major items:

Chemical Reaction Units
Solids Contact/Sludge Recirculation Clarifier
Dual Media Polishing Filters
Sludge Conditioning Equipment
All Necessary Chemical Feeds and Chemical Handling
Process and Effluent Monitoring Instrumentation and Controls

II. Extended Wastewater Treatment System

After collection of the various extended wastewater flows from the power plant, the wastes are piped to a large equalization pond. The pond locations at are shown in Appendix B. At Silver Gate, the CW deck voids will be used and at a system will be used that can accommodate the maximum flow rates.

The wastewater in the equalization sump will be treated for oil removal prior to chemical treatment. The chemical treating system will have provisions to remove trace oil.

A constant wastewater flow will be pumped from the equalization ponds so equipment will not have to be sized for a large instantaneous flow, such as an air preheater wash, except in the case of

The solids separation phase of the chemical treatment process is made up of three (3) discrete steps; mixing, flocculation and clarification. The objective of coagulation and flocculation is to attain envelopment of suspended particles within the floc particles and to condition the floc particles so that they will be readily removable in the subsequent process of clarification.

II. Extended Wastewater Treatment System (continued)

Coagulation is the drawing together of colloidal particles by chemical forces. The process occurs within seconds of application of the coagulating reagent to the water. Because of this, intense mixing is necessary at the point of chemical application in order to insure uniform chemical distribution and exposure of the fine particles in the water to the coagulation reaction is completed. Flocculation refers to the assembling of coagulated particles into floc particles. Flocculation may be partly a chemical budging mechanism, enhanced by the use of substances like polyelectrolytes, but it is much slower, and more dependent on time and amount of agitation than is coagulation. Coagulation and flocculation are influenced by physical and chemical forces such as electrical charges on particles, exchange capacity, particle size and concentration, pH, water temperature and electrolyte concentrations.

Clarification of wastewaters involves the removal of the suspended solids. The easiest method of clarification is to allow water to stand for a period of time or to reduce its velocity so that the readily settleable solids are separated by gravity. The settleable solids will be directed to a thickener to increase the solids content of the sludge and to supply storage capability. The sludge will then be dewatered to approximately forty to forty-five per cent (40 - 45%) solids and disposed of in a sanitary landfill.

The final pH adjustment will be a continuous process to insure the effluent pH is between six (6) and nine (9). The final filter will handle the possible flocculant overflow and will reduce the suspended solids to below EPA limitations.

The test pond will allow the retention time necessary for testing. If for some reason the effluent does not meet the EPA standards, the wastewater can be recirculated back to the equalization pond for retreatment.

III. Low Volume Wastewater Treatment System

The chemical treatment process for the low volume wastewater is similar to the extended except for the solids separation phase. Wastewaters are collected in the power plant and piped to the equalization ponds.

From the pond, the wastewater flow will be directed through a sand filter or equivalent filter media for suspended solids removal. The filter will be back-washed into the extended equalization sump. After filtering, the wastewater will be pH adjusted and trace oil filtered and tested just as described in the extended treatment system. The treated wastewater meeting the EPA standards will be

CHEMICAL TREATMENT EQUIPMENT DESCRIPTIONS (CONTINUED)

III. Low Volume Wastewater Treatment System (continued)

collected in the discharge sump and batch discharged with the treated extended wastewaters into the circulating water discharge. If there is insufficient land available for a discharge sump, the treated wastewaters will be continuously discharged.

IV. Alternative System

An alternative chemical treatment system is available which keeps separate the two (2) streams during treatment. The flow diagrams demonstrate the various equipment configurations.

Quotations will be solicited for both systems. A decision on which system to proceed with will be made after analyzing the extra costs involved, reliability, extra chemical costs and "approvability" by the EPA.

V. Chemical Treatment Plant Operator Requirements

It is estimated that one additional full-time operator per power plant will be required to operate the proposed treatment plant. The need of one additional full-time laboratory technician is also anticipated at this time.

Sempra Silvergate Substation
Phase I
Environmental Site Assesment

Prepared for:
San Diego Gas and Electric
8315 Century Park Court
San Diego, CA 92123-1548
Contact: Mr. Chris Terzich

RBF
CONSULTING

PLANNING
DESIGN
CONSTRUCTION

Sempra Silvergate Substation
Phase I
Environmental Site Assesment

Prepared for:
San Diego Gas and Electric
8315 Century Park Court
San Diego, CA 92123-1548
Contact: Mr. Chris Terzich

March 2005

Prepared by:

RBF Consulting
14725 Alton Parkway
Irvine, CA, 92618
Contact: Mr. Bruce R. Grove Jr., REA
949/855-3686

RBF
CONSULTING

PLANNING ■ DESIGN ■ CONSTRUCTION

PHASE I
ENVIRONMENTAL SITE ASSESSMENT

Sempra Silvergate Substation
(APNs 538-700-01, 02 and portions of 05, 06)

City of San Diego
County of San Diego, State of California

Prepared For:

SAN DIEGO GAS & ELECTRIC
8315 Century Park Court, CP 21E
San Diego, California 92123
Contact: Mr. Chris Terzich

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14725 Alton Parkway
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March 14, 2005

JN 25-101591

March 14, 2005

JN 25-101591

Mr. Chris Terzich
SAN DIEGO GAS & ELECTRIC
8315 Century Park Court, CP 21E
San Diego, CA 92123

SUBJECT: **PHASE I ENVIRONMENTAL SITE ASSESSMENT**
Sempra Silvergate Substation (APNs 538-700-01, 02 and portions of 05, 06), located within the City of San Diego, County of San Diego, California

Dear Mr. Terzich:

RBF Consulting (RBF) is pleased to submit this Phase I Environmental Site Assessment for the above referenced project, herein referenced as the "subject site." This Assessment has been prepared to evaluate the potential presence of hazardous materials and the expected nature of the materials that may be on the subject site addressed within this Assessment. This Assessment has been prepared for the sole use of **Sempra Utilities**, for the above referenced subject site. Neither this Assessment, nor any of the information contained herein shall be used or relied upon for any purpose by any person or entity other than **Sempra Utilities**.

The Phase I Environmental Site Assessment was performed in general accordance with ASTM Standard Practice E 1527-00, the scope-of-services and inherent limitations presented in our proposal. The Assessment is not intended to present specific quantitative information as to the actual presence of hazardous materials on or adjacent to the subject site, but is to identify the potential presence based on available information.

Should you or your staff have any questions after reviewing the attached report, please do not hesitate to contact me at 949/855-3686.

Sincerely,

Bruce R. Grove Jr., REA
Senior Associate/Environmental Assessor
Environmental Services-Special Projects

Richard Beck
Environmental Analyst
Environmental Services-Special Projects

Statement of Quality Assurance

I have performed this Assessment in accordance with generally accepted environmental practices and procedures, as of the date of this report. I have employed the degree of care and skill ordinarily exercised under similar circumstances by reputable environmental professionals practicing in this area. The conclusions contained with this Assessment are based upon site conditions I readily observed or were reasonably ascertainable and present at the time of the site inspection.

The conclusions and recommendations stated in this report are based upon personal observations made by employees of RBF and upon information provided by others. I have no reason to suspect or believe that the information provided is inaccurate.

Signature of RBF Environmental Assessor-*Richard Beck*

Signature/Environmental Assessor

Statement of Quality Control

The objective of this Environmental Site Assessment was to ascertain the potential presence or absence of environmental releases or threatened releases that could impact the subject site, as delineated by the Scope-of-Work. The procedure was to perform reasonable steps in accordance with the existing regulations, currently available technology, and generally accepted engineering practices in order to accomplish the stated objective.

The Scope of this Assessment does not purport to encompass every report, record, or other form of documentation relevant to the subject site being evaluated. Additionally, this Assessment does not include or address reasonable ascertainable Environmental Liens currently recorded against the subject site. To the best of my knowledge, this Environmental Site Assessment has been performed in compliance with RBF Standard Operating procedures protocol for Phase I Environmental Site Assessments.

Signature of RBF Environmental Project Manager-*Bruce R. Grove Jr., REA #06865, CEI #14551*

Signature/Environmental Project Manager

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1.0
INTRODUCTION

The purpose of conducting this Phase I Environmental Site Assessment (ESA) is to permit the use of this report to satisfy one of the requirements to qualify for the Innocent Landowner Defense to CERCLA (Superfund Law) liability, by providing an appropriate inquiry into the previous uses of the property in order to identify ***Recognized Environmental Conditions (RECs).*** *As defined in American Standards for Testing and Materials (ASTM) Standard Practice E 1527-00, a* ***REC*** *is "the presence or likely presence of any hazardous substances or petroleum products on a property under conditions that indicate an existing release, a past release, or a material threat of a release of any hazardous substances or petroleum products into structures on the property or into the ground, groundwater, or surface water of the property." The term includes hazardous substances or petroleum products even under conditions in compliance with laws. The term is not intended to include* ***"de minimis"*** *conditions that generally do not present a material risk of harm to public health or the environment and that generally would not be the subject of an enforcement action if brought to the attention of appropriate governmental agencies. Conditions determined to be* ***"de minimis"*** *are not* ***RECs.***

1.1 SUBJECT SITE

The approximate five-acre property, herein referred to as the "subject site" in this Assessment, is located within the City of San Diego, County of San Diego, State of California (Township.17S [T.17S], Range.2W [R.2W], San Bernardino Base and Meridian [SBBM]) (refer to Exhibit 1, *Regional Vicinity* and Exhibit 2, *Site Vicinity*). Specifically, the subject site is located south of Harbor Drive and west of Sampson Street.

The subject site is comprised of four parcels, defined by Assessor's Parcel Numbers (APNs) 538-700-01, 02 and portions of 538-700-05, 06, which comprise a gross acreage of approximately 5.58-acres. APN 538-700-01 and 02 are also defined by a street addresses; 01 is defined by 1348 Sampson Street (Silvergate Substation) and 02 is defined by 1304 Sampson Street (Propulsion Control Engineering [PCE]). Currently, the subject site consists of the Silvergate power plant, electrical substation, parking/storage lot, and PCE (refer to Exhibit 3, *Subject Site*).

The subject site has consisted of the current uses since 1948. Prior to that, the subject site was utilized as a lumberyard. On-site topography is relatively flat, and is approximately 20 feet above mean sea level (msl) and gently slopes to the southwest, towards the San Diego Bay.

Overall, the subject site is primarily situated within an industrial/ military area within the City of San Diego. The subject site is bounded by Harbor Drive to the north, the Burlington Northern Santa Fe Railroad tracks to the south, Sampson Street and industrial uses to the east, and industrial uses to the west. Refer to Section 2.0, *Physical Setting*, for a complete description of on-site and off-site conditions.

Exhibit 1, *Regional Vicinity*

Exhibit 2, *Site Vicinity*

Exhibit 3, *Subject Site*

1.1.1 Anticipated Future Uses

The future uses of the subject site will remain similar to the current uses, however the site will be reconstructed with a modern electrical substation.

1.2 EXECUTIVE SUMMARY

A partial summary of results of the Phase I Environmental Site Assessment (ESA) is as follows (refer to Sections 2.0 through 5.0 of this Assessment for a complete discussion of our investigation and conclusions):

1.2.1 Site Inspection

Evidence of RECs within the boundary of the subject site were observed during the February 1, 2005 and February 24, 2005 site inspections, and consist of the following:

- The subject site consists of industrial-type uses. The majority of the subject site is situated on concrete or asphalt foundations. Typically, chemicals from on-site uses and maintenance operations include oil and grease, solvents, and gasoline. The use of the subject site as a power plant and substation is considered to pose a potential REC.
- Cracked and peeling paint was noticed throughout the power plant, especially on the ceiling. Based on the year the structure was constructed, it is likely that lead based paints are present within the wall and ceiling paint.
- Hundreds of 55-gallon drums were stockpiled within **Area 3** of the subject site. The contents and specific use of the drums remains undefined.
- Stockpiled equipment was noted through **Area 3**. The equipment was located on wood pallets. However, the ground surface underneath the equipment could not examined.
- Surficial staining was noted throughout the subject site. Within **Area 1** the staining was noted on floor tiles and appeared to consist of diesel or fuel. Within **Area 2**, the staining was noted at the base of the substation infrastructure. In **Areas 3 and 4** the staining was noted on the ground surface and appeared to be typical staining of parking lots. This staining appeared to consist of grease or fuel and was located on concrete, rocks, and dirt. The on-site stained surfaces are considered to be a potential REC since the extent of contamination remains undefined.
- It was noted that the subject site has hydraulic lifts on-site. Due to health impacts, the Environmental Protection Agency (EPA) banned some uses of PCBs in 1977 and most production/use in 1979. However, many hydraulic lifts and associated fluids still contain PCBs. The primary concern with hydraulic lifts is the potential for subsurface leakages of hydraulic fluids from the lift's piston. RBF could not confirm the actual presence of PCBs associated with on-site lifts during the course of this ESA.
- Fluorescent lighting was noted within the on-site structure during the February 1, 2005 and February 24, 2005 site inspections. It should be noted that some fluorescent lamp ballasts contain capacitors, and therefore, may contain PCBs.
- **Area 2** of the subject site consists of the electrical substation. High voltage power lines and several transformers were noted within this area. Due to the age of the

structures, it is likely that PCBs are present within the power lines and transformers.

- Several manholes were noted within **Area 2** of the subject site. It was indicated by SDG&E staff that underground storage tanks (USTs) are present below the manholes. It was also indicated that these USTs were used to store fuel oil. Several additional USTs were identified within the power plant structure. It was indicated that all tanks on-site are empty.

- Aboveground storage tanks (ASTs) were observed to occur within **Area 1** and 4 of the subject site.

- Railroad tracks are present within the subject site. The subject site was historically utilized as a lumberyard, and SDG&E staff noted that these tracks were utilized for transport. Due to the historical use of portions of the subject site as a railroad ROW and the known past practices of railroad companies to use diesel fuel as a method to control weeds, and the use of creosote to seal the wood railroad ties, the potential exists for soils within the railroad ROW to be contaminated.

- Numerous gauges are present within **Area 1** and **Area 2** of the subject site. Based on the year the structure was constructed, it is likely that mercury is present within the gauges.

1.2.2 Asbestos Containing Materials

Based on a previous Phase I and II ESA and the year the existing on-site structure was built (prior to 1978), the potential for asbestos-containing materials (ACMs) to be found on-site is considered likely. ACMs are likely to be present within the roofing felt, roof patch mastic, floor tile, tile mastic, thermal insulation, and motors located within **Areas 1** and **2**. ACMs are also likely to be present within **Area 4**, based on the year the structure was built.

1.2.3 Lead-Based Paints

Based on a previous Phase I and II ESA and the year the existing on-site structure was built (prior to 1978), the potential for lead-based paints (LBPs) to be found on-site is considered likely. The Phase II ESA sampled the paint within **Area 1** and determined it contains lead. It is also likely that LBPs are present within **Area 4**.

1.2.4 Adjacent Properties

The presence of hazardous materials on the subject site that may have been generated from adjacent properties was not visible during the February 1, 2005 and February 24, 2005 site inspections. However, the presence of hazardous materials on-site that were generated from adjacent properties is considered to be likely due to the ground contamination and the surrounding industrial uses.

1.2.5 Public Records

Available public records were reviewed. The lists, which were reviewed, identified two regulatory sites reported within the boundaries of the subject site (refer to Exhibit 4, *Overview Map*). The subject site was listed as the following:

EXHIBIT 4, *Overview Map*

- **Propulsion Controls Engineering (1304 Sampson Street)**: PCE was listed within the San Diego County Hazardous Materials Management Division Database (San Diego Co. HMMD). The San Diego Co. HMMD database contains the business name, site address, business phone number, establishment permit number and type, and the business status. Additionally, the database provides inspection dates, violations received by the establishment, hazardous waste generated, the quantity, method of storage, treatment/disposal of waste and hauler, and information on USTs. This database also includes a unauthorized release list, which includes a summary of environmental contamination cases in San Diego County.

  According to the EDR Database, the subject site maintains an active San Diego County HMMD permit. There is a small quantity generator on site, for which violations exist. Additionally, the site produces the following hazardous waste: asbestos-containing waste, other inorganic solid waste, waste oil and mixed oil, liquids with halogenated organic compounds, and unspecified organic liquid mixture with a reported disposal method of disposal, landfill, and recycler. The potential for an environmental condition to exist on-site as a result of PCE is considered to be low since no contamination was reported.

- **San Diego Gas & Electric Silvergate Power Plant (1348 Sampson Street)**: This property was listed within the Resource Conservation and Recovery Act Information–Small Quantity Generator (RCRA-SQG), Facility Index System/Facility Identification Initiative Program Summary Report (FINDS), Aboveground Storage Tank (AST), Historical Underground Storage Tank (HIST UST), and Leaking Underground Storage Tank (LUST) databases. The RCRA-SQG database includes selective information on properties that generate, transport, store, treat and/or dispose of quantity generators. SQGs generate between 100kg and 1,000kg of hazardous waste per month. The FINDS database contains both facility information and guidance to other sources that contain more detail. The AST database contains information on sites that maintain aboveground petroleum storage tank facilities. The HIST UST database is a historical listing of UST sites. The LUST database maintains information on leaking underground storage tank incident reports.

  According to the EDR Database the subject site maintains a small quantity generator, however no violations exist. There are five historical USTs reported for the subject site which were used to store diesel fuel and waste. One 21,459-gallon AST is present within the subject site as well. Diesel contamination occurred to soil only within the subject site. The case was closed on February 4, 1988. Additionally, the subject site has an inactive San Diego Co. HMMD permit. The potential for an environmental condition to occur on-site appears to be low due to the status of the subject site.

The lists identified fifty-five listed regulatory properties located within a one-mile radius of the subject site. A potential REC on the subject site caused by these properties is considered to be high due to the groundwater flow direction towards the subject site, proximity of the subject site, and/or the status of the identified site. Refer to Section 3.0, *Historical and Regulatory Information Searches*, for a detailed discussion.

1.2.6 Historic Recognized Environmental Condition

A *"historic recognized environmental condition"* (HREC) is defined as a condition which in the past would have been considered a REC, but which may or may not be considered a REC currently. HRECs are generally conditions, which have in the past been remediated to the satisfaction of the responsible regulatory agency. Based on this definition, no HRECs have been noted within the boundaries of the subject site.

1.2.7 Historical Use(s) Information

Based upon the site inspection, review of available historical aerial photographs, and interview, the subject site has consisted of the Sivergate Substation since 1948. Prior to 1948 the subject site consisted of a lumberyard. Therefore, the potential that adverse environmental conditions were created by historic activities on-site is considered to be low.

Table 1
Summary of Findings

ISSUE	Not noted	Noted	Historical	*De Minimus*	REC	HREC	Data Source (Section No.)	Comment
Existing Structure(s)		X					Site Inspection	Three structures are present on-site.
Evidence of Past Uses (Foundations/ Debris)	X							
Hazardous Substances Storage		X					Site Inspection	
• Staining/Odors/Poor Housekeeping		X					Site Inspection	Staining was noted on soil and concrete.
• Absent Secondary Containment	X							
• Unauthorized Disposal/Discharge	X							
Aboveground Storage Tank(s) (ASTs)		X					Site Inspection	Several ASTs were noted within the parking lot area.
Underground Storage Tanks(s) (USTs)/ Dispenser(s)		X					Interview	It was noted that several USTs were present within the substation portion of the subject site.
Soil Staining/Pooled Liquid(s)		X					Site Inspection	Soil staining was noted within the substation portion of the subject site.
Potential PCB-Containing Equipment		X					Site Inspection	Transformers and power lines were noted throughout the subject site.
Subsurface Hoist(s) or Hydraulic Equipment		X					Site Inspection Interview	Hydraulic equipment (pumping and piping equipment) was noted throughout the subject site.
Floor Staining/Pavement Staining		X					Site Inspection	Staining was noted throughout all portions of the subject site.
Floor Drain(s)		X					Site Inspection	Floor drains were noted within the power plant structure and the southern parking lot.
Drainage ditches, ravines, gullies	X							
Pit(s), Pond(s), Basin(s), Lagoon(s), Surface Waters		X					Site Inspection	Surface water was noted within the southern portion of the subject site.
Stressed Vegetation	X							
Septic System(s)/Dry Well(s)	X							
Soil Pile(s)	X							
Miscellaneous Debris Pile(s)	X							
Domestic Water Well(s)	X							
Agricultural Water Well(s)	X							
Groundwater Monitoring Well(s)	X							
Oil Well(s)/Suspected Drilling Mud Pits	X							
Sump(s)/Oil-water Separator(s)	X							

Undocumented Pipe(s)	X							
Subsurface Pipeline(s)		X					Site Inspection Interview	Pipelines were noted throughout the subject site.
Adjacent or Vicinity Property Issue(s)		X					Site Inspection	Several adjacent properties exhibited potential to pose environmental concerns on the subject site.
Agricultural Chemicals Storage or Mixing	X							
Groundwater Issue(s)	X							
Railroad Tracks or Spur(s)		X					Site Inspection	An abandoned railroad track was noted traversing the subject site.
Mine(s) or Mining Activities	X							
Sewer Lateral(s)/Pipeline(s)	X							
Vehicle/Equipment Servicing or Repairing	X							
Gasoline Station Usage History	X							
Dry Cleaner Usage History	X							
Industrial/Commercial Usage History		X					Site Inspection	The subject site has consisted of a power plant since 1948.
Observed High-Voltage Power Lines		X					Site Inspection	One portion of the subject site consists of a electrical substation.
• Transformers		X					Site Inspection	Transformers were noted within the substation portion of the subject site.
Clean-up Lien(s)	X							
Data Failure	X							
• Unknown Date of First Development	X							
• Unknown Date of Sewer Connection	X							
• Other	X							

1.2.8 Opinions/Recommendations

Based on the records and other data reviewed during the preparation of this Phase I ESA, in accordance with ASTM Standard Practice E 1527-00 and the scope-of-services, and subject to the limitations thereof, the following measure is recommended:

- Every floor of the on-site structure within the subject site should be visually inspected prior to decommissioning, demolition, or renovation activities, with particular attention to all industrial uses. Should hazardous materials be encountered within the on-site structure, the materials should be tested and properly disposed of in accordance with State and Federal regulatory requirements. Any stained soils or surfaces underneath the removed materials should be sampled. Results of the sampling would indicate the appropriate level of remediation efforts that may be required.

- Based on the year the existing structures located within the subject site were built (prior to 1978); LBP and ACMs may be present within the structures present in **Areas 1** and **2**.

  According to previously conducted Phase I and Phase II ESA's, samples have [illegible]

  plant indicate that approximately ten percent of the building surfaces and painted equipment have peeling paint. If during demolition and decommissioning activities of the structures, paint is separated from the building material (e.g., chemically or physically), the paint waste should be evaluated independently from the building material to determine its proper management. According to the Department of Substances Control, if paint is not removed from the building material during demolition (and is not chipping or peeling), the material could be disposed of as construction debris (a non-hazardous waste). It is recommended that the landfill operator be contacted in advance to determine any specific requirements they may have regarding the disposal or lead-based paint materials.

ACMs have been identified and located on all floors of the power plant building, the administration building, and on all three roof levels of Silvergate. Any decommissioning or demolition of the existing buildings must comply with State law, which requires a contractor, where there is asbestos-related work involving 100 square feet or more of ACMs, to be certified and that certain procedures regarding the removal of asbestos be followed. Workers should be notified of the presence of ACMs as required by California State Law; and an Asbestos Management program should be implemented to prevent further damage of the ACMs.

- All miscellaneous equipment, materials, wood pallets, 55-gallon drums, and miscellaneous stockpiled debris should be removed off-site and properly disposed of at an approved landfill facility. Once removed, a visual inspection of the areas beneath the removed materials should be performed. Any stained soils observed underneath the removed materials should be sampled. Results of the sampling (if necessary) would indicate the level of remediation efforts that may be required.

- Due to the visible evidence of surficial staining of potential oil/petroleum products located within the industrial portions of the subject site, and due to the on-site historical/present land use (auto services and metal-working), stained concrete and soils should be excavated and removed to determine the exact vertical extent of the contamination. If during soil/concrete removal, staining (evidence of petroleum products) appears to continue below the ground surface, sampling should be performed to characterize the extent of contamination and identify appropriate remedial measures.

- PCB fluids may be present within hydraulic lifts located within the interior of the on-site structures. The primary concern with hydraulic lifts is the potential for subsurface contamination associated with hydraulic fluid leakage from the lift's position. Therefore, it is RBF's opinion that, at minimum, the hydraulic fluids should be tested to determine the presence or absence of PCBs. Additional confirmation samples should be collected around the pistons to determine if a subsurface release of hydraulic fluids has occurred. If found, appropriate remedial measures should be implemented to the satisfactory of the lead regulatory agency.

- Any transformers to be relocated during site construction/demolitions should be conducted under the purview of the local utility purveyor to identify proper handling procedures regarding potential PCBs.

site. The specific location of the documented USTs should be determined. Once found, the USTs should be removed and properly disposed of at an approved landfill facility. Once the USTs are removed, a visual inspection of the areas beneath and around the removed USTs should be performed. Any stained soils observed underneath the USTs should be sampled. Results of the sampling (if necessary) would indicate the level of remediation efforts that may be required.

◆ According to the current on-site tenant interview, one 21,495 gallon AST is located on-site. However, several additional ASTs were noted during the site inspection within **Area 3** and **Area 4**. The ASTs should be removed and properly disposed of at an approved landfill facility. Once the ASTs are removed, a visual inspection of the areas beneath and around the removed ASTs should be performed. Any stained soils observed underneath the ASTs should be sampled. Results of the sampling (if necessary) would indicate the level of remediation efforts that may be required.

◆ Active and inactive railroad beds frequently have concentrations of petroleum products and lead elevated above natural background conditions. Petroleum product concentrations and lead concentrations are derived from drippings from rail vehicles and flaked paint, respectively. Wooden railroad ties may contain preservatives (i.e., creosote), some of which may contain hazardous constituents. Track switch locations often have elevated levels of petroleum hydrocarbons. Inorganic and organic herbicides, along with diesel fuel, may have been used for vegetation control.

Due to the historic railroad that traverses the subject site, and the portion of the track that has been paved over, the presence of gasoline, diesel, and/or creosote underneath the concrete and surrounding the railroad is likely. Any removal/relocation of railway during site decommissioning, demolition, or construction should be conducted under the purview of the local regulatory agency to identify proper handling procedures. Once the railroad tracks are removed, a visual inspection of the areas beneath and around the removed tracks should be performed. Any stained soils observed underneath the tracks should be sampled. Results of the sampling (if necessary) would indicate the level of remediation efforts that may be required.

◆ Due to the age of the on-site structure, the presence of mercury within the on-site gauges is likely. Any removal/relocation of gauges during site demolition/decommissioning should be conducted under the purview of the local regulatory agency to identify proper handling procedures. Additionally, removed gauges should be disposed of at an appropriate permitted landfill location.

◆ Any recommendations made in the previous Phase I and Phase II ESAs conducted by IT Corporation should be complied with in addition to the recommendations made in this Phase I ESA.

◆ If unknown wastes or suspect materials are discovered during construction by the contractor, which he/she believes may involve hazardous waste/materials, the contract shall:

- Immediately stop work in the vicinity of the suspected contaminant, removing workers and the public from the area;
- Notify the Project Engineer of the implementing Agency;

[illegible]

- Notify the implementing agency's Hazardous Waste/Materials Coordinator.

1.3 SCOPE OF SERVICES AND METHODOLOGY USED

The scope of this Phase I ESA follows guidance provided in ASTM Standard Practice E 1527-00. The ASTM 1527-00 document outlines a procedure for completing ESAs that includes a review of records, site reconnaissance, and interviews where possible. The ASTM document recommends the following regulatory database search distances from a property:

- National Priorities List (NPL)-1.0 mile
- RCRA Corrective Action Report (CORRACTS)-1.0 mile
- Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS/NFRAP)-0.5 mile
- RCRA Permitted Treatment, Storage, Disposal Facilities (RCRA-TSD)-0.5 mile
- RCRA Registered Small or Large Generators of Hazardous Waste (GNRTR)-0.125 mile
- State CERCLIS (SCL)-0.5 mile
- Toxic Release Inventory Database (TRIS)-0.25 mile
- Leaking Underground Storage Tanks (LUST)-0.5 mile
- Solid Waste Landfill List (SWLF)-0.25 mile
- RCRA Violations/Enforcement Actions (RCRA Viol)-0.25 mile
- Registered Underground or Aboveground Storage Tank Database (UST/AST)-0.25 mile
- ERNS and State Lists (SPILLS)-0.125 mile

The objectives of the Phase I ESA contained herein are as follows:

Evaluate the potential for hazardous materials on the subject site based upon readily discernible and/or documented present and historic uses of the property and uses immediately adjacent to the site; and

Generally characterize the expected nature of hazardous materials that may be present as a result of such uses, within the limits imposed by the scope of this Assessment.

This Assessment is not intended to provide specific qualitative or quantitative information as to the actual presence of hazardous materials at the site, merely to identify the potential presence based on available information. To achieve the objectives of this Assessment, RBF conducted a Phase I ESA of the subject site to provide preliminary conclusions relative to site conditions.

The assessment included the following components, which are designed to aid in the discovery and evaluation of recognized environmental conditions:

- RBF performed site visits on February 1, 2005 and February 24, 2005 consisting of a visual examination of the subject site for visual evidence of potential environmental concerns including existing or potential soil and groundwater contamination, as evidenced by soil or pavement staining or discoloration, stressed vegetation, indications of waste dumping or burial, pit, ponds, or lagoons; containers of hazardous substances or petroleum produces; electrical and hydraulic equipment that may contain PCBs, such as electrical transformers and hydraulic hoists; and underground and above ground storage tanks. RBF observed the physical characteristics of the property (i.e., apparent runoff directions, location of paved areas, etc.). It should be noted that the site visit specifically excluded any subsurface investigation including, but not limited to, sampling and/or laboratory analysis.

- An investigation of historical use of the subject site by examining locally available aerial photographs (one source) and other readily available historical information, for evidence of potential environmental concerns associated with prior land use.
- A review of information available on general geology and topography of the subject property and local groundwater conditions.
- A review of environmental records available from the property owner or site contact including regulatory agency reports, permits, registrations, and consultant's reports for evidence of potential environmental concerns.
- A site property line visual assessment of adjacent properties for evidence of potential off-site environmental concerns that may affect the subject property.
- A review of a commercial database summary (provided by Environmental Data Resources [EDR]), of federal, state and local regulatory agency records pertinent to the subject property and off site facilities located within ASTM-specified search distances for the subject property.
- RBF compiled the data reviewed, discussed findings, formulated conclusions, opinions and recommendations, and prepared this written report presenting the findings of the Phase I ESA.
- The performance of the Phase I ESA was not limited by any extraordinary conditions or circumstances.

1.4 LIMITING CONDITIONS OF ASSESSMENT

The findings and professional opinions of RBF are based on the information made available to RBF (listed in Section 6.0, *References*) from public records, and should be understood to be preliminary only.

RBF makes no warranties either expressed or implied, concerning the completeness of the data made available to us for this study and withholds certification of any type concerning the presence or absence of contamination of the subject site. RBF is not responsible for the quality or content of information from these sources. The report states our conclusion based on the limitations of our Scope-of-Services, in accordance with generally accepted standards for a Phase I Environmental Site Assessment.

Subsurface exploration, geologic mapping, laboratory testing of soil or water samples, lead and asbestos sampling, and operations/inventory review of adjacent uses were not performed in connection with this Assessment. This Assessment represents our professional judgment, based on the1- level of effort described above, as to the present potential for hazardous materials at the site.

Subsurface exploration, sampling and laboratory testing should be performed if it is deemed necessary or required to quantify the actual absence or presence of hazardous materials and recommend possible remediation measures for such hazardous materials (a "Phase II" investigation).

This Assessment addressed the likelihood of the presence of hazardous substances

and nearby properties. Certain conditions, such as those listed below, may not be revealed:

- Naturally occurring toxins in the subsurface soils (i.e., radon), rocks, or water, or toxicity of the on-site flora;

- Toxicity of substances common in current habitable environments, such as stored household products, building materials, and consumables;
- Biological pathogens;
- Subsurface contaminant plume from a remote source;
- Contaminants or contaminant concentrations that do not violate present regulatory standards but may violate such future standards; and
- Unknown site contamination, such as "midnight dumping" and/or accidental spillage, which could have occurred after RBF's site visit.

The information and opinions rendered in this Assessment are exclusively for use by Sempra Utilities. RBF will not distribute or publish this report without the consent of Sempra Utilities, except as required by law or court order. The information and opinions expressed in this Assessments are given in response to RBF's Scope-of-Services and Limitations indicated above and should be considered and implemented only in light of the Scope-of-Services and Limitations. The services provided by RBF in completing this Assessment were consistent with normal standards of the profession. No warranty, expressed or implied, is made.

2.0
PHYSICAL SETTING

Physical setting sources typically provide information regarding geologic, hydrogeologic, hydrologic, or topographic characteristics of a property. The following information is primarily based on review of the United States Geological Survey (USGS) Point Loma, California Quadrangle, dated 1994 and site inspections conducted by RBF on February 1, 2005 and February 24, 2005. Other miscellaneous resources utilized within this section and throughout the Assessment are referenced in Section 6.0, REFERENCES.

2.1 SUBJECT SITE DESCRIPTION

2.1.1 Location

The subject site is located at 1348 Sampson Street within the City of San Diego, County of San Diego, State of California (T.7S, R.2W, San Bernardino Base and Meridian [SBBM]). Specifically, the subject site is located south of Harbor Drive and west of Sampson Street.

2.1.2 Current Use(s) of the Subject Site

The subject site is comprised of two complete parcels and two partial parcels, defined by APNs 538-700-01, 02 and portions of 05 and 06, which comprise a gross acreage of 5.58-acres. Parcel 01 is also defined by a street address, 1304 Sampson Street, and parcel 02 is defined by 1348 Sampson Street. Currently, the subject site consists of four areas, the Silvergate Power Plant (**Area 1**), an electrical substation (**Area 2**), a parking lot (**Area 3**), and the PCE property (**Area 4**).

2.1.3 Description of On-Site Structures and Roads

The main plant structure contains four generating units, numbered 1, 2, 3, and 4. The building structure in **Area 1** is approximately 490 feet long by 125 feet wide and consists of six floors, a mezzanine, and a basement. The basement is located approximately 16 feet below street level. The building houses six boilers and four steam turbine-driven generating units.

The switchyard (**Area 2**) which also contains substation equipment is a group of exposed steel framed structures with a complex wiring system located north of **Area 1**. **Area 2** previously acted as a switchyard for the active power plant. Today the area is an active San Diego Gas & Electric substation. Several underground storage tanks, and associated electrically driven pumps used to store fuel oil are located under the substation. Four aboveground control houses are located in **Area 2**.

Area 3 consists of a parking lot and a miscellaneous equipment storage area. The property is approximately 40 feet wide and is rented by Kelco, Inc.

Area 4 is owned and operated by Propulsion Controls Engineering. The property consists of one structure and a parking lot/maintenance yard located to the west and south of the structures.

2.1.4 Zoning/Land Use Records

Zoning/land use records generally consist of records maintained by the local government in which the subject site is located. They indicate the uses permitted by the local government for particular zones within its jurisdiction. The records may consist of maps and/or written records. According to the City of San Diego, the subject site is zoned as Barrio Logan Planned District- Subdistrict D (refer to Appendix B, *Documentation*).

2.2 TOPOGRAPHY

The USGS maps show geological formations and their characteristics, describing the physical setting of an area through contour lines and major surface features including lakes, rivers, streams, buildings, landmarks, and other factors that impact the spread of contamination. Additionally, the maps depict topography through color and contour lines and are helpful in determining elevations and site latitude and longitude.

Based on the USGS Point Loma, California Quadrangle, photorevised in 1994, on-site topography is approximately 20 feet above msl and gently slopes to the west, towards the San Diego Bay. The subject site appears to consist of several structures. Main Street and vacant land appear to exist to the north of the subject site. Structures are noted to the east and west, and railroad tracks, Harbor Drive, and structures are noted to the south of the subject site. No on-site pits, ponds, or lagoons were noted on this topographical map.

2.3 CURRENT USES OF ADJOINING PROPERTIES

For the Scope of this Assessment, properties are defined and categorized based upon their physical proximity to the subject site. An adjoining property is considered any real property or properties the border of which is contiguous or partially contiguous with that of the subject site, or that would be contiguous or partially contiguous with that of the subject site but for a street, road, or other public thoroughfare separating them. An adjacent property is any real property located within 0.25 miles of the subject site's border. The following is a detailed description of each adjoining land use observed on February 1, 2005 and February 24, 2005.

North:	Main Street, another electrical substation, and other industrial uses are present to the north of the subject site.
East:	Sampson Street, a SDG&E substation yard, and industrial uses are present to the east of the subject site.
South:	The Southwest Marine parking lot, railroad tracks, Harbor Drive, and the Southwest Marine shipyard are located to the south of the subject site.
West:	Kelco, a division of Monsanto, and a chemical plant are located to the west of the subject site.

2.4 GEOLOGIC CONDITIONS

2.4.1 Geology

The USGS Geological Map Index was searched by EDR for available Geological Maps [illegible] geological formations that are overlaid on a topographic map. Some maps focus on specific issues (i.e., bedrock, sedimentary rocks, etc.) while others may identify artificial fills (including landfills). Geological maps can be effective in estimating permeability and other factors that influence the spread of contamination.

According to the EDR Report, the subject site is underlain by urban land. The land consists of a stratified sequence from the Cenozoic era. The depth to bedrock is greater than ten (10) inches.

2.4.2 Soils

According to the *Soil Survey of the San Diego Area, California (1973)*, the subject site is situated on the Huerhuero-Stockpen soil association. This association consists of moderately well drained loams to gravelly clay loams that have a subsoil of clay or gravelly clay. The soil exists on 0 to 9 percent slopes. One soil series is present on the subject site and is briefly described below:

Urban Land (UR): Urban land consists of closely built-up areas in cities. Buildings, streets, and sidewalks cover almost all of the surface. The soil has been so altered by urban works that identification is not feasible.

2.4.3 Radon

Radon is a radioactive gas that is found in certain geologic environments and is formed by the natural breakdown of radium, which is found in the earth's crust. Radon is an invisible, odorless, inert gas that emits alpha particles, known to cause lung cancer. Radon levels are highest in basements (areas in close proximity to the soil) that are poorly ventilated. It should be noted that a radon survey was not included within the scope of this investigation. However, according to the "*U.S. EPA Map of Radon Zones*," the County of San Diego is located within Zone 3, which has a predicted average indoor screening level of <2.0 Picocuries per liter (pCi/L). EPA recommends remedial actions when radon levels are greater than 4.0 pCi/L.

2.5 BIOLOGICAL SETTING

The subject site is completely constructed. No vegetation is present within the subject site or surrounding properties. The vegetation present is along roadways and consists of that typical of highly disturbed areas and roadways. The plants and animals in the developed surrounding areas have been introduced by man and are tolerant to urban land uses.

2.6 DRAINAGE/HYDROLOGY

2.6.1 Drainage

Drainage of the site is accomplished by downward surface percolation and overland sheet flow, which is generally in a southern direction across the subject site towards the San Diego Bay.

2.6.2 Flood Hazards

Flood Prone Area Maps published by the USGS show areas prone to 100-year floods overlaid on a topographical map. [illegible]

Emergency Management Agency (FEMA) flood maps; therefore, in cases where a property is located immediately adjacent to or within the flood prone boundary, a FEMA map should be obtained. If the Flood Prone Area Map indicates that the flood boundary is not nearby, a FEMA map can be provided. According to the EDR Database search, the subject site is not located within a 100-year flood zone. Refer to the Appendix A, *EDR Report*.

2.7 GROUNDWATER AND WATER WELLS

No technical groundwater or water well data was readily available for the subject site during the preparation of this Assessment. As a result, RBF assumes groundwater flow would follow the slope of the ground surface elevations towards the nearest open body of water or intermittent stream. The direction of this flow on-site is expected to be generally in a western direction.

Table 2
Summary of Property Information

General Location:	South of Harbor Drive, west of Sampson Street
Assessor's Parcel Number:	538-700-01, 02 and 05, 06
Topographic Map:	Point Loma, California
Topographic Location:	Within Township 17 South, Range 2 West, San Bernardino Base and Meridian
Topography:	Relatively flat. Elevation is approximately 20 feet above msl
Approximate Depth to Groundwater:	Greater than six feet
Regional Groundwater Flow Direction:	West
Existing Use:	Electric power plant, substation, parking lot, and industrial use.

3.0
HISTORICAL AND REGULATORY INFORMATION SEARCHES

The ASTM Phase I Standard (E1527-00) allows discretion in choosing from among eight standard sources, plus "other" non-specific sources (other non-specific sources can include newspaper archives and records in the files and/or personal knowledge of the property owner and/or occupants). The standard sources are fire insurance maps, historical topographic maps, street directories, aerial photographs, property tax files, building department records, planning department records, and a chain-of-title. The focus is on usage rather than ownership, which is why a chain-of-title is not required and not sufficient by itself.

Historical subject site use information was obtained from ***1921*** *to the present. Per ASTM, historical uses "shall be identified from the present, back to the* ***property's obvious*** *first development use [including agricultural and fill activities], or back to 1940, which ever is* ***earlier.****"*

3.1 HISTORICAL SITE USAGE

The following historical information is based upon review of available historical maps and documents, available public information, interviews, and a review of a series of historical aerial photographs dating from 1921 to 1971.

3.1.1 Interviews

3.1.1.1 City of San Diego Building Department

RBF interviewed staff with the City of San Diego Building Department on February 24, 2005. City staff indicated that building records were only available from the 1950's to the present. Refer to Section 3.2.1.1 for a summary of reviewed building department records.

3.1.1.2 San Diego Gas & Electric Staff

RBF interviewed Mr. Chris Terzich with San Diego Gas & Electric during the February 1, 2005 site investigation. Mr. Terzich lead the site inspection and provided information regarding current and historic uses of the subject site as well as information on potential areas of concern for the Phase I ESA. Mr. Terzich indicated that several portions of the subject site were unavailable for inspection due to safety concerns, including the elevators, basement, and all floors except the first and second floors.

During the site investigation, Mr. Terzich indicated that the power plant was constructed in 1948 and has been out of operation since 1982. He also mentioned that March 2005 is the proposed de-energizing/decomissioning date for the substation in **Area 1**.

During the site inspection, Mr Terzich pointed out potential areas of concern. These areas included the boilers and turbines located on the first and second floors, the presence of mercury in the gauges, the presence of lead based paint, polychlorinated biphenyls, and asbestos containing materials. Mr. Terzich pointed out several areas of surficial staining, both within the power plant and within the substation area. Mr. Terzich mentioned that the railroad tracks within the subject site were historically used for loading materials. Within the substation area (**Area 2**) of the subject site, Mr. Terzich indicated that several USTs were located under the manhole covers. He indicated that these tanks were historically used to store fuel and that all on-site tanks are empty.

3.1.1.3 CP Kelco Plant Manager

RBF interviewed Mr. Andrew Currie with CP Kelco during the February 1, 2005 and February 24, 2005 site inspections. Mr. Currie indicated that he leases **Area 3** of the subject site from PCE. This leased portion of the site is utilized as a parking lot and a storage area for miscellaneous equipment, tanks, and 55-gallon drums.

3.1.1.4 Propulsions Control Engineering President

RBF interview Mr. David Carr during the February 24, 2005 site inspection and through a written questionnaire. According to Mr. Carr petroleum products, degreasers, solvents, and paints are stored within **Area 4** of the subject site. Additionally, hazardous waste and used oil are stored on the property in drums. Mr. Carr indicated during the site inspection that the property has its own stormwater drainage system. This system is located in the northwest corner of his property and a UST is located within that area to catch the runoff.

3.1.1.5 City of San Diego Fire Department

The previous Phase I Report, prepared by IT Corporation, conducted an interview with the San Diego Fire Department. This interview indicated that two permits for the installation of tanks for inflammable/flammable liquids were on record with the fire department. The dates on the permits are October 24, 1950 and April 7, 1961. The 1961 permit refers to three USTs. Fire Department records were not reviewed during the course of this Phase I Assessment due to the decommissioning of the Substation in 1982. It is anticipated that no further records are on file with the San Diego Fire Department.

3.2.1 Documentation

3.2.1.1 Building Department Records

Building Department Records are those records of the local government in which the subject site is located indicating permission of the local government to construct, alter, or demolish improvements on the property. The purpose for a records review is to obtain and review available building permit records, which would help to evaluate potentially recognizable environmental condition(s), which could be connected with the subject site. Generally, Building Department Records are based on a property's street address. RBF contacted the City of San Diego on February 24, 2005. Records are maintained by the City from the 1950's to present. City staff indicated that records for the PCE property did

Phase I report prepared by IT Corporation for the subject site, one building department record is on file for the Silvergate Substation and consists of a plumbing permit (refer to Appendix B, *Documentation*).

3.2.1.2 Recorded Land Title Records

Recorded land titles are records usually maintained by the municipal clerk or county recorder of deeds which detail ownership fees, leases, land contracts, easements, liens, deficiencies, and other encumbrances attached to or recorded against the subject site within the local jurisdiction having control for or reporting responsibility to the subject site. RBF reviewed a 60-Year Property Chain-of-Title (dated January 6, 2005), provided by PDS Enterprises, in an effort to identify past ownership, and if possible, historical uses of the subject site. A summary of the subject site's 60-year ownership is presented in Table 1, *Property Chain-of-Title.*

Table 3
Property Chain-of-Title

Date	Document	Grantor	Grantee	Document No.
APN 538-700-01				
2/1/56	Grant Deed	Atchinson, Topeka, & Santa Fe Railway Company	William Volker & Company of Los Angeles	19417
2/14/67	Grant Deed	William Volker & Company of Los Angeles	William Volker & Company	20068
8/2/82	Grant Deed	William Volker & Company	Bayside Harbor Properties	272076
APN 538-700-02				
This property under APN No. 538-700-02 has been owned prior to 1945 by San Diego Gas and Electric Company as per Map No. 538, dated 1945.				
APN 538-700-05				
12/23/91	Grant Deed	Atchinson Topeka & Santa Fe Railway Company	Merck & Company, Inc.	66641
2/23/95	Grant Deed	Merck & Company, Inc.	Kelco Company	78890
APN 538-700-06				
12/23/91	Grant Deed	Atchinson Topeka & Santa Fe Railway Company	Merck & Company, Inc.	66641
2/23/95	Grant Deed	Merck & Company, Inc.	Kelco Company	78890

Source: PDS Enterprises, Property Chain-of-Title for APNs 538-700-02 and 06, dated February 7, 2005 and APNs 538-700-01 and 06, dated February 13, 2005.

3.2.1.3 Property Data

RBF searched property data for the subject site via *First American Real Estate Solutions.* This data typically provides current property ownership information and includes information regarding on-site improvements, zoning, land use, transfer of last sale, and other miscellaneous structural improvements. According to the property data, the subject site has a land use of residential acreage. No further property information was available for the subject site during this Assessment; however, the subject parcels (358-700-01, 02, 05, and 06) have been recorded and mapped (a copy of the parcel map has been included in Appendix B, *Documentation*). No further available information with respect to property data was reviewed during this Assessment.

3.2.1.4 City Directory Searches

City Directories, published by private companies (or sometimes the government), provide a chronological sequence of past site ownership, occupancy, and/or uses for a property by reference of an address. This type of search is particularly effective to determine the past uses of developed properties. Since no street address is available for the subject site, no City Directory was available.

3.2.1.5 Sanborn Fire Insurance Maps

Sanborn Maps contain detailed drawings, which indicate the location and use of structures on a given property during specific years. These maps were originally produced to show buildings in sufficient detail for insurance underwriters to evaluate fire risks and establish premiums, but now are utilized as a valuable source of historical and environmental risk information. Nine (9) Sanborn Maps were available (provided by EDR) for the subject site or immediate vicinity. Review of available Sanborn Maps, dated 1921, 1950, 1956, 1959, 1960, 1962, 1965, 1970, and 1971, provided the following chronological sequence of site history. Copies of the historical topographic maps as well as the most recent topographic map are presented in Appendix B, *Documentation.*

1921: In the 1921 Sanborn Map the subject site appears to consist of a lumber yard. Colton Avenue is present to the north and Sampson Avenue is present to the east of the subject site. The Atchinson, Topeka, and Santa Fe Railroad is present to the south of the subject site with the San Diego Bay located directly south of the railroad. The San Diego Marine Construction Company is located to the south of the subject site and is located on a wharf, which extends into the San Diego Bay.

1950: In the 1950 Sanborn Map, the subject site consists of the San Diego Gas and Electric Silvergate Substation. It is noted that transformers and buried tanks are located within **Area 1**. The Sanborn Map also indicates that the on-site structure was built in 1948. Vacant land is present to the north of the subject site. A San Diego Gas and Electric substation is located to the east of the subject site, along with the Richfield Oil Corporation Oil Depot. The railroad remains present to the south. However, the wharf has decreased in size and the land present to the south has increased. Several structures associated with the San Diego Marine Construction Company have been constructed on the land. A planned wharf is present to the southeast of the subject site.

1956-
1959: The subject site in the 1956-1959 Sanborn Map appears similar to the 1950 subject site however, a road is present to the north of substation and a structure has been constructed north of the road and is labeled WM Volker and Company. The road dead-ends in the western portion of the subject site. A freight terminal is present to the east of the subject site, located south of the SDG&E Substation. A structure that is labeled "oil and grease" is present to the southeast of the

1960-
1971: The 1960-1971 Sanborn Maps appear similar to the 1956-1959 maps, however, the road has been connected off-site and the WM Volker and Company property has been extended to reach Sampson Avenue. The remainder of the subject site

and surrounding land uses appear unchanged. Additionally, in the 1965-1971 maps, the property located to the southeast, labeled Oil & Grease, has expanded further to the east.

Based on review of the above referenced Sanborn Maps, the subject site appears to have consisted of lumberyard, the power plant, an electrical substation, and the WM Volker property. The presence of an REC on-site is considered likely due to the historic industrial use of the subject site.

3.2.1.6 Historical Topographic Maps

RBF reviewed historical topographic maps dated 1942 through 1996, for the subject site and adjacent areas provided by EDR. No visible or physical evidence of a REC associated with the subject site was noted during review of the available historical topographic maps. Review of available historical topographic maps provided the following chronological sequence of site history. Copies of the historical topographic maps as well as the most recent topographic map are presented in Appendix B, *Documentation.*

1930: In the 1930 USGS San Diego, California Quadrangle, the subject site appears to consist of vacant land. However, detail on the subject site is not visible due to the scale of the map. The 1930 Quadrangle is a 15-minute series topographic map. These maps typically label major peaks, railroads, lakes, and rivers; however, often time they lack detail as far as specific elevations, roadways, and detailed land uses. No on-site pits, ponds, or lagoons were noted on the 1930 topographic map.

1942: In the 1942 USGS Point Loma, California Quadrangle, the subject site appears to consist of vacant land. The subject site is located at approximately 25 feet above mean sea level. A street grid system is located around the subject site. The SD and AE Railroad is present to the northeast of the subject site and the Atchinson, Topeka, and Santa Fe Railroad is present to the southwest. Sampson Street is present to the southeast. The San Diego Bay is located to the south of the subject site. No pits, ponds, or lagoons were noted on the 1933 topographic map.

1953: In the 1953 USGS Point Loma, California Quadrangle, the subject site appears to consist of vacant land. The surrounding land uses appear similar to those viewed in the 1942 Quadrangle, however Highway 101 is present to the northeast of the subject site. No pits, ponds, or lagoons were noted on the 1953 topographic map.

1967: In the 1967 USGS Point Loma, California Quadrangle, the subject site appears to consist of the Silvergate Power Plant, substation, and the PCE structure. A railroad track is located to the northeast of the substation area of the subject site. Harbor Drive and several unidentified structures are present to the northeast of the subject site. Several round unidentified structures are present to the southeast of the subject site and unidentified structures are present to the

site. No on-site pits or lagoons were noted on the 1967 topographic map.

1967-
1994: In the 1967 through 1994 USGS Point Loma, California Quadrangle, on-site topography is similar to that viewed in the 1967 7.5-Minute Quadrangle.

However, several additional structures have been constructed to the southeast of the subject site. No on-site pits, ponds, or lagoons were noted on the 1958-1974 topographic map.

1996: In the 1996 USGS Point Loma, California Quadrangle, the subject site appears to consist of the Silvegate Power Plant. The railroad track remains present within the subject site. Several of the surrounding structures appear to have been removed as well. No on-site pits, ponds, or lagoons were noted on the 1996 topographic map.

Based on review of the above referenced historical topographic maps, the subject site appears to have consisted primarily of vacant land and agricultural uses.

3.2.1.7 Historical County Planning Maps

Beginning in the 1930's, historical county planning maps were used by highway departments to disburse federal funding based on each county's road system. Some states just mapped roads, but many added cultural features such as farms and factories. These features were usually shown everywhere except within city limits. These maps are especially useful in conjunction with historical topographic maps. The topographical map can indicate the size, shape, and location of structures, while the historical county planning map can identify their use. However, this Assessment has relied upon other standard historical information sources assumed to be either more accurate or informative than Historical County Planning Maps.

3.2.1.8 California Department of Oil, Gas, and Geothermal Resources

RBF reviewed a Wildcat Map provided by the California Department of Oil, Gas, and Geothermal Resources (DOGGR). These maps indicate existing and historical oil and gas wells within the immediate vicinity of the subject site. Current well status for any well indicated on the Wildcat Maps should be confirmed at the appropriate Division of Oil and Gas District Office. According to the Wildcat Map W1-7, San Diego County, dated February 6, 1999, the subject site does not appear to be located in a sedimentary basin with oil, gas, or geothermal production (refer to Appendix B, *Documentation*).

3.2.1.9 Previous Phase I Environmental Site Assessment Report

A Phase I Environmental Site Assessment was prepared for Sempra Energy by IT Corporation, dated October 10, 2000. The Phase I ESA was performed on **Area 1** of subject site. According to the Phase I, the subject site consists of four parts, the Main Power Plant; the Cooling Water System; the Switchyard, Fuel Tanks and Pump Room; and the Wastewater Treatment Plant. Based on a site inspection, interviews, and file reviews, IT Corporation provided the following conclusions with regards to the subject site:

The overall condition of the Property is excellent with respect to general housekeeping with the exception of a few areas as noted. The Property appears to be well maintained.

- Visual observations by IT and interviews of former plant employees indicated that asbestos and ACM are present throughout the Property as pipe insulation, boiler insulation, fire brick, roofing material, and other materials. Previous sampling and analysis by Sempra has confirmed the presence of asbestos.
- Visual observations by IT and interviews within former plant employees indicate that lead-based paint and other metal-based paints are present throughout the Property. Lead-based paint may be present on much of the interior and exterior equipment, walls, floors, and ceilings. Metal-based paint may be present as silver thermal paint on the boilers and as yellow paint on the equipment on the CW deck.
- Mercury-filled gauges and thermometers are present throughout the Property. Most of the mercury filled equipment is labeled or otherwise visually identifiable.
- Sediments are present in the plant trench system, sumps, voids and cooling water tunnels. The sediments may contain metals, petroleum hydrocarbons or PCBs due to releases from the Property.
- Residual chromated water is present in the service water system.
- Residual petroleum lubricants are present in the turbine lube oil system and other plant systems.
- Residual fuel oil may be present in fuel pumps.
- Small quantities of maintenance chemicals and cleaning supplies are present on the property.
- The buried former settling pond known as Nobles Lake may contain sediments and soil impacted with petroleum and metals.
- The bay sediments near the cooling water discharge tunnel may be impacted with metals due to past plant discharges from the cooling water tunnel.
- The soil and groundwater below the switchyard may be impacted with petroleum due to past releases from the fuel oil USTs, fuel oil pump house, and associated buried piping.
- PCBs have been detected in transformers, and may be present in light ballasts, auxiliary bank units, and capacitors.

The Phase I Report also indicated that the EDR report identified numerous sites in the vicinity of the Property that had RECs. If soil and groundwater impacts beneath the property become an issue to Sempra, then Sempra is advised to investigate potential off-site sources of contamination before concluding that soil and groundwater impacts are due to past activities at the Property.

3.2.1.10 Phase II Environmental Site Assessment Report

IT Corporation performed a Phase II ESA for **Area 1** of the subject site, dated March 2001. The Phase II ESA focused only on the power plant building and the adjacent circulation water deck. It did not address soil, groundwater, the switchyard, petroleum USTs, former Nobles Lake, or off-site portions of the seawater cooling tunnels.

The assessment revealed evidence of the following RECs:

- Given the age of the structures, it is assumed that the paint on most all surfaces contain lead. Analyses of point samples confirmed the presence of lead in paint. Observations of the power plant indicate that approximately 10 percent of the building surfaces and painted equipment have peeling paint. Demolition and decommissioning activities should be completed by a certified/licensed lead-based paint abatement contractor using DHS-certified workers and supervisors.

- ACMs have been identified and located on all floors of the power plant building, the administration building, and an all three roof levels of Silvergate. Most of the building materials sampled were nonfriable. Within the power plant there are substantial amounts of friable thermal insulation such as pipe insulation, air, exhaust duct insulation, blankets, etc., that were not sampled. These materials have been previously identified as containing asbestos.

  Some of the friable AMCs are damaged and there is debris present on or around some boilers and pipes. Care should be taken to avoid the areas where friable ACM debris is present. Workers should be notified of the presence of ACM as required by California State Law; and an Asbestos Management program should be implemented to prevent further damage of the ACM.

- Sediment analytical results were compared to California State Title 22 TTLC limit values to provide an understanding of the toxicity characteristics of the material in the trenches. Those compounds exceeding TTLC limit values are considered to be contaminants of concern.

  Analytical results from sediment samples collected in the basement trenching system indicate that the sediments contain copper above the TTLC limit value and lead and mercury at the TTLC limit value. Sediment should be removed and disposed of properly.

- Sediment analytical results for sediments collected from the cooling water tunnels indicated that the cooling water sediments do not contain metals in exceedence of the TTLC limit values and TPH concentrations are low. Volatile and semi-volatile organic compounds were detected at minor concentrations in sediments collected from the cooling water tunnels.

- The power plant contains four transformers that potentially contain PCBs at a concentration of less than 50 ppm. The visual survey identified 695 fluorescent light fixtures that likely contain PCBs in light ballasts. The power plant likely contains other PCB articles and PCB equipment.

- Mercury has been identified and located at Silvergate and should be addressed in future decontamination and decommissioning of the site.

3.2.1.11 *County of San Diego Department of Health File Review*

Sites listed in the EDR Database Report that are located within the subject site and within a ¼-mile radius of the subject site were reviewed to determine whether groundwater contamination or other unauthorized releases have occurred which could potentially affect surface or subsurface conditions of the subject site. Typically, contamination plumes within groundwater are relatively localized to the source. Topographic conditions generally dictate the movement of groundwater, thus, the surface gradient is used to determine whether contamination plumes could be moving towards the subject site.

Based on the EDR Database Report and other documents reviewed, six (6) off-site properties are subject to additional data analysis due to its location within ¼-mile of the subject site and/or the indication of groundwater contamination and are listed below. RBF contacted the County of San Diego Department of Health (DOH) in order to request a file search and review. RBF reviewed files at the DOH on February 24, 2005 in an effort to obtain the most recent reported information with respect to adjacent properties that have reported subsurface releases. The following discussion is based on the file review conducted a the DOH on February 24, 2005 (refer to Appendix C, *Documentation*):

- **1348 Sampson Street (SDG&E Silvergate Power Plant):** 1348 Sampson Street consists of the SDG&E Silvergate Power Plant. This site was listed within the RCRA-SQG, FINDS, AST, HIST UST, LUST, Cortese, and San Diego Co. HMMD databases. The RCRA-SQG database is EPA's comprehensive information system, providing access to data supporting the Resource Conservation and Recovery Act (RCRA) of 1976l and the Hazardous and Solid Waste Amendments of 1984. This database maintains information on sites which generate, transport, store, treat and/or dispose of hazardous waste as defined by RCRA. RCRA Small Quantity Generators (SQG) generate between 100 kg and 1,000 kg of hazardous waste per month. The AST database maintains information on properties where an above ground storage tank is located. The HIST UST database contains information on sites where historical underground storage tanks are located. The LUST database contains information on sites that maintain leaking USTs. The Cortese database identifies public drinking water wells with detectable levels of contamination, hazardous substance sites selected for remedial action, sites with known toxic materials identified through the abandoned site assessment program, sites with USTs having a reportable release and all solid waste disposal facilities form where there is know migration. The San Diego Co. HMMD database maintains information on sites that maintain a San Diego County Hazardous Materials Management Division Database permit.

  According to the files reviewed, three USTs, constructed of concrete and steel lined are present within the subject site. The tanks were utilized to store fuel. According to the *Underground Tank Assessment*, conducted by Woodward-Clyde Consultants, the tanks were installed in 1941 and have capacities of approximately 260,000 gallons each. The tanks were drained and cleaned in March 1984 and are presently empty. Soil and groundwater sampling, along with a visual inspection of the tanks was conducted on the subject site. Results of the sampling indicate that TEH concentrations are 60 mg/kg and elevated OVM reading and hydrocarbon odors were observed in the soil samples. The inspections did not provide any direct observations of defects in the liner that would indicate tank leakage had occurred. The files also indicated that the USTs located within the subject site have not been issued a formal closure.

A letter dated August 14, 2000 was addressed to the County of San Diego Department of Environmental Health requesting a cancellation of Health Permit #H13942 for the subject site. The letter indicated that hazardous materials are not stored or generated on-site in a quantity sufficient to warrant maintaining a permit for the facility.

- **2145 East Belt (Kelco):** 2145 East Belt Street (currently occupied by Kelco) is located immediately to the north of the subject site. According to the EDR Report, Kelco is currently listed within the CERCLIS-NFRAP database. The CERCLIS-NFRAP database is the Comprehensive Environmental Response, Compensation, and Liability Information System – No Further Remedial Action Planned database. This database maintains information on sites that have been removed from the CERCLIS list. NFRAP sites may be sites where following an initial investigation, no contamination was found, contamination was removed quickly without the need for the site to be place on the NPL, or the contamination was not serious enough to require Federal Superfund Action or NPL consideration.

  The files reviewed at the County of San Diego consisted of a Phase I/II Report for the Kelco property. This report indicated that some contaminants have been detected in soil and groundwater. However, the concentrations of the contaminants are well below screening levels that could pose a threat to human receptors or the environment.

- **2190 Main Street (Cleaning Dynamics/Pacific Treatment Corp./American Kelp):** 2190 Main Street is located east of the subject site. According to the EDR Report, 2190 Main Street is listed within the REF, HAZNET, LUST, Cortese, RCRA-SQG, FINDS, LUST, RCRA-TSDF, CORRACTS, CERC-NFRAP, and TX Ind. Haz. Waste. The REF database contains information on properties where contamination has not been confirmed and which were determined as not requiring direct Department of Toxic Substances Control Site Mitigation Program action or oversight. Accordingly, these sites have been referred to another state or local regulatory agency. The CORRACTS database identified hazardous waste handlers with RCRA corrective action activity.

  According to the file review, this file was inactiviated as of March 14, 2002. The business had moved from the site as of November 1, 2001 and as of January 29, 2002, no new businesses have moved into the property. No contamination has been reported for this site.

- **1995 Bayfront Street (Continental Maritime):** 1995 Bayfront Street is located west of the subject site. According to the EDR Report, 1995 Bayfront Street is listed within the FINDS, HAZNET, RCRA-LQG, LUST, CHMIRS, RCRA-LQG, and CERC-NFRAP databases.

  According to the field review, tanks are located within the site. However, no issues have been recorded. This site does not pose a potential groundwater threat to the subject site because the groundwater flow is away from the subject

  The file reviewed for 1995 Bayfront Street consists of a Corrective Action Plan (CAP) which is required by the San Diego DEH prior to approval of a closure of an unauthorized release case. The CAP described an unauthorized release case for one former concrete UST that was used to store fuel oil and possibly diesel. A permit for closure in place was granted in 1997, however the UST was not backfilled. Soil and groundwater samples were taken for the Continental Maritime Site. The samples produce a carbon concentration that is below laboratory detection limits. Based on the CAP, it was concluded/recommended that the source of the Continental Maritime release has been removed; the later extent of the release has been adequately assessed; the plume of dissolved-phase hydrocarbons from the release are decreasing in concentration and do not appear to be migrating towards San Diego Bay; there may have been other releases upgradient that may have impacted wells at the site; several potential upgradient sources for these upgradient petroleum hydrocarbons have been identified; and Continental Maritime should not be responsible for further investigations of the upgradient releases.

- **2295 Harbor Drive East (Arco Terminal):** 2295 Harbor Drive East is located south of the subject site. This site is listed within the LUST, Cortese, UST, TRIS, San Diego Co. HMMD, EMI databases. The TRIS database identifies facilities which release toxic chemicals into the air, water, and land in reportable quantities. The EMI database contains information on toxics and criteria pollutant emissions data collected by the ARB and local air pollution agencies.

  According to the file review, the most recent Quarterly Groundwater and Remediation Report, dated January 18, 2005 reported that liquid phase hydrocarbons are present underneath the site. The site is currently undergoing remediation efforts.

- **2351 East Harbor Drive (Chevron Bulk Terminal):** 2351 East Harbor Drive is located to the south of the subject site. This site is listed within the LUST, HAZNET, RCRA-LQG, HIST UST, UST, Cortese, and EMI databases.

  According to the file review and the most recent Groundwater Monitoring Report, dated January 28, 2005, groundwater depth ranges from 2.44 feet below ground surface. During the Groundwater Monitoring Report detectable levels of TPH-G, benzene, toluene, total xylenes, MTBE, TBA, TAME, DIPE, and ETBE were detected within the samples. A PSH removal program was also initiated at the site.

3.1.3 Aerial Photographs

RBF reviewed available aerial photographs for the subject site and immediately adjacent areas to assist in the identification of development activities that have historically occurred on-site. Review of available historical aerial photographs dated 1953 through 2002 provided the following chronological sequence of site history. The aerial photographs were provided by EDR and are listed in Section 6.0, *References*. Copies of these historical aerial photographs are presented in Appendix B, *Documentation.*

1953: In the 1953 aerial photograph, the subject site appears to consist of the existing structures and uses. The power plant structure is noted, along with the substation [illegible] the west of the subject site and are noted running into **Area 3**. Vacant land is present to the north of the subject site. A road and structures are present to the north of the subject site. Vacant land and a structure are present to the south of the subject site. Additional industrial uses are present to the west of the subject site. Additional docks and the San Diego Bay are also present to the west of the subject site.

1963-
1974: In the 1963 aerial photograph, the subject site appears similar to that viewed in the 1953 aerial photograph. **Area 3** remains undeveloped. The surrounding land to the north and south has been developed with industrial uses.

1989-
2002: In the 1989 through 2002 aerial photographs, the subject site appears similar to that viewed in the previous aerial photographs, however, it appears as though vehicles are present within **Area 3**.

Based on review of the above referenced historical aerial photographs, the subject site appears to have primarily consisted of the power plant, substation, parking lot, and additional structures.

3.1.4 Other Historical Sources

Other historical sources include miscellaneous maps, newspaper archives, and records in the files and/or personal knowledge of the property owner and/or occupants. No other historical sources beyond those previously identified within this Assessment were utilized during the historical investigation.

3.2 REGULATORY SOURCES

The governmental sources have been searched by EDR (at the request of RBF), for sites within the subject site and within an approximate one-mile radius of the subject property boundaries. Upon completion of their search, EDR provided RBF with their findings dated January 3, 2005 (refer to Appendix A, *EDR Search*). RBF makes no claims as to the completeness or accuracy of the referenced sources. Our review of EDR's findings can only be as current as their listings and may not represent all known or potential hazardous waste or contaminated sites. To reduce the potential for omitting possible hazardous material sites on the subject property and within the surrounding area, sites may be listed in this report if there is any doubt as to the location because of discrepancies in map location, zip code, address, or other information. The following federal and state records searched are presented below preceded by a description of the purpose of each database:

3.2.1 Federal Sources Federal ASTM Records:

Biennial Reporting System (BRS): The database is a national system, administered by the EPA, which collects data on the generation and management of hazardous waste. BRS captures detailed data from two grounds: Large Quantity Generators (LQG) and Treatment, Storage, and Disposal Facilities.

Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS): The CERCLIS database contains data on potentially hazardous waste sites that have been reported to the US EPA by states, municipalities, private companies, and private persons pursuant to

CERCLIS contains sites which are either proposed to or on the National Priorities List (NPL) and sites that are in the screening and assessment phase for possible inclusion on the NPL.

Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS/NFRAP): As of February 1995, CERCLIS sites designated "No Further Remedial Action Planned" (NFRAP) have been removed from CERCLIS. NFRAP sites may be sites where, following an initial investigation, no contamination was found, contamination was removed quickly without the need for the site to be places on the NPL, or the contamination was not serious enough to require Federal superfund action of NPL consideration. EPA has removed approximately 25,000 NFRAP sites to lift the unintended barriers to the redevelopment of these properties and has archived them as historical records so the EPA does not needlessly repeat the investigations in the future. This policy change is part of the EPA's Brownfields Redevelopment Program to help cities, states, private investors, and affect citizens to promote economic redevelopment of unproductive urban sites.

Delisted NPL: This is a database of sites that may be deleted from the National Priorities List when no further response is appropriate. The criterion used by the EPA to delete sites from the NPL is established by the National Oil and Hazardous Substances Pollution Contingency Plan.

Emergency Response Notification System (ERNS): ERNS records and stores information on reported releases of oil and hazardous substances.

Facility Index System/Facility Identification Initiative Program Summary Report (FINDS): The FINDS database contains both facility information and 'pointers' to other sources that contain more detail. The following FINDS databases are included in the report: PCS (Permit Compliance System), AIRS (Aerometric Information Retrieval System), DOCKET (Enforcement Docket use to manage and track information on civil judicial enforcement cases for all environmental statutes), FURS (Federal Underground Injection Control), C-Docket (Criminal Docket System used to track criminal enforcement actions for all environmental statutes), FFIS (Federal Facilities Information System), STATE (State Environmental Laws and Statutes), and PADS (PCB Activity Data System).

Federal Insecticide, Fungicide, & Rodenticide ACT (FIFRA)/Toxic Substances Control ACT (TSCA) Tracking System (FTTS): FTTS tracks administrative cases and pesticide enforcement actions and compliance activities related to FIFRA, TSCA, and EPCRA (Emergency Planning and Community Right-to-Know Act). It is maintained by the EPA/Office of Prevention, Pesticides, and Toxic Substances.

Federal Insecticide, Fungicide, & Rodenticide ACT (FIFRA)/Toxic Substances Control ACT (TSCA) Tracking System (FTTS INSP): This database tracks administrative cases and pesticide enforcement actions and compliance activities related to FIFRA, TSCA, and EPCRA (Emergency Planning and Community Right-to-Know Act). It is maintained by the EPA.

Federal Superfund Liens (NPL Liens): Under the authority granted the USEPS by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, the USEPA has the authority to file liens against real property in order to recover remedial action expenditures or when the property owner receives notification of potential liability. USEPA compiles a listing of filed notices of Superfund Liens.

Hazardous Material Information Reporting System (HMIRS): HMIRS contains hazardous material spill incidents reported to DOT.

Material Licensing Tracking System (MLTS): The MLTS database is maintained by the Nuclear Regulatory Commission and contains a list of approximately 8,100 sites which possess or use radioactive materials and which are subject to NRC licensing requirements.

Mines Master Index File (MINES): This database is maintained by the Department of Labor, Mine Safety, and Health Administration.

National Priorities List (NPL): The National Priorities List (NPL) is the United States Environmental Protection Agency's (USEPA) database of uncontrolled or abandoned hazardous waste sites identified for priority remedial actions under the Superfund program. A site must meet or surpass a predetermined hazard ranking system score, be chosen as a state's top priority site, or meet three specific criteria set jointly by the U.S. Department of Health and Human Services and the USEPA in order to become an NPL site.

PCB Activity Database System (PADS): The database identifies [illegible] storers, and/or brokers and disposers of PCB's who are required to notify the EPA of such activities.

Proposed National Priorities List (Proposed NPL): This database, maintained by the EPA, lists all proposed national priority list sites. A national priority site is an uncontrolled or abandoned hazardous waste site identified for priority remedial actions under the Superfund program. A site must meet or surpass a predetermined hazard ranking system score, be chosen as a state's top priority site, or meet three